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Wild avian species diversity and abundance at Al Ain Zoo in the United Arab Emirates

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Abstract. *Chanyandura A, Alhajeri MM, Alqahtani HA, Alotaiba AM, Khan MAR. 2025. Wild avian species diversity and abundance at Al Ain Zoo in the United Arab Emirates. Biodiversitas 26: 3397-3407.* Al Ain Zoo in the United Arab Emirates, serves as an important habitat for diverse bird species, providing a safe refuge and breeding ground for resident and migratory birds. Birds play an important role as bioindicators in different ecosystems. The primary objective of this study was to explore species diversity, frequency of occurrence, richness, and evenness in four habitat categories and land use zones, namely Safari, United Arab Emirates World Desert, Core Zoo, and Back of House in Al Ain Zoo. The data was collected using the line transect method in predetermined zones over seven years. A total of 106,288 records of single bird detection and 136 bird species were documented from 2017 to 2023, including breeding birds, non-breeding birds, and migratory birds. The data exhibited a fluctuating trend, starting with a sharp increase from 4,422 to 11,348 birds, a decline to 6,856, and then a recovery to 14,970. The decline can be attributed to the COVID-19 pandemic and other environmental changes. The most recent years (2022 and 2023) indicate a robust upward trajectory. Welch's ANOVA revealed a significant difference in species richness among the areas (FWelch (3, 13.19): 14.83, $p<0.0016$), with a large effect size (ωp^2) of 0.71. Significant differences in the diversity of species across the areas (FWelch (3, 12.6): 7.10, $p<0.0014$, ωp^2: 0.52) were observed. The Safari zone supported the highest species richness, with species distribution remaining relatively consistent across the areas surveyed. The findings enhance the understanding of spatial variations in biodiversity and highlight the importance of focused conservation initiatives to sustain ecological balance and enhance bird species diversity across various areas of the zoo. Human presence and zoo development activities must consider preserving habitats for native and migratory bird species.

Keywords: Bioindicators, ecological index, habitat, Principal Component Analysis

INTRODUCTION

Bird monitoring programs provide the foundational data for programs that study and conserve birds (Bianchini and Tozer 2023; Fournier et al. 2023). Inventories of ecosystems must be conducted to determine local and regional levels of diversity and integrate them into a national view of spatial distinction in endemism and diversity (Colwell and Coddington 1994; Guedes et al. 2020; Rocchini et al. 2021). Desert ecosystems, spanning roughly one-third of Earth's land area, are some of the planet's most extreme environments (Sharma 2023; Zhang et al. 2023). However, despite their harsh conditions, deserts sustain a surprisingly wide range of wildlife, including various bird species (Yamaguchi 2022; Conkey et al. 2023; Zhang et al. 2023). The United Arab Emirates (UAE) supports the occurrence of diverse flora and fauna with global biodiversity hotspots at various elevational gradients, land use, and habitats (Ahmed et al. 2022; Campbell 2023). Lying at the juxtaposition of four biogeographic regions, the diverse avifauna of the UAE represents a melting pot of species (Nelson 2022; Campbell 2023). The Arabian Peninsula guarantees the biannual passage of millions of birds on journeys spanning from southern Africa, western Europe, the Siberian Arctic, and Eastern China to India (Symes et al. 2015; Aspinall and Porter 2020; Campbell 2023; Ahmed et al. 2024). Zoological institutions (hereafter "zoos") provide knowledge on animal conservation and care by conducting research and developing methodologies in wildlife biology, animal behavior, health, and welfare (Hosey et al. 2013; Clay and Visseren-Hamakers 2022). Zoos also promote educational and research initiatives in collaboration with scientists, with a focus on animal conservation and preservation, and ecological diversity (Fatima 2024).

The spatial distribution of bird species, breeding success, and survival is influenced by the availability of key resources, including food, water, vegetation cover, and weather (Carey 2009; Sohil and Sharma 2020; Bhagarathi et al. 2024). The distinctiveness and attractiveness of habitats to bird species and other organisms are a function of their size and quality, largely mediated by biophysical factors, including land use change (Douini et al. 2024; Mugatha et al. 2024). Anthropogenic pressure and other environmental changes can affect the species' distribution due to modification and habitat loss (Shoo et al. 2005; Lee and Jetz 2011; Amani 2018; Pandey et al. 2020; Shah and Sharma 2022). Bird species richness is the result of the diversity of natural ecosystems (Kusi et al. 2020; Taybi et al. 2020; Douini et al. 2024), climate circumstances

(Tramblay et al. 2012), and geographical situation (Mansouri et al. 2021). Zoo landscapes serve as vital urban biodiversity refuges, offering sanctuary to a wide range of native and non-native species within increasingly developed city environments (Leslie and Griffiths 2022; Lato et al. 2023; Bhattacharya 2025). These green spaces support high species diversity and richness and act as safe havens for pollinators, birds, and small mammals often displaced by urban sprawl (Abanto 2025; Kowarik et al. 2025; Santiago 2024). By providing structurally diverse habitats, zoos contribute to local conservation and help maintain ecological functions such as pollination and seed dispersal (Negret et al. 2022; James and Douglas 2023; Cull 2024). Native species established within zoo grounds, especially birds and insects, can spill over into nearby parks and semi-natural habitats, reinforcing fragmented urban ecosystems (Jansen and Hobohm 2021; Follain et al. 2023; Grabow 2025). As such, zoos play a crucial role in urban ecological networks, bridging gaps between conservation, education, and real-world biodiversity protection (Greenwell et al. 2023; Cull 2024; Wang et al. 2024; Kodym et al. 2025). Small wildlife reserves, green spaces, zoos such as Al Ain Zoo in the UAE, and residential gardens provide area-sensitive species, ecosystem services, such as pollination and biological pest control, and cultural services, such as recreation and improved human health (Farina 2022; Greenwell et al. 2023).

