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Diet and Life-History Traits of Savannah Dwelling Waterbirds in Southern Africa: Implications for Their Conservation Status

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Simple Summary: Species population declines worldwide are worrisome. This study was driven by the interest to know if population trends of waterbird species are affected by their diet, factors linked to reproduction and growth. The cases of 163 waterbird species found in southern Africa were considered. Close to two-thirds of these species are in decline worldwide. Using the variety and size of diet items, this study discovered that species could be grouped into four categories, and species that are consumed as food by people could fit into one group. The groups with waterbird species that feed on small and large prey items had higher probabilities of having declining population trends when compared to those feeding on medium-sized items. Amphibians, coleopterans, crustacea, molluscs and tunicates were consumed by waterbird species across the four waterbird categories. If current climate change trends continue to suppress the populations of these prey bases, then waterbirds are also in imminent danger. It will be critical to control human disturbance in wetlands.

Abstract: This study evaluates the relative contribution of reproduction-based life history traits and diet to the population trends in waterbirds from southern Africa. Life history traits (clutch size, incubation period, fledging time, body mass and generation length), diet (prey weight, body lengths and number of taxa represented in its diet (NTD)) and conservation status (declining/not declining) of 163 waterbird species were reviewed. An index of diet generalism was created based on NTD. Cluster analysis was applied on life history traits to define groups of waterbirds. Binomial regressions were used to test if population trends were different across cluster groups and diet variables. Four clusters of waterbirds were defined, with most waterfowl clustering together. Species that feed on small and large prey had higher probabilities of declining (0.17 and 0.26, respectively) compared to those feeding on medium-sized prey (0.08). Amphibians, coleopterans, crustacea, molluscs and tunicates were used by species in all clusters, and the risk of waterbird populations declining further are high given the current dwindling of the prey base. The large proportions of declining species (61%) in waterbirds, which have constrained habitats, calls for continued efforts to mitigate disturbances to wetlands.

Keywords: waterbirds; diet; life history traits; index of diet generalism

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Citation: Tarakini, T.; Mabika, I.; Mwedzi, T.; Mundy, P.; Fritz, H. Diet and Life-History Traits of Savannah Dwelling Waterbirds in Southern Africa: Implications for Their Conservation Status. *Birds* **2021**, *2*, 173–184. https://doi.org/10.3390/birds2020013

Academic Editor: Jukka Jokimäki

Received: 11 March 2021
Accepted: 20 April 2021
Published: 11 May 2021

1. Introduction

The southern African region is endowed with a variety of waterbirds that feed in various coastal and inland habitats [1]. The waterbird diet has been central in many studies and its quality and quantity remains a conservation issue. Traits that promote dietary flexibility in a species can be beneficial given the global shifts in habitats [2], resources and climate [3]. Knowing that waterbird prey are responding at different rates to these global shifts [4], an exploration of the traits and diet requirements of species that are associated with various conservation states can provide vital information to be used for conservation planning.

Most life history traits in birds, in particular those linked to reproduction (e.g., clutch size, incubation period and fledging time), are positively related to individual body mass [5,6] and generation length [7]. It has been established that in evolutionary biology, traits do not evolve in isolation, but in a coordinated way with other characteristics that may include behaviour, physiology, morphology, and life histories [8]. Particular characteristics in life history traits could make some species more vulnerable to population declines if environmental conditions change [9]. Additionally, several studies have documented the dietary requirements of waterbird species [1,10,11] and species with narrow diet niches (specialist) could be more prone to changes in habitat and resources [2,12]. Specialist species are often associated with lower dispersal abilities [13], are more strongly regulated by intra-specific competition [14], and are less able to cope with environmental stochasticity than generalists species [12]. Already, various authors have linked dynamics in climate, disturbances and exploitation to waterbird trends [15,16]. Thus, future predictions of waterbird changes may be achieved given information on the life history traits of species [9] and their dietary requirements and flexibility.

