

# Factors influencing long-term and seasonal waterbird abundance and composition at two adjacent lakes in Zimbabwe

Josphine Mundava<sup>1</sup>, Alexandre Caron<sup>2,3,4\*</sup>, Nicolas Gaidet<sup>2</sup>, Fernando M Couto<sup>5</sup>, Jennifer T Couto<sup>5</sup>, Michel de Garine-Wichatitsky<sup>2,3</sup> and Peter J Mundy<sup>1</sup>

<sup>1</sup> National University of Science and Technology, PO Box AC 939, Ascot, Bulawayo, Zimbabwe

<sup>2</sup> CIRAD, UR Animals and Integrated Risk Management, TA 30/E Campus international de Baillarguet, 34398 Montpellier, France

<sup>3</sup> CIRAD, UR Animals and Integrated Risk Management, Department Environment and Societies, PO Box 1378, Harare, Zimbabwe

<sup>4</sup> Mammal Research Institute, University of Pretoria, Pretoria 0002, South Africa

<sup>5</sup> Birdlife Zimbabwe, PO Box RVL100, Runiville, Harare, Zimbabwe

\* Corresponding author, e-mail: alexandre.caron@cirad.fr

The spatial and temporal structures of waterbird communities are dynamic and complex with many driving factors. We used long-term waterbird census data at two lakes in Zimbabwe to explore the ecological and anthropogenic drivers of waterbird community composition and abundance. Ecological drivers predicted to influence waterbird communities include rainfall quantity and distribution, waterbird movement, breeding and moulting; anthropogenic drivers include activities such as fishing and agriculture. Results suggest that seasonal variations in resource availability influenced the waterbird community composition and abundance, as did movements at local, regional, and intercontinental scales. Bird numbers in the two perennial lakes experienced large changes in structure during two droughts. We also used the study as a baseline for considering the risk of spread of avian influenza virus (AIV) spread in waterbird communities in Zimbabwean lakes, which is likely to be higher in dry seasons and during drought years when waterbird abundance is high. Our study emphasises the importance of long-term ecological data in understanding crucial aspects of biodiversity conservation as well as pathogen dynamics in wild waterbird communities, with important management implications.

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## Introduction

Understanding waterbird community dynamics is important as it provides information for ornithological conservation and for the epidemiology of important diseases, some of which threaten public health such as highly pathogenic Avian Influenza (AIV). Waterbird community dynamics are complex and are influenced by many natural and anthropogenic factors. Natural dynamics of waterbird populations are mainly driven by rainfall or water availability, which influence the physical structure of habitats and determine resource availability and accessibility (Paillisson et al. 2002). Other drivers of waterbird community composition and abundance include bird biology (migration, breeding and moulting) and anthropogenic influences, such as hunting, water extraction for industrial and domestic purposes, and agricultural practices (Caziani et al. 2001, van Niekerk 2010).

Rainfall by itself may not directly affect waterbird communities but has a major influence on their habitats and food supply (Maclean 1990). Most studies on waterbird community dynamics have been carried out in temperate regions, which have less variable rainfall regimes than tropical regions. In southern Africa, as in most Afrotropical regions, rainfall quantities and patterns are unpredictable and most wetlands and lakes have large seasonal and interannual variations in habitat structure, which exert a strong influence on the diversities and abundances of waterbird communities (Cheke et al. 2007). Dry seasons

usually result in reduced exploitable water surfaces and birds tend to congregate in the few remaining waterbodies, whereas in the wet season they tend to disperse as temporary waterbodies form (Dodman and Diagona 2007). Anthropogenic activities also have high influence on waterbird composition and abundance. For instance, groundnut and wheat farming influence numbers of Egyptian Goose *Alopochen aegyptiacus*, Comb Duck *Sarkidiornis melanotos*, Spur-winged Goose *Plectropterus gambensis* and White-faced Duck *Dendrocygna viduata* because these species congregate in water bodies near farms in the harvesting season (Gordon 1987). Water extraction by humans influences water levels, especially in the dry season when there are high domestic and irrigation demands. Eutrophication resulting mainly from sewage disposal and agricultural activities influences the overgrowth of such weeds as water hyacinth *Eichhornia crassipes* and alters the natural habitats, changing bird abundance and composition dynamics. Migration influences waterbird numbers and composition spatially and temporally. Palaearctic migrants, for instance, arrive in large numbers in southern Africa from September to May (Hockey et al. 2005), and significantly change the composition and abundance of local waterbird communities.

In order fully to explore and understand the dynamics and drivers of waterbird community composition and

abundance, there is a need for long-term data producing species' lists, tracking trends in numbers and detecting changes in species' composition, both spatially and temporally. Analysis of these data can inform on biodiversity conservation and ecosystem health (Fouque et al. 2009) and may also help to identify possible drivers of abundance and species' composition. Long-term data capture interseasonal and interannual variations (Woodall 1974), and this provides an opportunity to test the relative importance of different drivers and to reveal trends invisible within short-term studies.