Birds are found in every country across the globe and inhabit nearly every type of environment, ranging from the lowest deserts to the highest mountain regions (Mittermeier et al. 2021). Therefore, it is critical to assess the conservation needs of birds facing mounting pressures from human population growth (Chaves et al. 2022), climate change (Bhagarathi et al. 2024), and habitat loss (Rime et al. 2020; Ahmed et al. 2022), including in the UAE. Configurations of species diversity, richness, abundance, and species frequency of occurrence were studied in four ecologically habitats within Al Ain Zoo. The study zones were identified as Safari (S), UAE World Desert (UAEWD), Core Zoo (CZ), and Back of House (BOH). The objectives of this study were to identify population trends, species diversity, richness, and evenness between 2017 and 2023 across different land uses and habitats within Al Ain Zoo. Long-term monitoring of bird populations can facilitate the detection of population trends; this can allow managers to make evidence-based decisions, such as the protection of ecosystems within park boundaries (da Costa Dias et al. 2024). Environmental organizations use bird population data to make decisions regarding land use, conservation funding, and wildlife protection policies. These studies conducted in zoos provide valuable scientific insights into avian health, behavior, and ecology, which can inform both captive care and wild population conservation efforts. Therefore, counting birds plays a pivotal role in conserving biodiversity and general environmental protection (Sohil and Sharma 2020; da Costa Dias et al. 2024; Fatima 2024).

MATERIALS AND METHODS

Study area

Al Ain Zoo (AAZ) is a government-owned zoo established in 1968 by the late Sheikh Zayed bin Sultan Al Nahyan in Al Ain City in the Emirate of Abu Dhabi, United Arab Emirates. Al Ain city is approximately 130 km equidistant from Abu Dhabi and Dubai 130 km and is adjacent to the UAE-Omani border (Reza 1992; Nelson 2022). The zoo is situated in the South of the city, bordering the foothills of the biodiverse Jebel Hafeet Mountain, an outlier of the Hajar Mountains, which reaches approximately 1,300 m. The surrounding environment includes urban areas, low limestone foothills, gravel plains, and deserts. The zoo's vegetation cover contains approximately 500 species of local and non-native plants distributed across various areas of the Zoo (Reza 1992).

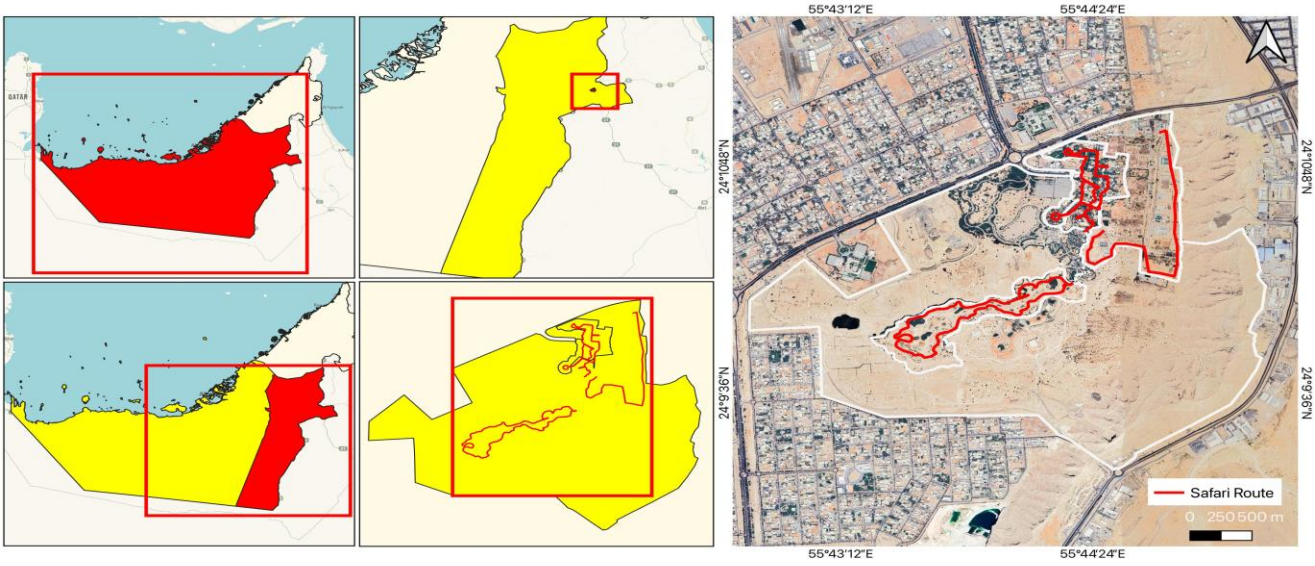

Figure 1. Al Ain Zoo in the United Arab Emirates (UAE) study areas, namely Safari, UAE World Desert, Core Zoo, and Back of House

