

Chapter 5: Discussion and conclusions

5.1. Species-area curve

The understanding and conservation of riparian avifauna requires perspectives and interpretations of that fauna relative to avian assemblages and the ecology of the entire study area (Knopf & Samson 1994). Descriptions and interpretations of avian community patterns within a study area can give meaningful perspectives on how bird variables are influenced, may be useful in the conservation of riparian avifauna, and could provide the motivation for additional studies.

However, the sample size in a community data set for a given study should be adequate in order to result in reliable findings. In this study the species-area curve shows that an adequate number of transects (97) were sampled as hardly any additional species were added after 50 transects (Figure 4.1, Section 4.1). Consequently, a sufficient number of sites were sampled to investigate the hypothesis.

The hypothesis that is tested by this study states that bird variables are affected by vegetation structure, anthropogenic factors and seasonal influences (Section 1.3). This chapter will thus show how the results (Chapter 4) provided evidence for testing this hypothesis.

5.2. Species richness

Riparian ecosystems are often more dynamic, diverse, and complex than the surrounding landscapes and encompass sharp environmental gradients or ecotones in ecological processes and communities (Naiman *et al.* 1993). In this study, 156 avian species were found and 76 690 observation records were obtained along the riparian corridors of Potchefstroom (Section 4.2). This signifies the complexity and heterogeneity of bird communities, and these ecosystems are maintaining a relatively high avian diversity, showing the importance of conserving these ecosystems within an urban area.

The majority of species were observed in the Mooi River (aggregate of 145 species over 50 transects), fewer in Spitskop Spruit (aggregate of 117 species over 12 transects), and an aggregate of 92 species (over 12 transects) in

Wasgoed Spruit (Table 4.1, Section 4.2). These data already show that bird variables differed between the streams, and therefore fluctuated on a spatial scale.

Additionally, the least number of records (4698) were recorded during June 2006, while most records (7446) were documented during December 2006 (Section 4.2). This difference of 2748 records between December and June 2006 shows that bird variables fluctuates seasonally.

In the following sections, a more detailed look at how avian variables changed will be provided by considering the spatial and temporal changes in community patterns.

5.3. Spatial and temporal changes in bird variables

Bird variables fluctuated on a spatial- (consecutive transects) and temporal scale (over the 13 month observation period), as shown by the transect-time profiles (Section 4.3). Climate, topographic variations, disturbances and anthropogenic activities influence the vegetation structure on a spatial scale, which consequently affect the relationships with birds (Naiman *et al.* 1993; Seoane *et al.* 2004; Wakeley *et al.* 2007; Wiens 1989b). Therefore, the changes in riparian habitats on a spatial scale consequently affect the processes that bring about community patterns.

Landscapes surrounding the study area, such as Potchefstroom Dam, Poortjie Dam, O.P.M. Prozesky Bird Sanctuary, and residential and agricultural areas could also have played a role influencing bird variables on a spatial scale (Figures 3.1 and 3.2, Section 3.1.1). However, the focus of this study was not on a specific landscape but rather to investigate the associations between different habitat types, seasonal influences, and bird variables (Hypothesis, Section 1.3).

In accordance with the hypothesis (Section 1.3), the influences that vegetation structure and anthropogenic factors have on bird variables were tested. Therefore, maps of the distribution of different habitat types characterised according to vegetation structure and anthropogenic factors were drawn (CAHs, Appendix B). From these maps, it is apparent that the different vegetation structures and anthropogenic factors were distributed heterogeneously in the study area (Appendix B).

A consistent pattern emerged in Section 4.3 regarding the bird variables (RAD, species richness, diversity index, and TAB) on the transect-time profiles. Sectors A (Transects S1 – S4) and E (Transects S11 – S13) of Spitskop Spruit, Sector H (Transects W10 – W12) of Wasgoed Spruit, and Sectors N, O, P and Q (Transects M34 – M50) of the Mooi River consistently had relatively higher bird variables than other sectors (Figures 4.2 – 4.9, Section 4.3). Sectors A, E and H were mainly covered by grass and reeds, drainage pipes, footpaths, and had informal settlers, while Sectors N, O, P and Q largely consisted of trees, shrubs and reeds, as well as drainage pipes, informal settlers, roads, tar roads and train bridges (Appendix B). These environmental factors were therefore associated with relatively high bird variables on the transect-time profiles.

Conversely, sectors B and C (Transects S5 – S9) and F (Transects S14 – S15) of Spitskop Spruit, Sector G (Transects W5 – W9) of Wasgoed Spruit, and Sectors I, J, K, L and M (Transects M1 – M32) of the Mooi River had a consistent pattern of relatively low bird variables (Figures 4.2 – 4.9, Section 4.3). Sectors B, C and F were mainly covered by herbs, shrubs and grass; and B and C also had dirt roads and electric pylons (Appendix B). A concrete riverbed and houses occur in Sector G (Appendix B). Sectors I, J and L are covered by shrubs and reeds, while K and M were covered by trees and grass (Appendix B). Sectors I, J, K, L and M had additionally informal settlers, footpath-bridges, tar roads, train bridges and houses (Appendix B) and associated with relatively low bird variables.

It is evident that there is an association between the bird variables and the distribution of different vegetation structures and anthropogenic factors. In the next section, additional insights on these existing relationships will be provided when considering multivariate analyses findings.

Bird variables showed irregular patterns on a temporal scale as illustrated on the transect-time profiles (Figures 4.2 – 4.9, Section 4.3). The variations in these patterns were mainly due to seasonal influences. Doherty *et al.* (2000) and Wiens (1989b) documented that bird variables change over time in response to habitat changes (Section 2.1.1). Vegetation structure changed between summer and winter months (as seen in the successional vector lengths, Figure 4.10, Section 4.4), which caused habitat changes, and

consequently influenced change in bird variables on a temporal scale. It is therefore apparent that the fluctuation of bird variables responded to the seasonal changes in vegetation structure.

Detailed illustrations on vegetation structure that changes between summer and winter months, with the related bird abundance, species richness and RAD fluctuations are shown on the ecological profiles (Appendix A).