Overall, there is not yet a good understanding of the dynamics and drivers of waterfowl communities in most countries in southern Africa, except for South Africa (Milstein 1975, Harebottle and Harrison 2001). Long-term longitudinal databases are rare, mainly due to the necessary long-term commitment of funding agencies to local ornithological NGOs or research agencies and long-term motivation of individuals or groups of individuals. In Africa, these issues are critical as ornithological interest is less developed than in the Northern Hemisphere and local NGOs are rarer. However, in recent years the African Waterfowl Census coordinated by Wetlands International (Dodman and Diagana 2003) has created new incentives to build such databases.

In this study we analysed an 11-year (1993–2003) database of waterbird counts at two adjacent wetlands in Zimbabwe in order to assess the relative importance of different ecological drivers on the dynamics of waterfowl community composition and abundance. We hypothesised that environmental factors, through rainfall and lake levels, influence variations in waterbird diversity and abundance. We predicted that in dry seasons and drought years the diversity and abundance of waterbirds would increase at large perennial water sources as they are used as refuge sites, whereas in wet seasons and years the reverse would be true. These variations were predicted to be best observed at the guild level, as changes in resource availability are likely to be reflected by groups of species sharing similar habitats and resources (Simberloff and Dayan 1991). We also predicted that bird ecology, through migration, breeding and post-breeding movements, play an important role in determining community abundance and diversity. Finally, anthropogenic activities such as fishing and water extraction were thought likely to have a significant impact on waterbird communities, although their impact proved difficult to measure in practice.

## Materials and methods

### Study area

The study was conducted at Lake Chivero (centred on 17°54' S, 30°47' E), at altitude 1 367 m and Lake Manyame (centred on 17°49' S, 30°33' E), at altitude 1 270 m. The lakes are relatively large, artificial, permanent water sources near Harare, Zimbabwe. They were recognised as an Important Bird Area (IBA) in 1998 (Childes and Mundy 1998, Birdlife International 2012). The lakes are also listed as important wetlands for waders on the central flyway of Africa (Tree 1988). Both lakes are on the Manyame River, with Lake Chivero upstream of Lake Manyame, absorbing all flood waters and spilling into the latter. Lake Manyame

is also fed by two small rivers, Gwebi and Muzururu (Tree 1988). Table 1 summarises basic information for the two lakes. Lake Chivero is characterised by a deep shoreline with many granite boulders and dead standing trees interspersed within the lake, whereas Lake Manyame has a gently shelving shoreline, with no boulders. Mudflats and both floating and submerged freshwater plants, such as the invasive water hyacinth and water lettuce *Pistia stratiotes*, make up the most common habitats of the lakes.

### Bird census

The first counts for Lake Chivero (then called Hunyani Poort Dam and, later, Lake Mcllwaine) were done from January 1953 to March 1954 (Campbell and Miles 1956). Due to the high numbers of waterbirds at the two lakes, they were selected for counting as a part of the African Waterfowl Census coordinated by Wetlands International. There was particular emphasis on undertaking counts in January and July (to a lesser extent April and October) and the collected data were used to determine if the sites were of national and international importance (Dodman and Diagana 2003). Total counts were made for the two lakes during the period 1993–2003, in order to obtain an unbiased estimate of abundance.

All waterbirds (including Ciconiiformes, Gruiformes, Charadriiformes, Anseriformes and Coraciiformes) as well as Osprey *Pandion haliaetus* and African Fish Eagle *Haliaeetus vocifer* (both of the order Falconiformes – a non-waterbird order) were counted from a canoe by two people. All birds in the water or on the shoreline and its vicinity were counted and recorded. The count periods covered all the seasons occurring in Zimbabwe: hot/wet (January), warm/moderately wet (April), cold/dry (July) and hot/dry (October). For Lake Chivero, all counts had 100% coverage, whereas coverage for Lake Manyame varied between 25% and 100%. Consequently, in the analysis, all Lake Manyame data were scaled down to represent 25% coverage, and all results are presented as such. The disparity in the counting intensity between the two lakes made comparisons of abundance between the two lakes difficult. The most extensive data were collected in the period 1993–1994 (inclusive) for both lakes, and less frequent counts occurred mostly from 1997–2003, when counts were mainly limited to January and July. Counts were mostly done for birds on the lakeshore and its vicinity, and birds further into the water bodies were likely missed.