Procedures

Before the routine bird observation, transects were established in 2017 in each study area. The zoo was divided into four main survey zones based on landscape features, access levels, and to have a manageable study area. In these survey zones, a total of 4 transects, namely Safari (5 km), Back of House (2 km), UAE World Desert (1 km), and Core Zoo (2 km), were established. The routes in the transect were randomly selected but were often positioned along existing small tracks, approved research areas, and pathways (Figure 1). Bird observations were carried out monthly from 2017 to 2023, and the birds were recorded between 6:30 am and 12:00 pm in all transects. Six researchers walked (Core Zoo, and Back, UAE World Desert) and drove (Safari) along the 4 transects, counted and recorded the number of all the birds heard and observed within 30 meters of the route on each side (Emlen 1977; Zielonka et al. 2024). During a line transect count, birds were detected either visually (seen) or aurally (heard) by trained observers as they moved along the transect line. Each bird observed was recorded in real time, including information such as species, number of individuals, detection method (sight or sound), and location along the transect. The sizes of the transects were proportional to the size of the zones and were maintained throughout the study period. This method was chosen because it can trace the plot area of data quickly and allows repetition of data collection according to the desired time. The birds were observed with the aid of Bushnell Falcon 10×50 wide-angle binoculars (Pearl 2015). Birds were identified in the field (Jennings 2010; Aspinall and Porter 2020; Boland et al. 2020; Porter et al. 2024), and unidentified species were photographed using a Nikon NIKKOR Z Lens 180-600 mm f/5.6-6.3 camera for reference. Birds were identified to the species level, the feeding guild of identified species, and their taxonomic groups were categorized based on the Helm field guide (Borrow and Demey 2022). A Garmin GPS device was used to record the coordinates and location of the transect stations. Field guidebooks were used for bird identification, and expert consultation was performed for final confirmation (Gaunt et al. 1997; Brazil 2020).

Data analysis

Data were pooled across the 7-year study period, and total species counts were derived. Species accumulation curves were used to visualize and indicate the adequacy of the bird survey in representing the birds in a particular area. The data were tested for normality using the Shapiro-Wilk test, and the results indicated that the data were normally distributed. We compared the species richness, diversity, and evenness across the four locations, BOH, CZ, Safari, and UAEWD, proportional to their sizes, using Welch's ANOVA. Games-Howell post hoc test was carried out to assess pairwise differences. Data analysis was conducted using R software (version 4.3.0). Shannon-Weiner diversity (Cronholm 1963) and Pielou's species' evenness (Pielou 1966) were calculated from the collected data. Principal Component Analysis (PCA) was conducted using Canoco version 5 to summarize and visualize multivariate patterns in biodiversity metrics across sites and years (Maćkiewicz and Ratajczak 1993; Greenacre et al. 2022). Bayesian analysis was applied to the biodiversity metrics as the research integrated prior knowledge and expert opinion into the analysis.

RESULTS AND DISCUSSION

Bird species population trend in Al Ain Zoo, UAE

A total of 106,288 records of single bird detection and 136 bird species were documented from 2017 to 2023, including breeding, non-breeding, and migratory birds. There was a significant increase in the number of birds from 4,422 recorded in 2017 to 11,348 in 2018, representing an increase of 6,936, or approximately 156%, in AAZ, UAE. The number decreased from 11,348 in 2018 to 9,201 in 2019, a drop of 2,147, or about 19% (Figures 2 and 3). There was a further decline from 9,201 in 2019 to 6,856 in 2020, a decrease of 2,345, or about 25%. The number increased from 6,856 in 2020 to 8,172 in 2021 (an increase of 1,316, or about 19%) to 12,429 in 2022 (an increase of 4,257, or approximately 52%). The number increased from 12,429 in 2022 to 14,970 in 2023, an increase of 2,551, or about 21%. Comparatively, in 1992, 98 bird species were recorded, and in 2023, 116 species were recorded, there has been approximately an 18.37% increase in the number of bird species. Linear regression was performed using R software to analyze the correlation between changes in bird species populations over time. The R^2 value of 0.502 suggests a moderate positive linear relationship between the year and the value. This implies that as the years increase, the values show a general upward trend, but with some variability. The data show a volatile trend characterized by an initial sharp increase, followed by a decline and subsequent recovery. The most recent years indicate a robust upward trajectory. The moderate correlation suggests that while the general direction is upward, individual yearly changes contribute to the observed variability. More than 30 uncommon species were also recorded during this study period, including the black kite (*Milvus migrans*), barbary falcon (*Falco pelegrinoides*), greater spotted eagle (*Aquila clanga*), straited heron (*Butorides striata*), blue-cheeked bee-eater (*Merops persicus*), shikra (*Accipiter badius*), spotted flycatcher (*Muscicapa striata*), and the indian pond heron (*Ardeola grayii*), among others. In 2023, 4 new bird species were recorded, namely black kite *M. migrans*, barbary falcon *F. pelegrinoides,* greater spotted eagle *A. clanga*, and straited heron *B. striata.*

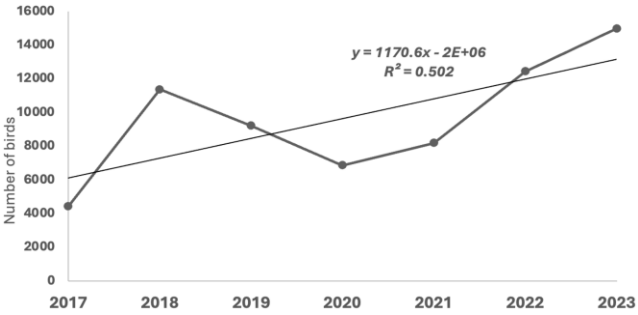

Figure 2. Bird species population trend over a seven-year sampling period in Al Ain Zoo, UAE

Classification of birds observed in Al Ain Zoo

Migratory statuses among these birds include long-distance migrants like the barn swallow (*Hirundo rustica*), partial migrants such as the black kite *M. migrans*, and short-distance migrants represented by the black redstart (*Phoenicurus ochruros*). Summer migrants include the crested honey buzzard (*Pernis ptilorhynchus*), while winter visitors like the little egret (*Egretta garzetta*) arrive during colder months. Altitudinal migrants are shown by the wood snipe (*Gallinago nemoricola*), and nomadic species include the cockatiel (*Nymphicus hollandicus*). Residents like the Arabian babbler (*Argya squamiceps*) stay year-round, while introduced species such as the common myna (*Acridotheres tristis*) have been added to the local ecosystem. This diversity reflects a wide range of movement patterns.