Doherty *et al.* (2000) and Wiens (1989b) compiled other seasonal factors, listed in Section 2.1.1. These factors include the change in habitat selection behaviour (e.g. breeding and non-breeding), community and diversity variations in nearby habitat patches, fluctuations in food, site tenacity, weather conditions over seasons, migration, breeding, variation in predation and parasitism, and a lack of saturation of suitable habitats. Variable combinations of these factors may have contributed to the irregular seasonal patterns.

Some of these factors are noticeable on the NMS successional vector ordination graphs (Figures 4.14, 4.17, 4.18 – 4.30, Section 4.4), where the vectors showed the magnitude and direction of change in avian community trajectories. Discussions on these will follow.

5.4. Multivariate analyses

Due to the complexity and heterogeneity of the data, multivariate analyses techniques were used to illustrate the temporal changes in vegetation structures, anthropogenic factors, and avian communities along the riparian corridors of Potchefstroom (Section 4.4).

5.4.1. Characterised avian habitats (CAHs)

Bird communities can be defined in terms of associated habitat types or life-form categories (Wiens 1989a) (Section 1.1.6). In this study, bird communities in the riparian corridors of Potchefstroom were defined according to the different CAHs. A number of avian communities were characteristic of the riparian corridors of Potchefstroom, and were characterised according to vegetation structure (Figures 4.11 and 4.12, Section 4.4.1), anthropogenic factors and informal settlers (Figures 4.15 and 4.16, Section 4.4.2). Figure 4.12 (Section 4.4.1) shows that vegetation structure was the predominant environmental factor, because seven habitats characterised according to

vegetation structures, and only one habitat was characterised by an anthropogenic factor (concrete riverbed, C/R). The seven vegetation CAHs (Figure 4.13) were further reduced to five due to convergence in avian communities among CAHs with similar vegetation types (Section 4.4.1). The CAHs that were combined were HSG and H/S, and Re and GrA (Section 4.4.1). Therefore, the birds were ordinated with five vegetation CAHs and with one anthropogenic CAH (C/R) (Figure 4.14, Section 4.4.1), referred to as the six summer CAHs (the same CAHs were used in winter to track changes in avian communities). The five vegetation CAHs were G/R (grass and reeds), HSG (herbs, shrubs and grass), S/R (shrubs and reeds), T/G (trees and grass) and TSR (trees, shrubs and reeds).

Although the vegetation factors were predominant (Figures 4.11 and 4.12, Section 4.4.1), it is known that bird variables can also be influenced by anthropogenic factors (Section 2.1.3.2). Anthropogenic factors influence avian diversity among riparian corridors (Knopf & Samson 1994; Rottenborn 1999; Smith & Wachob 2006). Therefore, habitats were also characterised by anthropogenic factors, shown in Figures 4.15 and 4.16 (Section 4.4.2). The anthropogenic factors were drainage pipes (Dpi), footpaths (Fpa), dirt roads and electric pylons (DrE), informal settlers (InS), concrete riverbed (C/R), footpath bridges (FpB), roads, road/train bridges (TrB), and houses (Hou).

5.4.2. Bird communities and vegetation structure

Vegetation structure influence niche size and niche diversity (Begon *et al.* 1996; Diaz 2006; Doherty *et al.* 2000; Smith *et al.* 2008; Wiens 1989a; Wiens 1989b), and birds select their habitats according to the physical and biotic properties (niche size), which leads to distinct bird distribution patterns (Cody 1985).

Among the six summer CAHs that were ordinated with bird species, it is noticeable that mainly divergent community trajectories were found, with only two communities (T/G and S/R) showing convergence, or overlap (Figure 4.14, Section 4.4.1). TSR, G/R and HSG, were distinguished by different combinations of vegetation types, and vegetation was limited in C/R due to the concrete surface coverage. Thus, available resources and physical properties varied among each CAH, and species select appropriate habitats

according to their specific behaviours and needs (Section 1.1.5). Therefore, the structural differences between CAHs reflect niche diversity, and consequently a divergence in avian communities.

This divergence in community trajectories correlates with other studies that showed that avian communities varied according to the type of vegetation structure that was present (Brand *et al.* 2008;Diaz 2006;Malan *et al.* 2007;Posa & Sodhi 2006;Powell & Steidl 2000;Simons *et al.* 2006;Vidaurre *et al.* 2006;Wakeley *et al.* 2007).

A number of species congregated at TSR (such as the European Bee-eater, African Paradise-Flycatcher, Little Bittern, Squacco Heron, South African Shelduck, White-faced Duck, Cape Shoveller, Fulvous Duck, South African Cliff Swallow, Woodland Kingfisher, and the Willow Warbler).

Others ordinated away from TSR in three different directions (Figure 4.14, Section 4.4.1). Some ordinated from TSR towards T/G (such as the Greater and Lesser Honeyguide, Malachite and Brown-hooded Kingfisher, and the Cardinal Woodpecker), while others ordinated in the direction of HSG (such as the Rattling Cisticola, Common Fiscal, Red-backed Shrike, Sobata and Rufous-naped Lark, and the Common Waxbill). Several species also ordinated towards G/R (such as the Marsh Sandpiper, Hottentot Teal, Common Moorhen, White-winged Widowbird, and the African Snipe) (Figure 4.14, Section 4.4.1).

Resources vary among different vegetation types (Begon *et al.* 1996;Wiens 1989a;Wiens 1989b). Grasses were a common factor among T/G, HSG and G/R. However, trees, shrubs and reeds differentiated these three CAHs. Trees, shrubs and reeds provided niche diversity and different types of resources (Section 2.1.3.1), which directly influence processes such as nesting and/or feeding, and results in a pattern of divergence in communities.

Alternatively, convergent community trajectories appear in CAHs with some shared properties and factors that create niche overlap. S/R and T/G also differed in vegetation structure, but were mostly located adjacently (Appendix B), which favours bird movement between these CAHs - partially explaining why convergent communities were found. Furthermore, the process of seasonal migration also contributed to the convergent community

pattern. Summer migrants such as the European Honey Buzzard, Red-chested Cuckoo and European Cuckoo were observed in both S/R and T/G during the warmer months. This explains the convergence between the avian community trajectories of S/R and T/G during the summer months (Figure 4.14, Section 4.4.1).