**Table 1:** Summary of characteristics for Lake Chivero and Lake Manyame (when full)

	Chivero	Manyame
Date of completion	1952	1976
Surface area (km <sup>2</sup> )	26.3	81
Volume (m <sup>3</sup> ; × 10 <sup>6</sup> )	250	490
Maximum depth (m)	27.4	22.6
Average depth (m)	9.4	6
Shoreline length (km)	74	192
Length (km)	14.4	31.5
Surrounding land type	Heavily wooded	Open farmland
Shore topography	Often rather steep, many granite boulders	Gently shelving

Such birds include flightless moulting ducks that tend to congregate in the middle of large water bodies during the day and go offshore to feed at night (Swanepoel et al. 2006). Counting during the day also misses species such as Spur-winged Goose, Egyptian Goose and Comb Duck, which utilise agricultural fields during the day and roost at the lakes at night (Gordon 1987, Hockey et al. 2005).

### Guilds

Waterbird species were allocated to bird guilds, defined according to literature sources and field observations. A guild here is defined as a group of species exploiting the same class of environmental resources in a similar way (Simberloff and Dayan 1991). Guild classification was done mainly according to ecological similarities, such as the feeding site location, type of food taken, and foraging method, and combines species regardless of their taxonomic position (Table 2). We determined six guilds: Cormorants (White-breasted Cormorant *Phalacrocorax lucidus*, Reed Cormorant *P. africanus* and African Darter *Anhinga rufa*; Brown et al. 1982, BirdLife International 2010); Egrets, storks and ibises (all herons, storks, ibises, egrets and African Spoonbill *Platalea alba*); Wildfowl (all ducks, geese, moorhens, gallinules and Red-knobbed Coot *Fulica cristata*); Shorebirds (e.g. plovers, sandpipers and thick-knees); Gulls and terns (gulls, terns and African Skimmer *Rynchops flavirostris*); and Other (included raptors and kingfishers).

### Movements

Resident/sedentary, nomadic, Afrotropical migrant and Palaearctic migrant waterbirds were analysed separately to identify the influence of different movement patterns on composition and abundance of the waterbird community. Resident/sedentary birds normally use the same localities at most times only making short and temporary movements. Nomadic bird species, e.g. Red-billed Teal *Anas erythrorhyncha* and White-faced Duck, undertake opportunistic movements governed by rainfall and the need for security at some stages in their ecological cycles (Cumming et al. 2008). Afrotropical migrants breed in central, western

or eastern Africa and move to southern Africa in their non-breeding season, e.g. Abdim's Stork *Ciconia abdimii*, or breed in southern Africa and move to central, western or eastern Africa in their non-breeding season, e. g. Lesser Moorhen *Gallinula angulata* and Collared Pratincole *Glareola pratincola* (Hockey et al. 2005). Palaearctic migrants breed in Europe and Asia, and migrate southward to Africa during their non-breeding season, e.g. Wood Sandpiper *Tringa glareola* and Little Stint *Calidris minuta* (Hayes 1995).

### Lake level

The lake levels were recorded after each counting session and were presented as percentages of the full capacity figure. They were recorded from gauges on the respective dam walls of the two lakes. This protocol was consistent throughout the study period.

### Statistical analysis

The Shapiro-Wilk test was used to test for normality on all variables analysed. For non-normal data, the Kruskal-Wallis test was used for non-parametric analysis of variance (ANOVA), whereas ANOVA was used for normally distributed data. The Shannon-Wiener diversity index was used to estimate species diversity. One-way ANOVA was used to test for differences in the means of the diversity indices between seasons and years. The Kruskal-Wallis test was used to test for significant differences of count figures between years and seasons. The Pearson's product-moment correlation test was used to test for the significance of the correlation between counts and lake levels for the two lakes. Statistical significance of all tests was set at  $\alpha = 0.05$  and computed using R version 2.13.0 (R Development Core Team 2011) and SPSS version 16 (SPSS, Inc., Chicago).

### Results

From 1993 to 2003, 91 waterbird species were recorded for both lakes. Summary results for all the counts carried out during this period are shown in Table 3. Total abundance of waterbirds exhibited seasonality, with abundance figures

**Table 2:** Description of guilds

Guild	Habitat/habits	Food	Movements
Cormorants	Still open water, reeds, dead standing trees. Colonial breeders	Fish, frogs	Sedentary to partial migrants depending on wetland conditions
Egrets, storks and ibises	Wade in shallow water. Have long legs and bills. Hunt by pursuit, or stand and wait, or stir water to expose prey	Small fish, crustaceans, molluscs, other invertebrates	Sedentary to migratory depending on wetland conditions
Wildfowl	Open water, shallow water, agricultural fields. Feed by dabbling, diving, upending, grazing	Plant matter (leaves, roots, fruits), small invertebrates, larvae.	Nomadic in search of ephemeral water
Shorebirds	Wade along water edges, mostly on mudflats. Long-legged with large bills	Insects, invertebrates, plant matter	Palaearctic and afrotropical migrants, nomads and sedentary species
Gulls and terns	Aerial foraging above open water and water edges. Also feed in dump sites. Colonial nesters	Fish, small frogs, molluscs, insects, other invertebrates	Migrants, partial migrants and dispersers
Other	Varied habitats within the water body	Mostly fish, insects	Migrants, nomads and sedentary species

generally low in the wet season (January and April) and high in the dry season (July and October). Species such as African Jacana *Actophilornis africanus* peaked in January and April, and reached their lowest numbers in July and October. Palaeartic migrants were mainly present in October and January, with a few recorded in April and even fewer in July. Vagrant, rare birds and presumed domesticated escapees recorded during the whole counting period included Osprey, Garganey *Anas querquedula*, Mallard *Anas platyrhynchos*, Caspian Tern *Sterna caspia*, Slaty Egret *Egretta vinaceigula* and Lesser Black-backed Gull *Larus fuscus*.