The recorded bird species came from 27 different families: Accipitridae, Anatidae, Ardeidae, Muscicapidae, Psittaculidae, Threskiornithidae, Hirundinidae, Columbidae, Phylloscopidae, Meropidae, Laniidae, Cisticolidae, Sylviidae, Motacillidae, Rallidae, Falconidae, Upupidae, Nectariniidae, Charadriidae, Estrildidae, Pandionidae, Corvidae, Ploceidae, Emberizidae, Passeridae, Phasianidae, and Phalacrocoracidae. A few selected examples include hawks and eagles from the Accipitridae family, ducks, and geese from Anatidae, herons and egrets from Ardeidae, flycatchers from Muscicapidae, and parakeets from Psittaculidae. This variety shows how different these birds are in their lifestyles and diets, ranging from fierce predators to gentle seed eaters and insect hunters.

Feeding guilds recorded were diverse as well, and they included insect eaters like the desert wheatear (*Oenanthe deserti*), aerial insect eaters such as the European bee-eater (*Merops apiaster*), and fish eaters such as the common kingfisher (*Alcedo atthis*). Grain eaters like the collared dove (*Streptopelia decaocto*) also play a role, along with fruit eaters such as the Alexandrine parakeet (*Psittacula eupatria*). Nectar eaters such as the Indian sunbird (*Cinnyris asiaticus*) were recorded, omnivorous birds like the common black-headed gull (*Chroicocephalus ridibundus*), and scavengers like the raven (*Corvus corax*) were also recorded. Raptor species, which are predatory birds, include Bonelli's eagle (*Aquila fasciata*), and herbivores like the Egyptian goose (*Alopochen aegyptiac*), were part of this diverse group in Al Ain Zoo.

Species richness, diversity, and evenness comparison across Al Ain Zoo Areas

The Eurasian collared dove (*S. decaocto*), white wagtail (*Motacilla alba*), and house sparrow (*Passer domesticus*), among others, were the most dominant bird species in Safari, BOH, UAEWD, and CZ, respectively. While the laughing doves (*Spilopelia senegalensis*), red vented bulbul (*Pycnonotus cafer*), and leaf warblers were the least dominant bird species across the study area. The species richness, diversity, and evenness across the four areas (BoH, CZ, Safari, and UAEWD) were compared using Welch's ANOVA, followed by a Games-Howell post hoc test to assess pairwise differences (Figures 4, 5 and 6). Welch's ANOVA revealed a highly significant difference in species richness among the areas (F_{Welch} (3, 13.19): 14.83, *p:* 0.0016), with a large effect size (ωp^2) of 0.71. The confidence interval for the effect size (0.38, 1.00) suggests a substantial impact of the area on species richness. Pairwise comparisons showed significant differences (*p:* 0.0014) in the species richness between BOH (mean: 36.29) and Safari (mean: 63.86). Similarly, Safari exhibited significantly higher richness p: 0.0028) compared to CZ (mean: 36.00). The richness in UAEWD (mean: 35.86) was also significantly lower than in Safari, confirming the overall trend that Safari supports higher species richness as well. However, no significant difference was found between BOH and UAEWD in terms of species richness, with both areas having similar richness levels (Figure 4). Their comparable levels hint at shared ecological characteristics or similar degrees of habitat pressure. This also implies that management or conservation efforts aimed at boosting biodiversity in UAEWD or BOH may benefit from strategies successfully employed in the Safari. On the other hand, the evenness of species distribution did not vary significantly across the areas, indicating that while the number of species differs, their relative abundance within each area is more consistent.

The evenness of species distribution across the areas was also assessed using Welch's ANOVA. However, unlike richness, the analysis did not reveal a statistically significant difference in evenness among the areas (F_{Welch} (3, 12.28): 1.93, *p:* 0.18), with a moderate effect size of 0.15 (Figure 6). The confidence interval for this effect size (0.00, 1.00) suggests that any true differences in evenness are likely small or negligible. These findings illustrate clear differences in species richness across the study areas, with Safari displaying significantly higher richness compared to CZ and UAEWD. The Bayesian analysis, with a posterior Bayesian (R^2: 0.61) (Figure 4), supports the robustness of these findings. The significant difference between BOH and CZ further highlights the variability in species richness across different sites within the study area.