Summer migrants (such as European Bee-eater, African Paradise-Flycatcher, White Stork, Willow Warbler, South African Cliff Swallow, and the Woodland Kingfisher) ordinated with the spring and summer months of TSR along dimension 1 (x-axis). However, the winter and autumn months ordinated along dimension 3 (y-axis) away from the summer migrants (Figure 4.14, Section 4.4.1). The presence of summer migrants increased the species richness within the community of TSR and attributed to community change. Competition also tends to increase, due to the presence of summer migrants (Skagen *et al.* 2005). Therefore, competition also attributed to community change along TSR.

Despite the presence of summer migrants, T/G still had the smallest community change between seasons (Figure 4.14, Section 4.4.1). Vegetation coverage and heights were similar between seasons (Appendix A), thus the little transformation within the habitat and resulted in a more stable bird community trajectory.

Grass and reed-nesting birds, such as Red-knobbed Coot, Red-Collared Widowbird, White-winged Widowbird, Red-billed Teal, African Snipe, and Black Heron ordinated closer towards the warmer months of G/R (Figure 4.14, Section 4.4.1). These birds utilised grass and reeds as nesting sites during the warmer months (Table 4.2, Section 4.2) - during these periods, grass and reeds had greater heights and coverage than the colder months (Appendix A). Therefore, due to breeding preferences and change in vegetation structure, the community trajectory of G/R was strongly affected between warmer and colder months.

Few species ordinated with S/R, HSG and C/R, and comparatively greater changes (longer vectors) in community trajectories was found between seasons (Figure 4.14, Section 4.4.1). Changing levels of resources, conditions, and disturbances between seasons may have contributed to

predation and competition, resulting in an increase in bird migration among habitats.

Species associated with S/R and HSG, ordinated closer to the warmer months, while vegetation covered larger areas. Annual plants (grass, reeds and herbs) grew higher (Appendix A), thereby probably contributing to usable resources. Thus, the change in vegetation structure between seasons influenced the levels of exploitable resources; in turn, this affected species interactions and changes within communities.

None of the species was ordinated in the direction of the summer months of C/R, (Dimension 1 on Figure 4.14, Section 4.4.1). Large conversions of natural surfaces (vegetation structure) to unnatural ground coverage (concrete) in C/R limited exploitable resources (nesting-, perching sites, and nesting material, shelter, and food availability). Therefore, it seems that birds tended to avoid C/R during the warmer months.

The colder months of S/R, HSG and C/R ordinated towards each other (Figure 4.14, Section 4.4.1). Although these bird community trajectories are divergent, the ordination toward each other in the colder months indicates that there were more similarities in these communities during this season. Restriction of resources due to seasonal influences increases competition probably resulted in birds having to move between areas, and may account for the detectable convergence of the respective bird communities.

Therefore, change in vegetation structures, anthropogenic factors, and seasonal influences had a direct affect on niche diversity, resource availability, presence of summer migrants, habitat selection and competition, which obviously resulted in differences and changes in bird community patterns.

5.4.3. Bird communities and anthropogenic factors

It was apparent that more convergence appeared in communities among anthropogenic CAHs (Figure 4.17, Section 4.4.2) than vegetation CAHs (Figure 4.14, Section 4.4.2). This is most likely attributable to a convergence or homogenization in niches among anthropogenic factors.

FpB (footpath bridges) and TrB (tar roads, road/train bridges) had convergent communities, presumably due to the similarity in exploitable

resources. Both are permanent structures constructed at certain heights above the water surface and crossing the stream canal. Birds with similar requirements concerning shelter, perching and nesting therefore utilised both FpB and TrB, which explains the convergent community trajectory (Figure 4.17, Section 4.4.2). However, divergence was found in the summer months of FpB and TrB, due to different summer migrants that joined FpB and TrB. This pattern confirms that seasonal influences affect bird communities associated with anthropogenic factors.

InS was characterised by the abundance of informal settlers and was the only anthropogenic factors that showed a divergent community trajectory (Figure 4.17, Section 4.4.2). InS was associated with relatively high and low bird variables (Section 5.3). Figure 4.17 shows that the majority of species ordinated with InS (such as Lesser Swamp-Warbler, Little Rush-Warbler, Cardinal Woodpecker, Cape Robin-Chat, Mallard Duck, African Red-eyed Bulbul, Marico Flycatcher, Burchell's Coucal, Spur-winged and Egyptian geese, and the Crowned and Blacksmith lapwings).

However, InS itself was associated with low avian diversity (will be discussed in Section 5.4.4.). Informal settlers create feeding opportunities for birds, which may explain why many species ordinated with InS. However, this predominant ordination of species with InS is not only effected by the activities of settlers, but is also influenced by surrounding landscapes. One must take into account that the InS CAH was situated adjacently to the Van Der Hoffpark Marshland and the OPM Prozesky Bird Sanctuary (Figure 3.2 and Figure B10, Appendix B) which played a significant role in maintaining high bird variables. The high niche diversity of the surrounding landscapes may explain why a divergent community was associated with this anthropogenic factor.

Fpa (footpaths), Dpi (drainage pipes) and C/R (concrete riverbed) mainly have convergent community patterns with relatively long avian trajectories. Interestingly, these three anthropogenic CAHs were all associated with the substrates of the C/R habitat, which forms a niche overlap and can explain the convergence in community trajectories of Fpa, Dpi and C/R.

Footpaths, drainage pipes and concrete reduce vegetation, influence shelter, perching- and nesting sites, and affect feeding opportunities for birds. The reduction in vegetation enhanced nest exposure, allowing nest predators

and brood parasites to locate nests easier. Destruction of riparian vegetation reduces the ability of populations to recolonise sites (Knopf & Samson 1994) and enhances nest predation. Nest predation is considered as an important force shaping avian communities (Borgmann & Rodewald 2004). Therefore, relatively long community trajectories were found along Fpa, Dpi and C/R (Figure 4.17, Section 4.4.2).

High bird nest predation has been found along recreational trails in lowland riparian areas in the Front Range of Colorado (Miller & Hobbs 2000). Nest predators were also found to be more abundant along urban streams than rural streams or streams in more natural areas (Borgmann & Rodewald 2004). Conversely, nests were more concealed in areas with relatively high vegetation densities (Powell & Steidl 2000). The lower vegetation density of Fpa and C/R is likely to enhance nest exposure; therefore, brood parasites and nest predators can more easily locate nests. Nest predation influences change in communities (Doherty *et al.* 2000;Wiens 1989b) (Section 2.1.1). In this study, a presumable increase in nest predation along Fpa and C/R may have caused individuals and species to move away, and consequently relatively large changes occurred in community trajectories of Fpa and C/R (Figure 4.17, Section 4.4.2).