### Variations in abundance

Overall abundance of birds was not statistically different between seasons for Lake Chivero (KW,  $\chi^2 = 0.655$ ,  $df = 3$ ,  $p = 0.88$ ) or Lake Manyame (KW,  $\chi^2 = 4.034$ ,  $df = 3$ ,  $p = 0.258$ ). However, there was significant interannual variation in abundance for Lake Chivero (KW,  $\chi^2 = 20.238$ ,  $df = 10$ ,  $p = 0.03$ ) (Figure 1) but not for Lake Manyame (KW,  $\chi^2 = 14.601$ ,  $df = 10$ ,  $p = 0.14$ ) (Figure 2). For Lake Chivero, the number of birds counted in 1995 (especially July) was much higher than in any preceding or subsequent year (Figure 1), and indeed for any other count on either of the lakes. When this year was excluded from the analysis, interannual variation for Lake Chivero was not significant (KW,  $\chi^2 = 13.18$ ,  $df = 9$ ,  $p = 0.16$ ).

For Lake Chivero generally, as the lake levels decreased, the total number of waterbirds increased (Figure 1). This was evident for the period July 1995 to October 1995 during a major drought and also from July 2002 to October 2002 during a less severe drought, when the lake levels were low. Usually lake levels dropped in the peak of the dry season (October), with corresponding increases in waterbird numbers. By contrast, a relationship between lake level and waterbird abundance was not apparent in Lake Manyame (Figure 2). Pearson's product-moment correlation tests showed that for Lake Chivero, waterbird counts were negatively correlated with lake level ( $t = -3.91$ ,  $df = 36$ ,  $p = 0.0003$ ; sample estimates correlation =  $-0.54$ ) but for Lake Manyame, there was no correlation between the two variables ( $t = 0.5$ ,  $df = 26$ ,  $p = 0.62$ ; sample estimates correlation =  $0.09$ ).

### Community composition and species' diversity

The Cormorant guild was important at Lake Chivero in all seasons and the Waterfowl guild in July and October (Figure 3). The main species in the Cormorant guild were the Reed Cormorant and the White-breasted Cormorant. The Reed Cormorant contributed 19% of the total number of birds counted in July 1995, when the highest number of birds was counted at the Lake. Lake Manyame was mainly

dominated by the Waterfowl guild (Figure 4), with the most abundant species being Red-billed Teal, White-faced Duck, Southern Pochard and Red-knobbed Coot.

There was a significant increase in the Shannon-Wiener diversity index (ANOVA,  $df = 3$ ,  $p = 0.03$ ) in the transition from July to October in Lake Chivero (Figure 5). The Shannon-Wiener diversity indices of the other seasons were not significantly different from each other in Lake Chivero. Lake Manyame showed no significant changes in interseasonal diversity indices (Figure 6). Overall waterbird diversity did not differ significantly between years for either of the two lakes.

### Seasonal variations of waterbird communities

The waterbird populations of the two lakes are composed of resident/sedentary species, nomadic species, as well as Afrotropical and Palaeartic migrants (Figures 5 and 6). Lake Chivero consistently supported high numbers of resident/sedentary species, mainly composed of Reed Cormorant, White-breasted Cormorant as well as herons and egrets. Lake Manyame mainly supported nomadic species (ducks, geese and African Jacana) throughout the year, with a significant peak of numbers in October. Both lakes received an input of Afrotropical and Palaeartic migrant waterbirds from October to April. For both lakes, the common and abundant Palaeartic migrants included Wood Sandpiper, Little Stint, Ruff *Philomachus pugnax* and White-winged Tern *Chlidonias leucopterus*.

Uncommon or rare Palaeartic migrants occurring in the two lakes were Common Redshank *Tringa totanus* and Black-tailed Godwit *Limosa limosa*. The Common Sandpiper *Actitis hypoleucos*, Wood Sandpiper, Ruff and White-winged Tern were the most common overwintering species. The most common Afrotropical migrants were the Collared Pratincole and Lesser Moorhen.