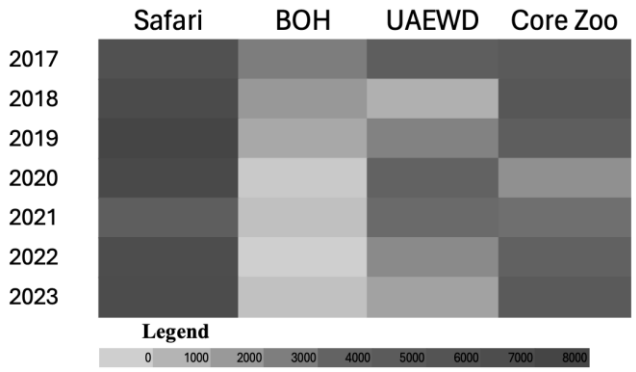

Figure 3. Bird species diversity heat map in Al Ain Zoo, UAE (Light colors showing less diversity and dark colors showing more diversity)

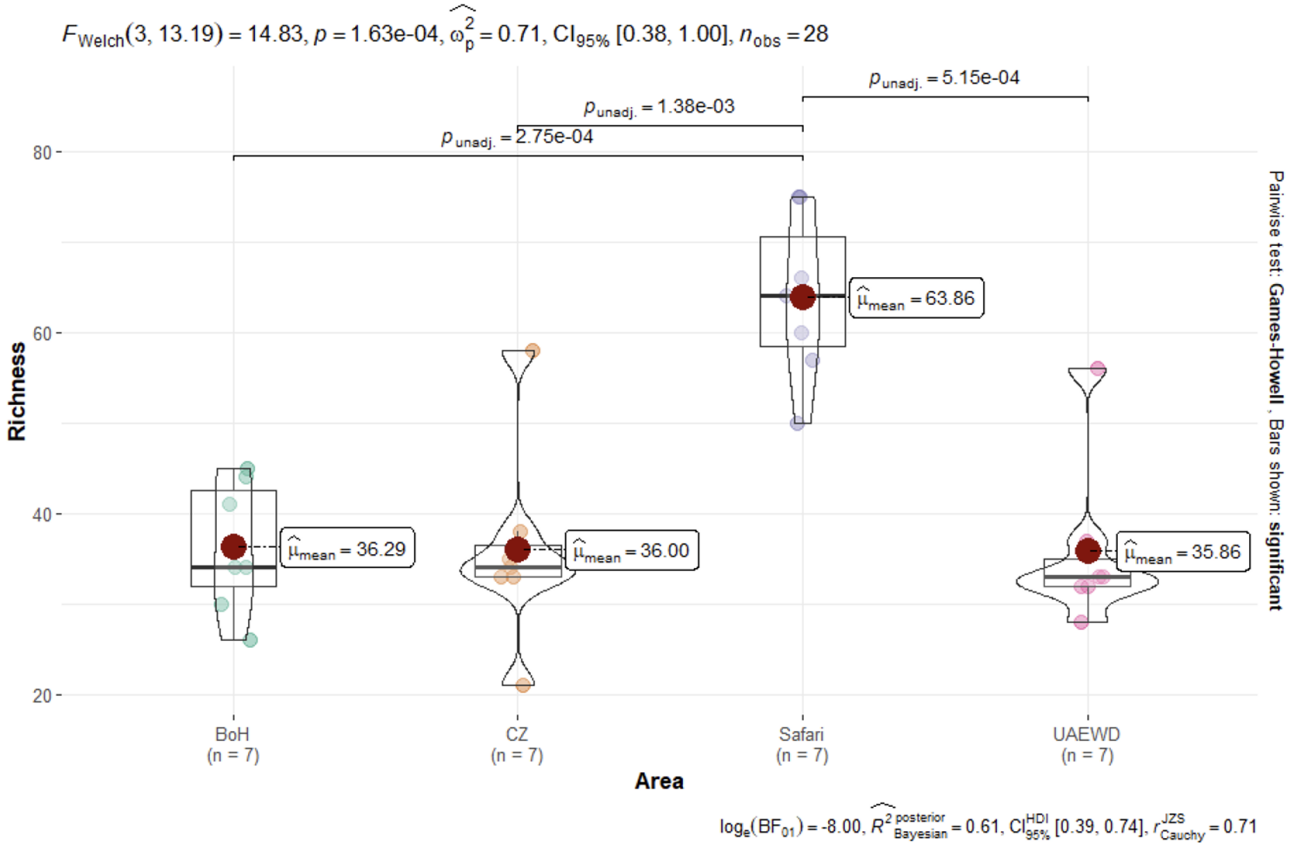

Figure 4. A pairwise test showing different bird species richness in BOH, CZ, Safari, and UAEWD in Al Ain Zoo, UAE