DrE had electric pylons as well as dirt roads. Electrical pylons provide perching sites for hawking and perching foragers, and dirt roads create forage opportunities (mainly for arthropods) for ground gleaners (Hockey *et al.* 2005;Maclean 1993) (Section 2.1.4). DrE created a unique niche and as a result, a divergence of communities was associated with DrE. However, the DrE community trajectory changed on a relatively large scale when compared with the trajectories of InS, TrB, FpB and houses. This possibly indicates the effects of frequent disturbances in DrE. Disturbances include the presence of local residents, and the overgrazing of their cattle that reduce vegetation densities, and enhance nest exposure which favour the nest predators (DrE is located in Sectors B, C and D close to rural residents, Figures 3.2 and 3.3, Appendix B).

The results showed that the magnitude of community changes varied between the different anthropogenic CAHs. Smaller differences in community trajectories were found between FpB, InS, TrB and Hou (Figure 4.17, Section

4.4.2). Relatively greater change in community trajectories were found for DrE, Fpa, Dpi and C/R, which show instability of communities among these four CAHs.

Niche overlap resulted in convergence between community trajectories of the anthropogenic CAHs. Varying resource levels, human activities, nest predation, and seasonal factors probably affected the magnitude of change within the communities.

5.4.4. Avian diversity and CAHs

Species distribution patterns among the CAHs (Figures 4.14 and 4.17), and indicator species for each CAH are shown in Tables 4.3 and 4.4 (Sections 4.4.1 and 4.4.2). In the study, results were compiled for both species richness and abundance. Avian diversity combine these two variables (Magurran 2008) (Section 1.1.3). It was found that avian diversity differed between the CAHs (Figures 4.14 and 4.17, and Tables 4.3 and 4.4 in Sections 4.4.1 and 4.4.2).

The majority of species ordinated between TSR, G/R, T/G and HSG (Figure 4.14, Section 4.4.1). However, the highest avian diversity was associated with TSR (78 species, of which 54 were indicators for TSR, Tables 4.3 and 4.3.6, Section 4.4.1). Examples of indicators for TSR were the White-breasted Cormorant, White-faced Duck, Black-crowned Night Heron, Little Bittern, Pied Kingfisher and the Black-shouldered Kite (Table 4.3.6, Section 4.4.1).

TSR was located close to the O.P.M Prozesky wetlands (Appendix B and Figure 3.3) where water was easily accessible, indicating that that availability of such resources in the surroundings also influence avian diversity. As mentioned, the vegetation in TSR differed in height classes (Tables 3.1 and 3.2), and the structural heterogeneity of TSR is illustrated in the ecological profiles (Appendix A). Heterogeneity of vegetation structures influences niche diversity (Diaz 2006) as noted in Section 2.1.3.1. Trees, shrubs and reeds seem to enhance the divergence of communities (Section 5.4.2). Trees, shrubs and reeds as one habitat (TSR), were associated with relatively high avian diversity (Figure 4.14 and Table 4.3 in Section 4.4.1).

10 indicators and 19 species were associated with T/G (Table 4.3.5, Section 4.4.1). Examples of indicators were Crested Barbet, Black-collared Barbet, Giant Kingfisher, Brown-hooded Kingfisher, and Malachite Kingfisher (Table 4.3.5, Section 4.4.1).

Furthermore, 12 indicators and 25 species were associated with G/R (Table 4.3.1, Section 4.4.1). Examples of indicators were Black Heron, White-winged Widowbird, African Snipe, Cape Longclaw, Red-collared Widowbird, and Little Grebe (Table 4.3.1, Section 4.4.1).

Lastly, 11 indicators and 19 species were associated with HSG (Table 4.3.2, Section 4.4.1). Examples of indicators were Kalahari Scrub-Robin, Blue Waxbill, and Familiar Chat (Table 4.3.2, Section 4.4.1).

Therefore, according to Tables 4.3, 4.3.5, 4.3.2 and 4.3.1, a moderate avian diversity (when compared with the other CAHs) was found for T/G, G/R and HSG (Section 4.4.1). However, there was also a divergence in avian community trajectories between these three CAHs (Figure 4.14 and Tables 4.3, 4.3.5, 4.3.2 and 4.3.1, Section 4.4.1).

Birds make decisions to select an appropriate habitat according to their specific behaviours, and this leads to distinct bird distribution patterns (Cody 1985) (Section 1.1.5). The divergence found between T/G, G/R and HSG (Figure 4.14, Section 4.4.1), shows that these habitats probably had niche combinations that differed from one another and resulted in diverge community trajectories due to habitat selection behaviour and other factors.

S/R had only one indicator, Mallard Duck (Table 4.3.4) and six associated species (Table 4.3) (Section 4.4.1). As mentioned earlier, S/R and T/G were situated adjacently and had convergent communities due to niche overlap and proximity. Several species that occurred in both CAHs were more closely ordinated to T/G, which explains why S/R is associated with relatively lower (when compared with the other CAHs) levels of avian diversity.

Two species were indicators (Three-banded Plover and the Spotted Thick-knee, Table 4.3.3) and eight were associated with C/R (Table 4.3) (Section 4.4.1). Vegetation structure in C/R has mostly been replaced by concrete. Some nest predators (Section 2.1.8), brood parasites (Section 2.1.5), and exotic species respond positively to human-altered landscapes, probably

causing other birds to relocate to other habitats (Martin 1993; Pennington *et al.* 2008; Saab 1999). Therefore, C/R had relatively lower levels of avian diversity.