### Discussion

Previous work has shown that variations in abundance and diversity of waterbird communities result from numerous and complex population processes and environmental events (Poulin et al. 1993, DuBowy 1998, Romano et al. 2005) including migration, breeding success, moulting regimes, seasons, floods, and droughts. Our results using a long-term series of count data on two lakes in Zimbabwe identified several factors that are likely to be key drivers in determining the waterbird community structure.

A high seasonality in the waterbird composition and abundance was observed and coincided with seasonal variations in resource availability. A negative relationship between Lake Chivero lake level and waterbird abundance,

**Table 3:** Summary statistics for waterbirds counts at Lake Chivero and Lake Manyame, 1993-2003

Parameter	Chivero	Manyame
Number of counts	38	28
Total number of species recorded during the study	88	91
Average number of species recorded (min.-max.)	42 (29-56)	48 (30-62)
Proportion of the overall number of resident species (%)	93.7	72.9
Proportion of the overall number of Afrotropical and Palaeartic migrant species (%)	6.3	27.1

with highest waterbird numbers when water levels were lowest, was found, with high numbers of birds in 1995, when water level was low (Marshall 1997).

Overall during the 11-year period considered, numbers of waterbirds recorded at the perennial Lakes Chivero and Manyame increased in the dry season, probably as a result of a complex interplay of bird movements occurring at local, regional and intercontinental scales. In Zimbabwe, the dry season is characterised by the drying out of small water bodies, which causes a congregation of waterbirds at larger permanent water bodies (Campbell and Miles 1956), particularly for nomadic waterbird species that include ducks and geese. These species had lower abundances in January and April, with peaks from July to October. The

same pattern was observed by Campbell and Miles (1956), Woodall (1974), Jarvis (1984), Boshoff et al. (1991) and Tyler (2001), suggesting that nomadic species respond to resource availability at regional level with use of localities depending on spatial heterogeneity of rainfall.

The lower numbers of waterbirds observed in Lakes Chivero and Manyame during the wet season were due to the dispersal of waterfowl to breed. Since waterfowl (ducks and geese) form a significant part of the community of these two lakes (Woodall 1974, Irwin 1981, Jarvis 1984), their breeding patterns have a significant impact on overall bird abundance. Most duck species breed during the wet season (Irwin 1981), when they move away from large lakes into smaller pans that form seasonally and are likely to have

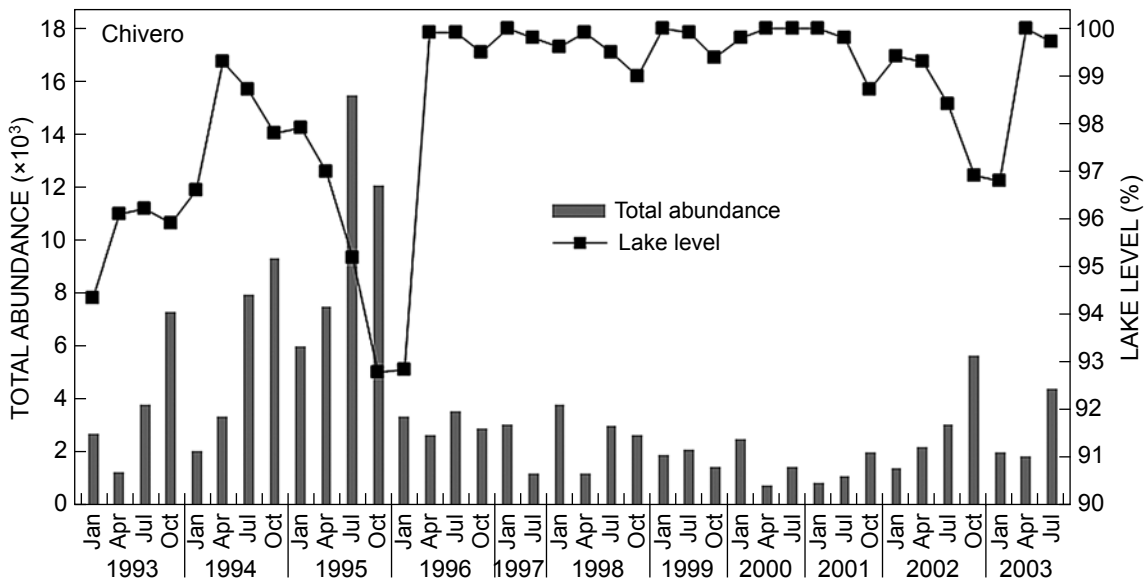


Figure 1: Variations in waterbird abundance and lake level for Lake Chivero, 1993–2003