Some prey may be considered as important in an ecosystem by considering the number of organisms that rely on them [8,10,17]. Environmentalists should, therefore, monitor the trends of such prey species as their population declines may have domino effects on other species that are reliant on them. In the interior of southern Africa, most wetlands have freshwater systems which are heavily utilised by humans [10,18], hence, the quality and quantity of water in the wetlands are also affected. Such dynamics may be important to model future trends of waterbird species.

This study attempts to understand the associations between conservation status, diet and life history traits of waterbird species found in southern Africa. It is predicted that large species with long incubation and fledging periods (hence slow rates of adapting to stochastic events) could be experiencing more significant declining trends given the current environmental perturbations compared to smaller species. Additionally, specialists (those with narrow diet niches) are expected to demonstrate more declining trends as they are less able to cope with environmental stochasticity [12] compared to generalists. It is considered that these two approaches (diet and reproduction) will reveal significant underlying mechanisms that will be helpful to conservation.

2. Materials and Methods

Diet studies and published information for 163 waterbird species that have been recorded in southern Africa (Botswana, Madagascar, Malawi, Mozambique, Namibia, Swaziland, Zambia and Zimbabwe) were reviewed and the taxa they ingest were recorded. The sources used various methods including direct observations [19], regurgitate analysis [17], and scat analysis [20] to determine species diet. The number of taxa in the diet (NTD) were summarised per species. By considering the mean weight and size (body lengths) of all the prey items in a species' diet, each species was assigned to its respective size class. This was achieved through modification of the methods by Arzel [21] to come up with diet weight classes: A = 0–50 g, B = 51–100 g, C = 101–500 g and D = weight > 501 g. The classification according to diet item lengths were considered as 1 = 0–10 mm, 2 = 11–50 mm, 3 = length > 50 mm. For the waterbird species, a review on their mean clutch size, incubation period (days), fledging time (days), body mass (in kilograms) and generation length (in years), movement patterns (migrations) and their global population trend was conducted following information provided on the Birdlife International website on www.datazone.birdlife.org/species (accessed on 4 February 2018).

Waterbird population trends from Birdlife International were re-categorised as either declining or not declining (stable/increasing). A case-by-case simplification of the known ecological guilds of waterbirds was done by considering the main components of their diet, a modified method from Liordos [22], and some rare species were grouped according to their closest guild. The results of the grouping exercise retained five broad categories of waterbirds as herbivores (largely feeding on vegetation matter), insectivores (mainly feeding on insects and other aquatic invertebrates such as crustacea and annelids), piscivores (predominantly feeding on fish and amphibians), semi-omnivores (consuming a variety of invertebrates and also plant matter), and omnivores (when diet consisted of items from herbivores, insectivores and piscivores). Raptors were excluded from the dataset as they frequently forage in non-wetland areas [20].

The gap statistic method [23] was used to determine the optimal number of clusters that best describe the life history data (clutch size, incubation period, fledging time, body mass and generation length) using the *NbClust* package [24]. This optimal number was then used in carrying out the k-means partition cluster analysis to create reproduction-based clusters that described the data. Thus, each species was assigned to its resulting cluster.

Correlations tests between all the life history trait variables were conducted with the aim of dropping those that are highly correlated (correlation coefficient $r > 0.8$ [25]). An "index of diet generalism" (i.e., a score of how a species could be considered a generalist or specialist) was derived by taking $\log_{10}$ (NTD/median of NTD for all species in the dataset). This index of diet generalism ranged from positive values (generalist species) to negative (specialist ones). Chi-squared tests were used to investigate the relationships between waterbird allocated clusters and the global trends. Binomial logistic regressions were performed to model species global population trends to the single and interactive effects of species allocated cluster, diet weight, diet lengths, diet guild, and index of diet generalism. The best model was selected using the lowest Akaike information criteria [26] that retains the most influential variables for global population trends. All analyses were done in the R package for Statistical Computing [27].