It was found in the Santa Clara Valley in the USA that bird species richness and density, as well as native vegetation decreased as the number of bridges per length of river increased (Rottenborn 1999). Construction of roads and bridges adjacent to streams is therefore likely to affect the integrity, continuity, and stability of riparian ecosystems (Mensing *et al.* 1998), reflected here in a changed avian community. Within the riparian corridors of Potchefstroom, however, roads and bridges were associated with a greater diversity of birds when compared with other anthropogenic factors. TrB (tar roads and train bridges) was associated with the majority of species (an aggregate of 57 species, Table 4.4, Section 4.4.2); 32 species were indicators (Table 4.4.7, Section 4.4.2). Examples were the South African Cliff Swallow, Marsh Owl, Burchell's Coucal, and the Pied Kingfisher (Table 4.4.7, Section 4.4.2). Additionally, FpB (footpath bridges) was associated with 29 species of which 16 were indicators (Tables 4.4 and 4.4.6, Section 4.4.2), such as Cape Robin-Chat, Karoo Thrush, Mallard Duck, Brown-hooded Kingfisher, and Malachite Kingfisher (Table 4.4.6, Section 4.4.2). Therefore, relatively high (when compared with the other anthropogenic CAHs) avian diversity was found for FpB and TrB. As described earlier, bridge-type structures can be seen as an exploitable resource for birds, and subsequently, resulting in relatively high avian diversity in FpB and TrB.

A relatively lower avian diversity (when compared with TrB and FpB) was found along DrE, Dpi, Fpa, InS, C/R and Hou (Tables 4.4, 4.4.1 – 4.4.5, Section 4.4.2). DrE had 11 indicators and 20 associated species (Tables 4.4 and 4.4.3, Section 4.4.2). Examples of indicators for DrE were the Kalahari Scrub-Robin, Sobata Lark, Fiscal Flycatcher, Common Fiscal, Familiar Chat, and the Rattling Cisticola (Table 4.4.3, Section 4.4.2).

Eight indicators and 16 species were associated with Dpi (Tables 4.4 and 4.4.1, Section 4.4.2). Examples of indicators were the Red-knobbed Coot, Red-billed Teal, Common Moorhen, Little Grebe, Squacco Heron, African Snipe, and Yellow-billed Duck (Table 4.4.1, Section 4.4.2).

Six indicators and 10 species were associated with Fpa (Tables 4.4 and 4.4.2, Section 4.4.2). Examples of indicators were the White-winged

Widowbird, Common Waxbill, Orange-breasted Waxbill, and Red-collared Widowbird (Table 4.4.2, Section 4.4.2).

Furthermore, 5 indicators and 15 associated species were identified for InS (Tables 4.4 and 4.4.4, Section 4.4.2). Examples of indicators were the Cape Longclaw and the White-backed Mousebird (Table 4.4.4, Section 4.4.2).

No indicators and only two species were associated with houses (Table 4.4, Section 4.4.2). Lastly, four indicators and six species were associated with C/R (Tables 4.4 and 4.4.5, Section 4.4.2). Examples of indicators were the Cape Sparrow and Grey-headed Sparrow (Table 4.4.5, Section 4.4.2).

Vegetation CAHs had a higher number overall of indicator species than anthropogenic CAHs. The vegetation CAHs reflected a greater difference in number of indicator species between TSR (54 indicators) and the other vegetation CAHs (G/R, 12 indicators, HSG, 11 indicators, T/G, 10 indicators and S/R, one indicator). A reduction in the number of indicator species was found for the anthropogenic CAHs (e.g. the 32 indicator species of TrB, decreasing to zero at Hou).

Consequently, avian diversity differed on a greater scale between vegetation CAHs than between anthropogenic CAHs, and anthropogenic CAHs were associated with a reduction in avian diversity.

5.4.5. Nesting and feeding guild communities

Species in the different nesting and feeding guilds were ordinated with the six summer CAHs. The following patterns demonstrate how birds of similar ecological functions are affected by seasonal, vegetation and anthropogenic influences in different riparian environments.

5.4.5.1. Nesting guild communities

1. Tree-nesting birds

Tree-nesting species were mainly associated with TSR, T/G, S/R and G/R (Figure 4.18, Section 4.4.3). Divergence of tree-nesting community trajectories was found between TSR and T/G, but convergence was found for S/R and G/R.

The presence of grass (in T/G), and shrubs and reeds (in TSR), indicate that niches varied between T/G and TSR, which explains a divergence in tree-nesting community trajectories between TSR and T/G.

The White-breasted Cormorant and the African Paradise-Flycatcher Species ordinated closer to TSR, and the Little Egret and Red-eyed-, Cape Turtle- and Laughing Dove ordinated closer towards T/G (Figure 4.18, Section 4.4.3).

Less change appeared in tree-nesting community trajectories of TSR and T/G, compared to the other tree-nesting community trajectories. The abundance of trees in both T/G and TSR create ample nesting opportunities for tree-nesting birds, which resulted in a stability of tree-nesting communities in TSR and T/G. With short vegetation structure (as in HSG) and lower coverage (as in C/R), the presence of tree-nesting communities were lower, and resulted in the instability of tree-nesting communities in TSR and T/G.

Therefore, vegetation structure (e.g. tree abundance) influenced habitat selection, resulting in divergent riparian tree-nesting communities.

2. Tree/shrub and shrub-nesting birds

Three main tree/shrub and shrub-nesting communities distinguished HSG, TSR, and T/G and S/R; with relatively little change in community trajectories over time (Figure 4.19, Section 4.4.3). This is mainly due to the abundance of shrubs and trees in these four CAHs that provide nesting sites for these birds.

The tree/shrub and shrub-nesting community trajectories of T/G and S/R (characterised by Karoo Thrush, African Red-eyed Bulbul and Cape Robin-Chat) were convergent but divergent from TSR (characterised by Cape White-eye, Chestnut-vented Tit-babbler, Speckled Mousebird and Squacco Heron) and HSG (Fiscal Flycatcher, Common Fiscal, Blue Waxbill and Kalahari Scrub-Robin) (Figure 4.19, Section 4.4.3). This convergence is due to the proximity and adjacent locations of T/G and S/R (Appendix B) and niche overlap, which enhanced movement between these CAHs.

The community trajectories of HSG, G/R and C/R were convergent, but the trajectories of G/R and C/R were comparatively longer than the trajectories of HSG (Figure 4.19, Section 4.4.3). Therefore, tree/shrub and shrub-nesting birds probably utilised the shrubs in HSG for breeding, and may

also have moved between G/R and C/R as shown by the comparatively long vector lengths of G/R and C/R (Figure 4.19, Section 4.4.3). Trees and shrubs were scarce and/or absent in G/R and C/R, consequently instability in tree/shrub and shrub-nesting communities occurred in G/R and C/R. This is evidence of vegetation providing nesting sites and is a determining factor for birds to select one habitat over another.