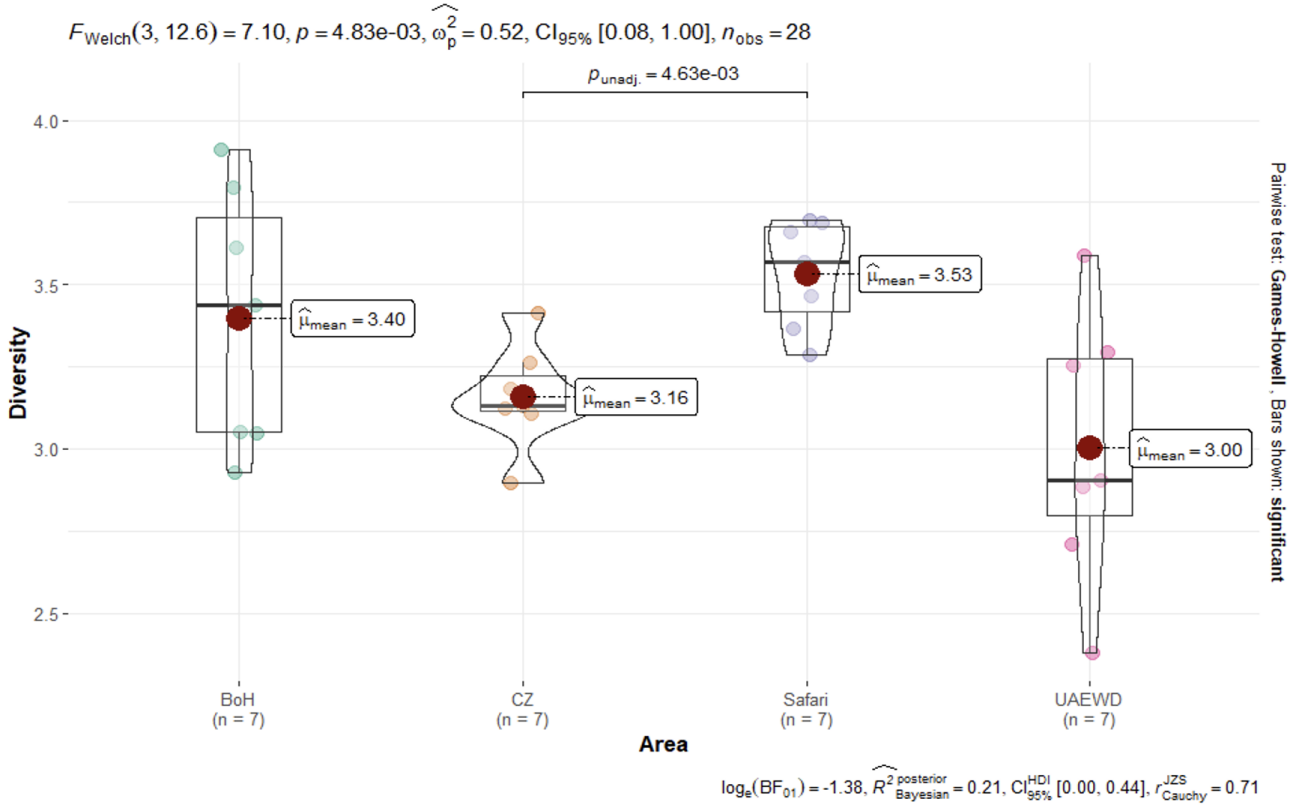

Figure 5. Bird species diversity in BOH, CZ, Safari, and UAEWD zones in Al Ain Zoo, UAE

Cluster 1 had the highest species richness, moderate diversity, and evenness. Cluster 2 had moderate diversity and evenness and lower species richness. Cluster 3 had mid-range species richness, the highest diversity, and evenness (Figure 7). To lower the dataset's dimensionality, a principal component analysis was performed. Of the total variance, 55.67% was captured by the first principal component (PC1) and 44.00% by the second (PC2). The fact that PC1 and PC2 together explained 99.67% of the variability suggests that the underlying data structure is essentially two-dimensional. Just 0.33% of the variance was accounted for by the third component (PC3) (Figure 7).

Discussion

The Eurasian collared dove, white wagtail, and house sparrow, among others, were the most dominant bird species in Safari, BoH, UAEWD, and CZ, respectively. While the laughing doves, red vented bulbul, and leaf warblers were the least dominant bird species across the study area. The low dominance of laughing doves, red-vented bulbuls, and leaf warblers in AAZ's four zones could be influenced by a combination of habitat preference, availability of food resources, anthropogenic disturbance, and interspecies competition. Laughing doves could be facing dietary overlap and stiff foraging competition from collared doves and wild pigeons found in the zoo (Benghedier et al. 2020; Koenig 2020; Lea et al. 2024). Our study also concurs with (Benghedier et al. 2020; Eddajjani et al. 2022), who found that there is a convergence and competition between doves in exploiting their ecological niches, especially nesting areas, nest placement, and nest orientations. Laughing doves' competition with more aggressive or territorial columbids (e.g., feral pigeons or larger doves) could suppress their population density (Benghedier et al. 2020; Eddajjani et al. 2022; Soh et al. 2024).

The laughing dove's foraging strategy, which relies heavily on ground feeding, also makes it susceptible to competitive pressure in environments where food is limited or where dominant species are present in high densities (Benghedier et al. 2020; Shabbir et al. 2024). Aggressive interactions at feeding sites, displacement from perches, and competition for nesting cavities may all contribute to reduced breeding success and lower population densities (Charter et al. 2016; Benghedier et al. 2020; Lermite et al. 2021; Korňan 2023). Red-vented bulbuls are known for their adaptability to urban and suburban environments (Eddajjani et al. 2022; Koenig 2020; Lea et al. 2024). However, their reduced dominance in our study could indicate stronger competition from more dominant omnivorous bird species within the zoo. In some regions, their numbers may also be controlled due to their status as invasive species, although this depends on local policies and ecosystems (Reidinger Jr and Miller 2013; Cohen et al. 2022). Habitat alteration and urbanization can exacerbate competitive imbalances (González-Lagos et al. 2021; Ahmed et al. 2022). Urban landscapes often favor generalist and bolder species, like feral pigeons, that can exploit anthropogenic resources more efficiently (Konijnenberg 2020; Lato et al. 2023).