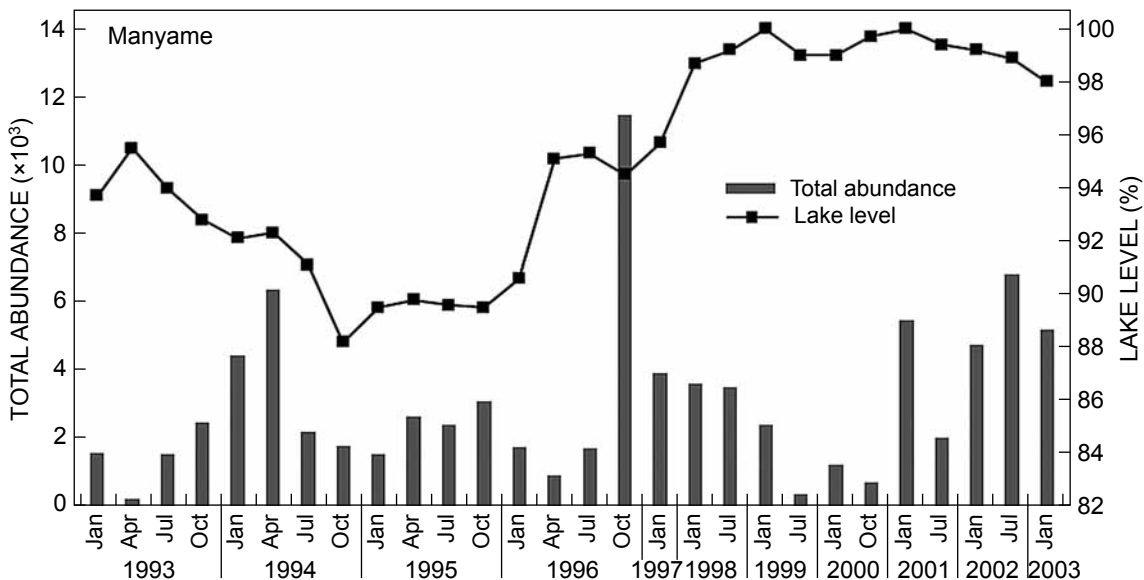


Figure 2: Variations in waterbird abundance and lake level for Lake Manyame, 1993–2003

lower risks of predation and disturbance than the larger lakes (Boulton and Woodall 1974, Thomson 1978, Godfrey 1992). As a consequence of breeding dispersal, waterfowl remaining at large permanent water bodies during the wet season are mostly the non-breeding stock of resident bird species (Woodall 1974) and Palaeartic migrants.

For the Cormorant guild, which is comprised of nomadic and sedentary resident species, the observed seasonal variations in abundance likely resulted from variations in food (fish) availability, water surface accessibility (Guadagnin et al. 2005, Hockey et al. 2005) and breeding behaviour. Large numbers of cormorants observed in the wet season coincided with the main breeding season of the guild (Irwin 1981).

The seasonal variations of waterbird abundance observed in Lakes Chivero and Manyame also resulted from large-scale movement of migratory birds. The high numbers of birds observed in October corresponded to the arrival of Afrotropical and Palaeartic migrants (Hockey et al. 2005). Between July and October, exposed shorelines of large water bodies provide foraging space and increased accessibility to invertebrates for the shorebirds and they aggregate in large numbers (Dodman and Diagana 2007). Conversely, low shorebird numbers are generally associated with high water levels (Tree 1988). However, the month of April corresponds to the period during which most Palaeartic migrants gather at large water bodies in preparation for