3. Tree/reed-nesting birds

Tree/reed-nesting birds ordinated alternatively between T/G and S/R, and TSR and G/R, thereby forming two divergent communities. However, the majority of these birds ordinated with TSR and G/R (Figure 4.20, Section 4.4.3), which shows that tree/reed-nesting birds preferred TSR and G/R above the other CAHs.

It is noticeable from Figure 4.20 that smaller changes in tree/reed-nesting community trajectories occurred in CAHs that predominantly consisted of either trees and/or reeds (e.g. T/G, S/R, G/R and TSR), while greater levels irregular occurrences and migration ensue among habitats not composed of either trees and/or reeds (e.g. HSG and C/R). Therefore, greater instability of tree/reed-nesting communities occurred in HSG and C/R.

Consequently, vegetation structure influenced habitat selection, migration, and diversity of tree/reed-nesting birds, which led to the arrangement of two communities in the study area.

4. Grass and/or reed nesting birds

Grass and/or tree nesting birds ordinated with TSR, S/R, G/R, HSG, and T/G, and the community trajectories of these CAHs were convergent indicating niche overlap (Figure 4.21, Section 4.4.3). These CAHs shared similarities in that they were primarily composed of grass and/or reeds, thereby providing ample nesting sites for this bird guild.

The community trajectory of C/R was clearly divergent and ordinated away from the species due to the concrete surface that impaired growth of grass and reeds (Figure 4.21, Section 4.4.3). Therefore, the abundance of grass and reeds influenced the distribution of grass and/or reed nesting species,

and the preferred nesting sites for these birds was an essential consideration in habitat selection.

5. Shrub/grass- and shrub/reed-nesting birds

Shrub/grass- and shrub/reed-nesting birds ordinated mainly with TSR, S/R, HSG and G/R, and the community trajectories were convergent (Figure 4.22, Section 4.4.3). The warmer months of TSR, S/R, HSG and G/R, also ordinated closer to the species coordinates. Although obvious from the CAH names, shrubs and reeds predominated in TSR and S/R, shrubs and grass predominantly appeared in HSG, and both grass and reeds were present in G/R. Therefore, two preferred vegetation types in each CAH provided nesting sites for these birds. C/R with inadequate vegetation structure for breeding purposes was again ordinated away from species coordinates.

Consequently, the abundance and scarcity of shrubs, reeds and grass affected the distribution of this guild, and seasonally associated behaviours such as breeding were probably responsible for community changes.

6. Ground- and ground/grass-nesting birds

Twelve ground- and ground/grass-nesting species ordinated with T/G, S/R, HSG and G/R, and these community trajectories were convergent (Figure 4.23, Section 4.4.3). Examples of those species that ordinated with T/G, S/R, HSG and G/R were the Blacksmith-, Crowned- and Wattled Lapwing, Three-banded Plover, Spotted Thick-Knee, Little Grebe, and Mallard Duck (Figure 4.23, Section 4.4.3).

The other twelve species rather associated with TSR (Tables 4.3 and 4.3.6, Section 4.4.1). Therefore, TSR ground- and ground/grass-nesting community trajectory was divergent from the others (Figure 4.23, Section 4.4.3). Examples of species that ordinated with TSR are the Cape Teal, Fulvous Duck, White-faced Duck, South African Shelduck, and Helmeted Guineafowl (Figure 4.23, Section 4.4.3).

Ground- and ground/grass-nesting birds presumably have a risk of high nest predation because their nests are on or near the ground, and therefore need to conceal their nests from nest predators (Powell & Steidl 2000). Vegetation, especially shrubs, grass and reeds helps with nest concealment

(Hockey *et al.* 2005; Maclean 1993; Steyn 1996). Vegetation is also useful building material for nests (Hockey *et al.* 2005; Maclean 1993; Steyn 1996) (Section 2.1.5). Thus, ground and ground/grass-nesting birds benefit from the vegetation in T/G, S/R, HSG, G/R, and TSR.

It is evident that vegetation structure influenced the divergence in ground- and ground/grass-nesting communities, and that these birds prefer areas abundant by vegetation rather than areas with limited vegetation.

7. Parasitic-nesting birds

Figure 4.24 (Section 4.4.3) shows that two main parasitic communities existed in the study area. The one associated with HSG and G/R (Pin-tailed Whydah, Shaft-tailed Whydah, Long-tailed Paradise Whydah, and the Village Indigobird), and the other one was more associated with TSR and T/G (Red-chested Cuckoo, Jacobin Cuckoo, Diderick Cuckoo, Lesser Honeyguide, and the Greater Honeyguide). Those associated with TSR and T/G were summer migrants (except Lesser Honeyguide and Greater Honeyguide) and breed during the warmer months, which clarify why they ordinated closer with the summer months of TSR and T/G (Figure 4.24, Section 4.4.3). Those associated with HSG and G/R were parasitic granivores, and those associated with TSR and T/G were parasitic insectivores (Table 4.2, Section 4.2). Therefore, parasitic insectivores were associated with trees. This corresponds with Smith and Wachob (2006), who found that insectivores preferred riparian forest patches.

Therefore, vegetation structure influenced the divergence between two parasitic communities, and summer migrants (seasonal influences) influenced the parasitic community of TSR and T/G.

8. Cavity- and cavity/tree-nesting birds

The majority of cavity and cavity/tree-nesting species ordinated close to TSR, T/G and S/R, and only two ordinated with G/R, HSG and C/R (Figure 4.25, Section 4.4.3). TSR, T/G and S/R provided adequate resources for cavity/tree nesting, whereas G/R and HSG provided less suitable vegetation structures. Therefore, the species richness of cavity- and cavity/tree-nesting birds varied among vegetation structures.

The cavity and cavity/tree-nesting community trajectory of T/G was divergent from those of TSR and S/R (Figure 4.25, Section 4.4.3). Six cavity- and cavity/tree-nesting species (Crested Barbet, Black-collared Barbet, Giant Kingfisher, Brown-hooded Kingfisher, Malachite Kingfisher, and the Half-collared Kingfisher) were associated with T/G (Table 4.3 and 4.3.5, Section 4.4.1). None of these were summer migrants. Hence, little change between seasons appeared in the cavity and cavity/tree-nesting community trajectory of T/G (Figure 4.25, Section 4.4.3).