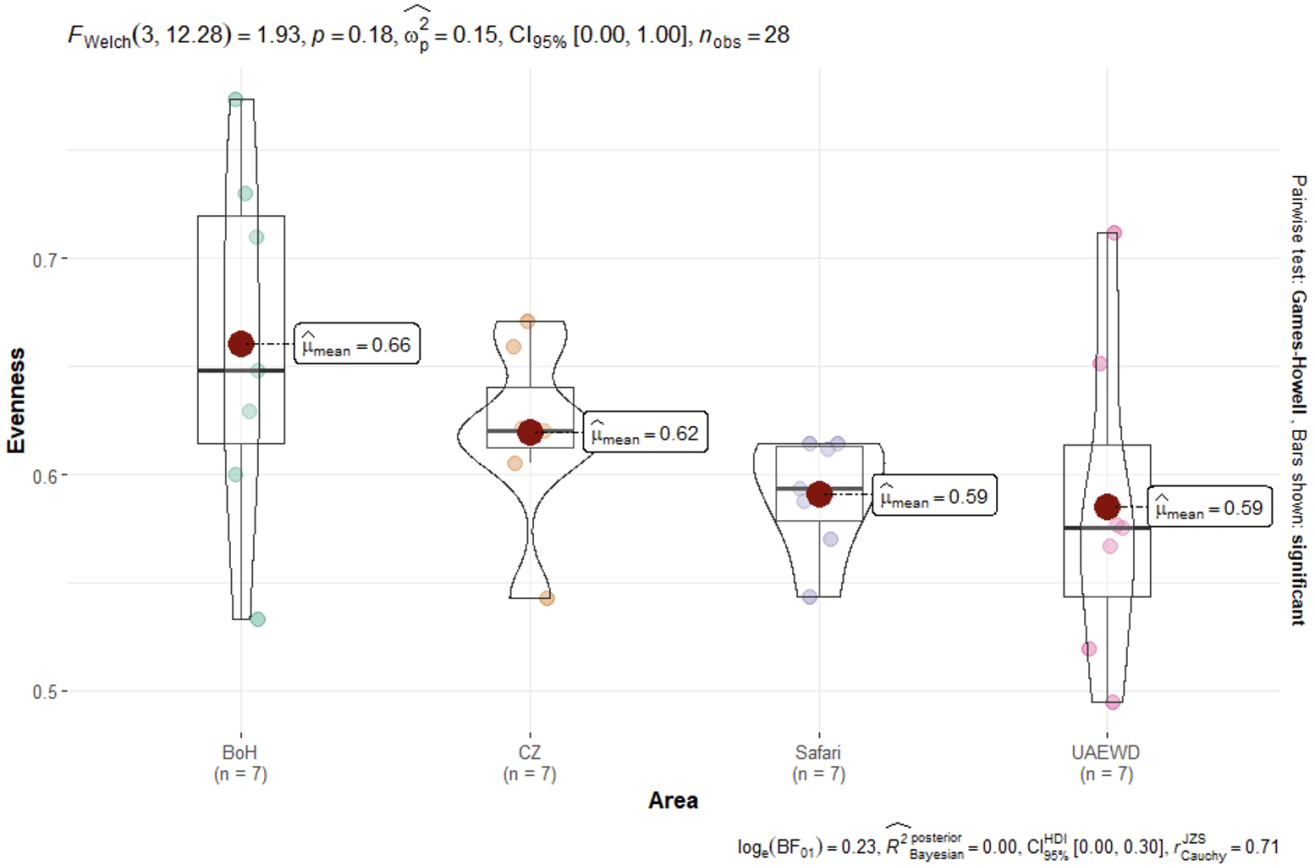

Figure 6. Bird species evenness in BOH, CZ, Safari, and UAEWD in Al Ain Zoo, UAE

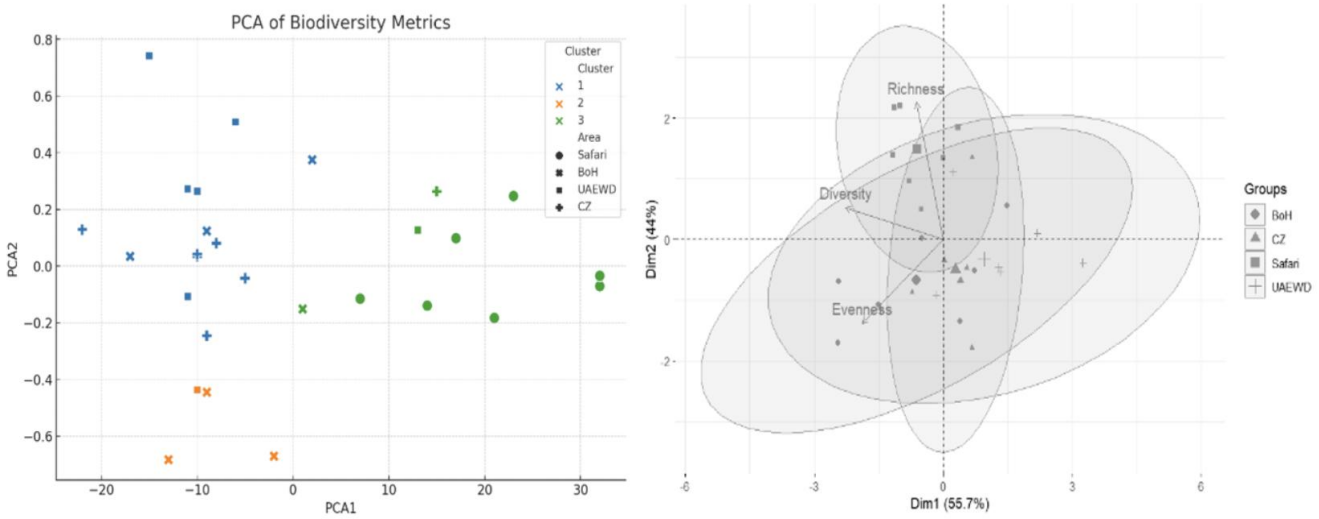

Figure 7. Principal component analysis of biodiversity metrics in BOH, CZ, Safari, and UAEWD in Al Ain Zoo, UAE