3. Results

The gathered waterbird dataset consisted of resident species (85), Afrotropical migrants (36) and Palaearctic migrants (42) ($n = 163$, Appendix A). Although most of these species (134) are considered to at least be of concern by the IUCN, 7 are vulnerable, 15 near threatened and 7 are endangered. Clutch size was negatively related to generation length ($r = -0.24$, $p = 0.002$) but there were no correlations between (1) clutch size and incubation period ($r = 0.12$, $p = 0.139$) or (2) clutch size and body mass ($r = 0.01$, $p = 0.908$). The rest of the relationships across the life history traits were significantly correlated, with r values ranging from 0.33 to 0.63 ($p < 0.001$ in all cases).

A large proportion of waterbirds in the dataset (48%) rely on small diet items (class 1). Insectivores formed the largest guild with 32% of all species. The herbivorous and omnivorous species were found to be declining most strongly (Table 1), with 80% and 71% of each guild, respectively.

Table 1. Distribution of waterbird population trends across diet body lengths and allocated guilds.

	Diet Body Length Classes			Waterbird Allocated Guilds				
Global Status	**1**	**2**	**3**	**Herb**	**Insect**	**Semi-Omniv**	**Omniv**	**Pisci**
Declining	55	20	24	8	31	8	24	28
Not declining	23	32	9	2	21	10	10	21
Total	78	52	33	10	52	18	34	49

Note: Herb = herbivores, Insect = insectivores, Omniv = omnivores and Pisci = piscivores.

3.1. Clusters on Life History Traits

The data optimally describe four clusters, as shown in Figure 1, with clusters one to four having 83, 50, 10 and 20 species, respectively. Dimension 1 seems to separate species according to body mass and generation length, where large long-living species had negative values (cranes, storks and flamingos in cluster three) and the small short living ones tend to have positive values (e.g., crakes, jacanas, coursers, mostly in clusters one and two). Dimension 2 seems to separate species with large clutch sizes (notably the wildfowl like ducks and geese in cluster four) from those with smaller ones (clusters two and three). There is considerable overlap between clusters one, two and four in terms of incubation and fledging periods.