Five species (Pied Kingfisher, Woodland Kingfisher, Ant-eating Chat, Cardinal Woodpecker and European Bee-eater) were associated with TSR (Table 4.3, Section 4.4.1). The European Bee-eater and the Woodland Kingfisher are summer migrants (Hockey *et al.* 2005). They were observed during the warmer months in TSR (Figure 4.25, Section 4.4.3). Therefore, the presence of these migrants in TSR resulted in a greater community trajectory change between seasons than in T/G.

Consequently, vegetation structure influenced the distribution of cavity and cavity/tree-nesting birds, and seasonal influences such as the presence of summer migrants resulted in community change.

9. Structure/tree- and structure-nesting birds

The structure/tree and structure-nesting community trajectories of TSR, T/G, S/R, HSG, G/R, and C/R were convergent (Figure 4.26, Section 4.4.3). The Speckled Pigeon, Rock Dove, Pied Crow and the three sparrow species ordinated with all six CAHs (Figure 4.26, Section 4.4.3), with P-values greater than 0.003 (Table 4.3, Section 4.4.1). Therefore, these birds are not habitat specific. However, structure/tree and structure-nesting birds rather utilised anthropogenic factors than vegetation structures as nesting sites (Table 4.2, Section 4.2). Thus, vegetation structure was not a main influence on structure/tree and structure-nesting birds, which explains the convergence in communities (Figure 4.26, Section 4.4.3).

5.4.5.2. Feeding guild communities

1. Insectivores

In the riparian corridors of Potchefstroom, diverged insectivore communities appeared (Figure 4.27, Section 4.4.4). They were the TSR, G/R, HSG and C/R insectivore communities.

Examples of insectivores that ordinated with TSR were the European Bee-eater, Willow Warbler, Marsh Warbler, Lesser Swamp-Warbler, and Little Rush-Warbler, African Paradise-Flycatcher, Barn Swallow, White-throated Swallow, Greater Striped Swallow, and South African Cliff Swallow, and the Woodland Kingfisher (Figure 4.27, Section 4.4.4).

Examples of insectivores that ordinated with G/R were the Cape Longclaw, Zitting Cisticola and Levaillant's Cisticola, Neddicky, and African Snipe (Figure 4.27, Section 4.4.4). Furthermore, examples of insectivores that ordinated with HSG were the Familiar Chat, Lesser Grey Shrike, Kalahari Scrub-Robin, and the Red-footed Falcon (Figure 4.27, Section 4.4.4). Lastly, none of the insectivores ordinated towards C/R (Figure 4.27, Section 4.4.4).

Seasonal influences such as the presence of migrants during the warmer months influenced change in these communities.

Due, to the difference in vegetation structure, arthropod species probably distributed heterogeneously, and consequently, insectivores distributed accordingly. It was found in a number of studies that the distribution of arthropods can affect insectivore distribution patterns (Johnson & Sherry 2001; Murakami & Nakano 2001; Whitaker *et al.* 2000). Murakami & Nakano (2001) concluded that species-specific behaviours of insectivores were responsible for their heterogeneous distribution within a riparian forest.

Alternatively, two insectivore community trajectories were convergent (S/R and T/G), but divergent from the others (Figure 4.27, Section 4.4.4). Examples of insectivores that ordinated with T/G and S/R were the Karoo and Groundscraper Thrush, Cape Robin-Chat, Red-chested- and Common Cuckoo, Cardinal Woodpecker, African Red-eyed Bulbul, and Greater- and Lesser Honeyguide (Figure 4.27, Section 4.4.4).

S/R and T/G were located adjacent to each other (Appendix B), which allowed movement between habitats. Niches could also overlap and similar

arthropods could occur in both S/R and T/G. Consequently, convergence in communities existed between S/R and T/G.

2. Granivores

The granivores predominantly ordinated with HSG and G/R, and some also with T/G (Red-eyed-, Cape-turtle-, and Laughing Dove) (Figure 4.28, Section 4.4.4). Grasses were predominant here; consequently, seeds and grain were presumably available in these CAHs. Hence, granivores selected habitats according to the presence of grasses.

However, while T/G ordinated with dove species, the other, smaller bodied granivores ordinated with HSG and G/R (such as widow, whydah, canary, and firefinch species, Village Indigobird, Blue Waxbill and Red-billed Quelea (Figure 4.28, Section 4.4.4)). Difference in body sizes differentiated the community trajectories of T/G from G/R and HSG. Consequently, grasses influenced the distribution of granivores, and the presence of trees resulted in a divergence in granivore community trajectories.

Granivore community trajectories of T/G changed on a smaller scale than those of HSG and G/R. Herbs and grass (in HSG), and grass and reeds (in G/R) are annual plants and their structure (height and cover) change seasonally, therefore abundance of seeds fluctuate accordingly (Tainton 1999). This annual cycle of vegetation may stimulate a greater change in granivore community trajectories of HSG and G/R. Thus, seasonal influences in vegetation structure resulted in granivore community changes.

3. Carnivores

The carnivores mainly ordinated with TSR (Figure 4.29, Section 4.4.4). Predators select habitats according to prey availability (Begon *et al.* 1996) (Section 2.1.8), and because TSR was associated with relatively high avian diversity (Section 5.4.4), prey availability was presumably higher here. Relatively short carnivore community trajectory changes occurred in the CAHs, but they did diverge (Figure 4.29, Section 4.4.4). This shows that carnivores, excluding summer migrants, inhabit their selected habitats throughout the study period. Some carnivores are summer migrants (such as the White and Abdim's Stork, Steppe Buzzard, Wood and Marsh Sandpiper,

and the Red-backed Shrike), and were only observed during the warmer months. Their presence and absence affected carnivore community trajectories (Figure 4.29, Section 4.4.4).

It is evident that vegetation structure influenced the divergence of carnivore communities. However, vegetation structure also influenced carnivore communities indirectly, by affecting the distribution of prey.

4. Omnivores

None of the omnivores were summer migrants, but omnivore community trajectories did change considerably over time. Omnivores are opportunistic feeders, and have a broader feeding range, which enhance their niche size (Begon *et al.* 1996). Therefore, a broader range of habitats are utilised by omnivores. Consequently, the majority of omnivore community trajectories were convergent (Figure 4.30, Section 4.4.4).