The differences observed in bird population numbers within our study are likely fixed by a combination of ecological and social drivers. Notably, the reduction from 11,348 in 2018 to 6,856 in 2020 was simultaneous with the COVID-19 pandemic, when nearly all survey work was suspended (Manenti et al. 2020; Neupane 2020; Hockenhull et al. 2021; Miller-Rushing et al. 2021; Primack et al. 2021). The subsequent sharp increase and recovery in the bird species population could be due to the enhanced survey efforts and overall habitat quality improvement within the zoo. The high diversity and population of birds in the CZ and Safari areas are likely due to the favorable habitats present in these locations. The safari area is characterized by evergreen trees (DeGraaf 2002; Ellis 2020) in the riverine (Menon et al. 2015; Rajpar et al. 2022), fenced and irrigated woodlots with mainly indigenous tree species (Pšeničková and Horák 2022; Sax 2023). These habitats attract birds year-round and provide optimal nesting and foraging sites. The core zoo has high tree density, more canopy cover, tall, old, and huge trees, both indigenous and exotic trees, attracting more birds throughout the year.

A rich diversity of wild mammals, reduced human interference, and more natural habitats found in the safari area may contribute to attracting additional bird species (Hamza and Hanane 2021). These findings highlight the exceptional biodiversity of the Safari area, which is significantly richer in species compared to other sites. Bird-animal interactions are common and can vary from mutually beneficial relationships to those where one species benefits at the expense of another (Jiang 2018; Burner et al. 2020; Perez 2021). The high diversity and richness of birds and animals in the safari area often arise from the interconnectedness (Cudmore 2009; Syrbe et al. 2013) of these species within this ecosystem, a heterogeneous habitat (Rime et al. 2020), availability of resources (Douini et al. 2024), and more natural biotic interactions (Boyce et al. 2019; Burner et al. 2020). Our results support other findings (Parker et al. 2023), which demonstrated that areas with higher tree density tend to host greater bird species richness and abundance. Habitat structure, along with herbaceous and shrub cover, are well-established factors influencing bird communities (Brüggeshemke et al. 2022; Schmitt et al. 2022). Therefore, any habitat management interventions that alter vegetation structure or cover are likely to affect the wildlife that depends on them. The notably lower diversity in UAEWD compared to both CZ and Safari may indicate potential ecological pressures or increased human interference (Brawn et al. 2001; Hillebrand et al. 2018; da Silva et al. 2021) in the UAEWD and CZ. Despite having suitable habitats, UAEWD experiences higher human concentration and infrastructure development than the Safari, which could have influenced these results. The results emphasize the importance of site-specific conservation strategies (Voskamp et al. 2021; Díaz et al. 2022), in this case, in areas where species diversity is significantly lower. The statistically non-significant difference in richness across the zones could be attributed to the balanced species abundances, equal disturbance levels, resource availability, and functional similarity of species in AAZ. It is ecologically important to note that evenness is not about the presence of species only, but rather about the balance of their numbers (Le Bagousse-Pinguet et al. 2021; Gregorius and Gillet 2022). Notably, the richness between BOH and UAEWD is not substantially different, implying that these two locations provide similarly favorable circumstances for supporting species variety. While neither matches the richness of Safari, their relative levels suggest common ecological traits or similar levels of habitat impact (Cook et al. 2020; Zhang et al. 2020). This also suggests that management and conservation efforts aimed at enhancing biodiversity in BOH and UAEWD may benefit from the successful strategies implemented in Safari and other comparable zones in the zoo.

Furthermore, the lack of significant differences in evenness suggests the adaptability of avian species in AAZ. The species in the zoo could be well adapted to the

conditions of the environment, allowing them to coexist in similar abundances, contributing to an even distribution (Kim and Ohr 2020; Yang et al. 2024). The same evenness across the zoo suggests a balance in species populations (Korňan 2023), potentially driven by environmental (Le Bagousse-Pinguet et al. 2021; Gregorius and Gillet 2022) ecological, or management-related factors that promote the stable coexistence of species. Conservation efforts should not solely focus on maintaining species numbers but also on ensuring that species populations are balanced within each ecosystem (Hillebrand et al. 2018; Chaves et al. 2022; Hoffmann 2022). Collectively, these studies suggest that static biodiversity estimates encompass multiple dimensions with various metrics potentially covarying (Brown and Williams 2016; Tu et al. 2020; Bianchini and Tozer 2023) or being independent of one another (Tidière et al. 2016). Measures of biodiversity are used to describe patterns and understand ecological and evolutionary processes. Variations in species diversity, abundance, and richness highlight the complexity of avian community dynamics and underscore the importance of habitat-specific conservation strategies.

In conclusion, since 2017, there has been a general increase in both the population and diversity of bird species at Al Ain Zoo. However, the observed decline can be attributed to disruptions in survey efforts caused by the COVID-19 pandemic. The higher diversity and abundance of species in Safari and Core Zoo relate to different habitats, a mature canopy, and less human disturbance. These factors are known to improve bird diversity. In contrast, UAEWD's lower diversity shows the need for focused conservation efforts. While species richness across zones did not differ much, indicating ecological balance, the evenness patterns emphasize that the presence and relative proportions of species are important. Maintaining habitat complexity, monitoring, and managing interactions between species are crucial for supporting bird diversity and maintaining balanced community dynamics in Al Ain Zoo. Management practices in the CZ and UAEWD areas, where human activity and infrastructure development are more prevalent, may require adjustments to enhance bird diversity and bring species richness closer to levels seen in Safari and other areas with minimal human presence. Collaboration among various stakeholders, including ecologists, land surveyors, municipalities, social scientists, environmentalists, communities, and birdwatching groups, is essential for effective bird conservation.

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