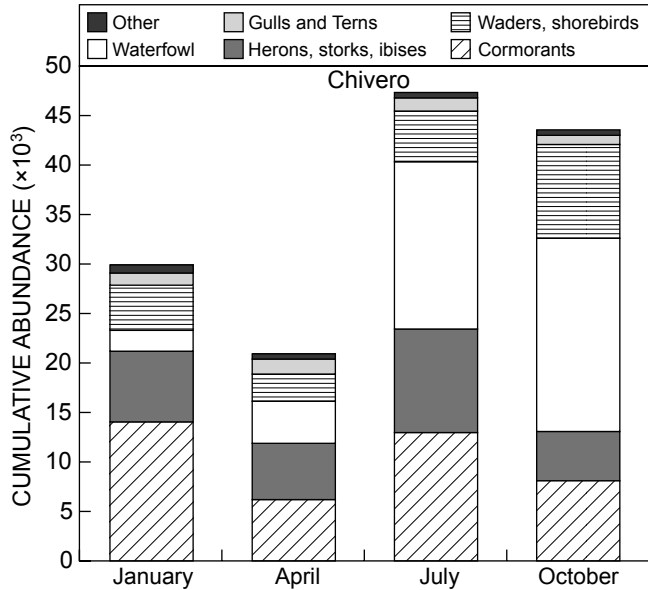


Figure 3: Interseasonal variation in guild structure for Lake Chivero

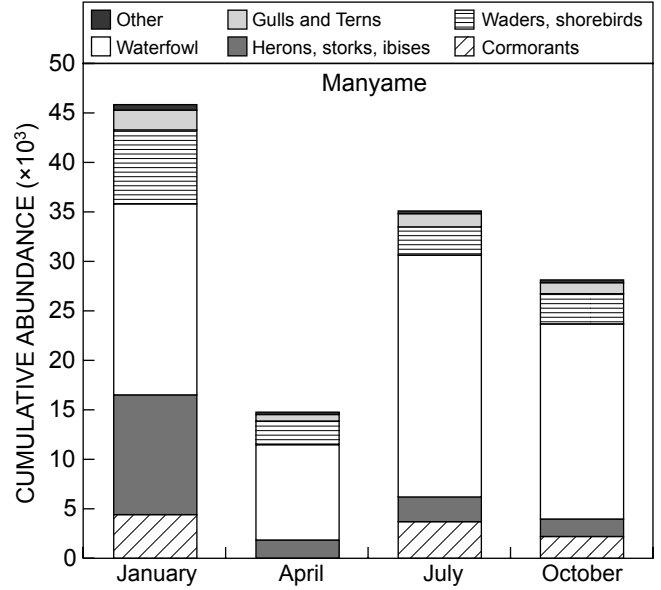


Figure 4: Interseasonal variation in guild structure for Lake Manyame

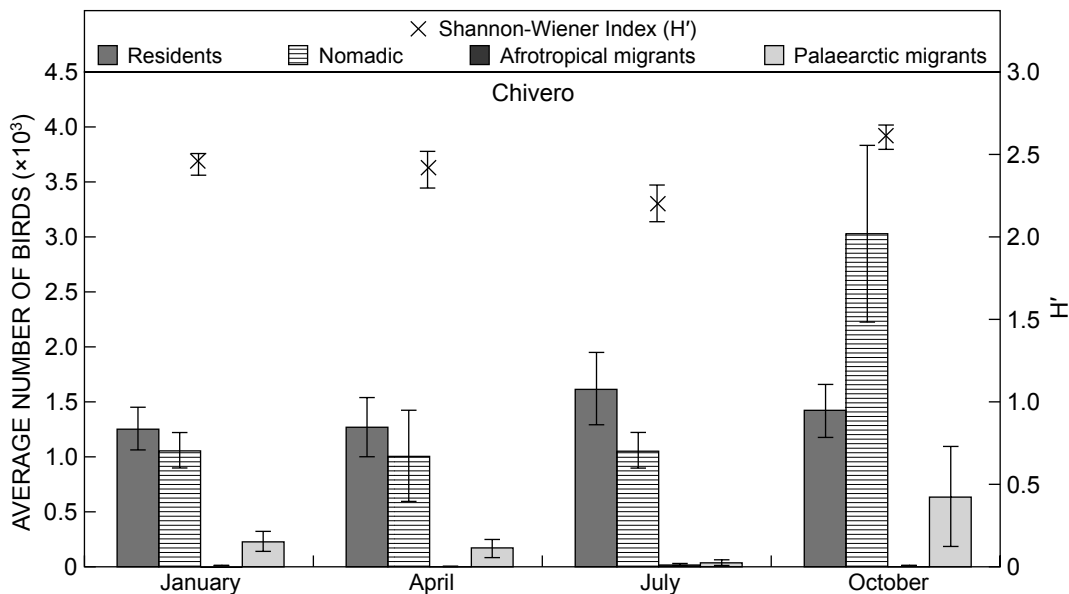


Figure 5: Interseasonal variation in the waterbird community and Shannon-Wiener diversity index (H') for Lake Chivero (bars are SE of the mean)

departure (Kaletja-Summers et al. 2001), and we observed such a peak of abundance at Lake Manyame.