Nevertheless, vegetation structure still influenced omnivore communities, because the majority of omnivores ordinated with TSR, such as the South African Shelduck, White-faced Duck, Fulvous Duck, Sacred Ibis, Common Moorhen, Black Crake and the Egyptian Goose (Figure 4.30, Section 4.4.4). Due to the predominant occurrence of these listed birds, the omnivore community trajectory of TSR was divergent from the others (Figure 4.30, Section 4.4.4). As described earlier, high levels in niche sizes and avian diversity occurred in TSR. Therefore, omnivores predominantly occur in TSR.

5.5. Conclusions

156 bird species were found in this study area from June 2006 to June 2007. This species richness represents the complexity and heterogeneity of bird communities within this ecosystem. Climate, topographic variations, and disturbances influence the vegetation structure on a spatial scale which consequently altered the relationships with birds, as also found by others (Naiman *et al.* 1993; Seoane *et al.* 2004; Wakeley *et al.* 2007; Wiens 1989b). Vegetation structures and anthropogenic factors also distributed heterogeneously within the riparian corridors of Potchefstroom (Appendix B), and an association was found between the fluctuation of bird variables (RAD, species richness, diversity index and TAB) and the distribution of different vegetation structures and anthropogenic factors.

Characterisation of riparian habitats into the six summer CAHs, specifically five vegetation structures (G/R, HSG, S/R, T/G, and TSR) and one anthropogenic CAH (C/R) illustrated that vegetation structures were a predominant factor. Despite this predominance, habitats were also separately characterised by the following anthropogenic factors: Dpi, Fpa, DrE, InS, C/R, FpB, TrB and Hou.

Ordination of bird species with the six summer CAHs showed that the community patterns associated with vegetation structures were mainly divergent. This divergence was a result of the structural differences in vegetation types, which enhanced niche diversity, represented by varying combinations of resource and availability, and therefore influenced habitat selection behaviour. Similar findings were found by others (Begon *et al.* 1996; Brand *et al.* 2008; Cody 1985; Diaz 2006; Malan *et al.* 2007; Posa & Sodhi 2006; Powell & Steidl 2000; Seoane *et al.* 2004; Simons *et al.* 2006; Vidaurre *et al.* 2006; Wakeley *et al.* 2007; Wiens 1989a; Wiens 1989b). Only two of the vegetation CAHs were convergent, presumably mainly due to their proximity, which created niche overlap and favoured bird movement between these two CAHs.

Seasonal influences also influenced changes in avian parameters. The change in vegetation structures between summer and winter months (e.g. annual plants) contributed to community changes on a spatial and temporal scale. It was also found that less transformation in vegetation coverage and

heights between seasons resulted in fewer changes (shorter vectors) within a bird community. Additionally, the presence of summer migrants increased species richness and the migration of these birds augmented change within communities.

Vegetation structure and the availability of nesting material are important considerations when selecting habitats during breeding seasons (Cody 1985; Steyn 1996; Wiens 1989a; Wiens 1989b). In the current study, the ordination of birds with warmer months of the vegetation CAHs indicates that breeding within communities were influenced by vegetation structure.

Anthropogenic factors and a lack of vegetation structure are associated with low avian diversity as shown in a number of studies (Knopf & Samson 1994; Rottenborn 1999; Smith & Wachob 2006). None of the species in the riparian corridors of Potchefstroom was ordinated towards the summer months of C/R, confirming that a lack of vegetation structure was associated with low avian diversity. More convergence appeared in communities among anthropogenic CAHs due to niche overlap, disturbances, lowered vegetation densities, and presumably by brood parasitism and nest predation.

The destruction of riparian vegetation not only causes local extinction, but also reduces the ability of populations to recolonise sites (Knopf & Samson 1994). Therefore, the anthropogenic factors in the riparian corridors of Potchefstroom were associated with relative movements, which resulted in relatively large changes in community trajectories in anthropogenic dominated CAHs.

Birds have specific nest-site requirements (Cody 1985). This was the same for birds in the riparian corridors of Potchefstroom. The nesting guild communities ordinated with vegetation CAHs consisting of the preferred vegetation structure needed for nesting. These same nesting guild communities were ordinated away from C/R, indicating that anthropogenic factors were not favourable for nesting and breeding. Divergence and convergence of nesting communities was influenced by the presence, abundance and combination of the favoured vegetation type(s) for nesting sites, and greater levels of movement or community instability occurred in CAHs where there was a lack of ideal vegetation structure.

Structure/tree-and structure-nesting birds were the only nesting community whose ordination was associated with all six CAHs, including C/R. These communities were convergent because vegetation is not a main influence in habitat selection, and these birds can utilise anthropogenic factors for breeding purposes.

Insectivore, granivore and carnivore communities were divergent between the vegetation CAHs. Seoane *et al.* (2004) identified that vegetation structure as a source of potential predictors as they considered it as a more direct link with food availability. Hence, vegetation structure presumably had an association with the availability of food (e.g. arthropods, grains, prey). Therefore, insectivore, granivore, and carnivore bird communities in riparian corridors of Potchefstroom most likely selected CAHs that consisted of vegetation that was closely associated with their dietary source.

None of the omnivores in the riparian corridors of Potchefstroom were summer migrants. Therefore, the convergence and change in omnivore community trajectories can be attributed to their opportunistic feeding behaviours. However, the majority of omnivore species were ordinated with TSR, which indicates that vegetation structure did in fact influence all feeding guild communities.

Therefore, according to these findings, the hypothesis is verified, and it can be accepted that bird variables along the riparian corridors in Potchefstroom are affected by vegetation, anthropogenic, and seasonal influences.

As described in Section 1.2, the motivation for this study was to identify avian diversity and community patterns along urban riparian corridors, serving as a baseline for future riparian studies. The study showed that riparian corridors in Potchefstroom are complex in avian communities, high in avian diversity, and that bird variables change dynamically with seasons. The riparian vegetation provides a variety of habitats that serve as niche areas for birds. Anthropogenic factors can be an exploitable resource depending on the manner in which they are managed.

Transformation on the current riparian vegetation and anthropogenic factors may influence the current avian diversity and communities, and care must be taken that it does not have negative impacts on the current avian

diversity and communities. Therefore, in order for future practices to be conducted along the riparian corridors of Potchefstroom, it is important to consider this study as reference.