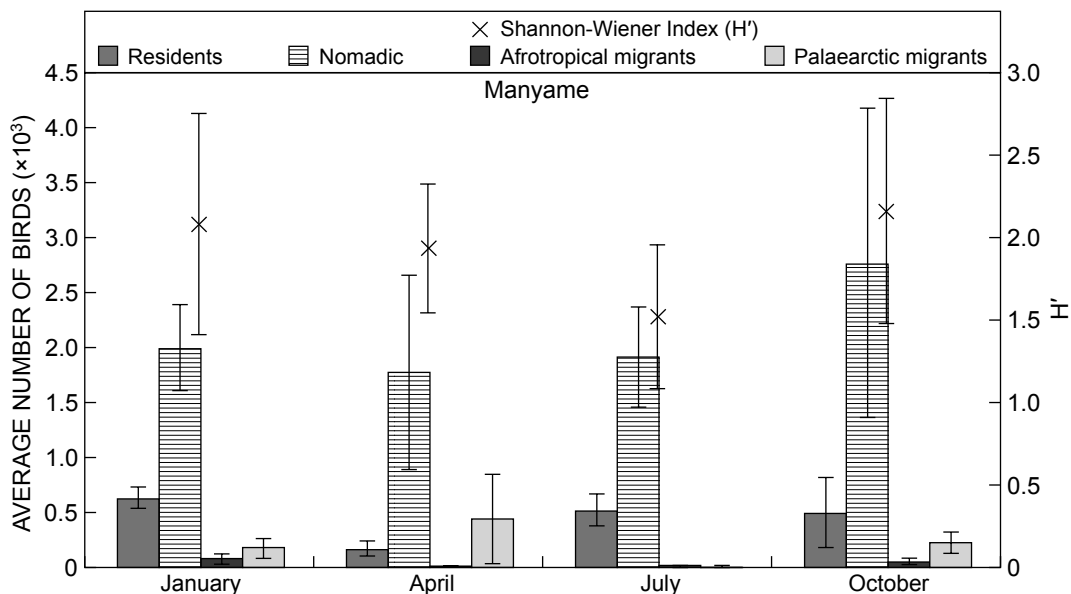
Bird communities in Lake Chivero and Lake Manyame experience a seasonal turnover of bird species, resulting from movements occurring at different scales (from local to intercontinental) and driven by several ecological and anthropogenic factors. However, this turnover of species did not result in major variations of diversity indices, with alpha diversity only significantly different between July and October for Lake Chivero. This is possibly due to the arrival of large numbers of Palaearctic migrants in September and October (Hockey et al. 2005). However, Lake Manyame did not show any significant differences in diversity across the different seasons, which could be due to different arrival times of different species between the two lakes but most likely results from biophysical differences between the two lakes. The large size of Lake Manyame provides several types of habitats, which may be utilised by different species all year round. Compared to Lake Chivero, which consistently had lower numbers of birds and lower diversity, the arrival and departure of migrant birds in Lake Manyame did not significantly alter the overall diversity of the waterfowl community, because migrant species represented a relatively small proportion of the overall number of birds.

Bird counts demonstrated that local bird numbers in perennial lakes experienced drastic interannual changes during exceptional climatic events. The drought that affected Zimbabwe in 1995 resulted in a large increase of bird numbers at Lake Chivero, whereas there were no significant interannual variations in numbers at both lakes in other more 'normal' years. Interannual variations in numbers and diversity are likely masked by seasonal variations (Elmberg et al. 1994) and are therefore difficult to determine. From an ornithological and bird conservation perspective, our results demonstrate the importance of the two study sites. Both lakes are used as post-breeding congregation sites

by ducks and geese and, as they are permanent water sources, they represent important refuge sites for waterbirds during the dry season. They are also important foraging grounds for migratory species, as they offer diverse habitats for different species.

Changes in rainfall influence the lakes' water levels and hence their habitats, which in turn drive abundance and diversity of waterfowl. It is therefore imperative to use appropriate management strategies that ensure that the lakes retain suitable habitats for waterbirds. Intervention can focus on the water resource through the biological control of water hyacinth (control – *Neochetina* weevils) and parrot's feather *Myriophyllum aquaticum* (control – *Neohydronomus affinis* weevils) (Chikwenhere 2001). Human disturbance could also be a focus of conservation management. Increasing subsistence and commercial fishing appears to disturb waterbirds and could reduce the fish supply for specialised guilds. Targeted actions could aim at controlling fishing and restricting access to those parts of the lakes that are important refuges for waterbirds, such as inlets and islands that are used for breeding. Conservation education for farmers surrounding the lakes is important as their fields also serve as habitats for waterbirds. Management guidelines must integrate large spatial scales, as these two lakes do not function in isolation. The presence of waterbirds in these lakes is dependent on resource availability in adjacent and distant (regional) wetlands. The socioecological changes in the lakes need to be constantly monitored in order to understand factors driving waterbird species diversity and abundance in the wetlands and to inform management decisions (Paillisson et al. 2002).

Recently, Anseriforms and Charadriiforms have attracted the scientific community's attention because of their role as a reservoir for strains of AIV around the globe (Olsen et al. 2006, Webster et al. 1992) and in Africa (Gaidet et al. 2007, Cumming et al. 2011, Gaidet et al. 2012) In our data set,



**Figure 6:** Interseasonal variation in the waterbird community and Shannon-Wiener diversity index ( $H'$ ) for Lake Manyame (bars are SE of the mean)

the abundance of waterfowl, waders and other shorebirds varied across time and between the two lakes. The risk of avian influenza is likely to be higher during the seasons when overall abundance is high (July and October), during drought years and at Lake Manyame rather than Lake Chivero because of the higher numbers of wildfowl at Lake Manyame. These results are in agreement with recent studies (Caron et al. 2010, Caron et al. 2011).

In conclusion, this retrospective analysis of waterbird variability in the two adjacent lakes underlines the complex ecological processes that influence waterbird abundance. In order to conserve biodiversity and ecosystem processes and be able to understand and predict diseases at risk of spreading into domestic or human populations, we suggest improved investment in the building and analysis of wildlife count data sets.

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