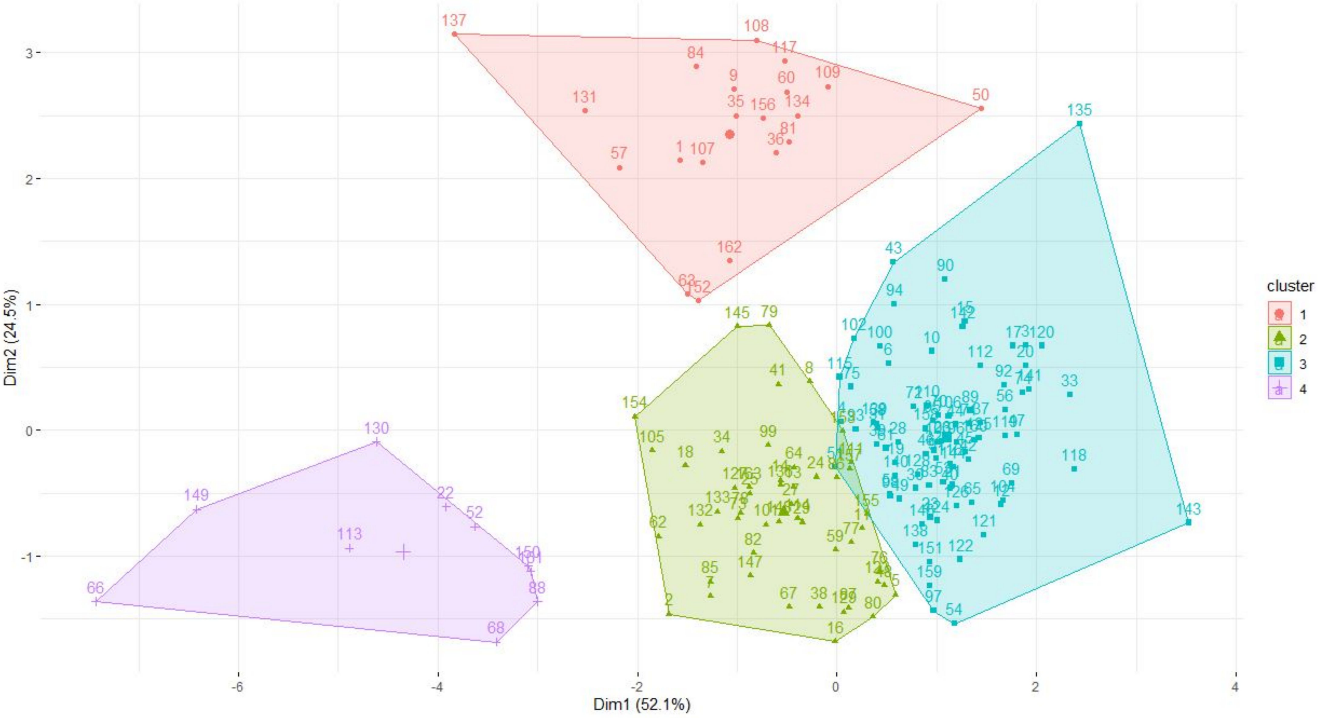

Figure 1. Clusters formed from analysing number of NTD, clutch size, incubation period, fledging time, body mass and generation length of waterbirds found in southern Africa. See Appendix A for the species represented by number codes.

Most (90%) herbivorous waterbirds are in cluster four. Cluster one contains the majority of insectivores (60%), semi-omnivores (61%), omnivores (65%) and the streaky-breasted flufftail was also in this cluster. The diet of species in cluster one represented all the diet taxa reviewed in this study but crustacea, tunicates, annelids, coleopterans and molluscs were predominantly consumed (Table 2). Piscivores were mostly in cluster three (53%) and cluster one (37%). Cluster two and three species' dominant diet items included tunicates, crustacea, small amphibians and coleopterans, although the diet tended to be more specialised for cluster two (generality index of −0.05) compared to cluster three (−0.14).

Table 2. Waterbird prey in southern Africa and their representation in the diets of waterbird clusters.

	Percentage of Birds Consuming Prey Item			
Prey Item	**Cluster 1**	**Cluster 2**	**Cluster 3**	**Cluster 4**
Algae/plankton	7	2	-	10
Annelids	49	38	-	20
Arachnids	25	6	-	-
Bird eggs	6	10	-	-
Birds	6	26	30	-
Chilopods	1	-	-	-
Chironomids	1	2	-	5
Clinids	1	-	-	-
Coleopterans	39	32	-	20
Crustaceans	59	62	50	55
Culicidae	5	-	-	-
Cyanobacteria	5	-	10	-
Demapterans	17	6	-	15
Diatoms	2	-	10	5
Diplopods	6	4	-	5
Dipterans	47	22	10	20
Echinoderms	4	-	-	-
Ephemeropterans	30	8	10	-
Fruits	7	6	20	90
Gastropods	20	12	20	05
Hemipterans	37	2	-	30
Homopterans	25	12	10	5
Hymenoptera	35	16	-	-
Isopterans	34	12	-	30
Leaves	23	10	20	90
Lepidopterans	35	16	20	15
Mantids	17	8	-	10
Molluscs	46	54	50	40
Odonata	25	18	-	5
Orthopterans	30	28	20	40
Roots/tubers	22	12	10	85
Rotifers	5	2	10	-
Scorpiones	8	8	10	20
Seeds	39	18	30	80
Small amphibians	30	42	60	20
Small mammals	7	24	20	-
Small reptiles	11	20	50	-
Trichopterans	17	12	10	20
Tunicates	54	66	50	30

3.2. Diet and Life History Traits in Relation to Population Trends

The majority (61%, n = 99) of the waterbirds presented in this study had declining population trends. Clusters one to three had a greater proportion of species that had declining population trends (68, 52 and 70%, respectively) compared to those in cluster four (50%). However, the population trends were not significantly different across the four clusters (χ^2 = 4.501, df = 3, p = 0.212). The best model explaining waterbird population trends retained only the diet body lengths (Appendix B). The diet body length (across three classes) significantly predicted population trends of waterbirds (β = 15.819, df = 2, p = 0.0004), as shown in Table 3.

Table 3. Results of model explaining the significant factor related to waterbird global population trends in Southern Africa.

Variable	Estimate	Std. Error	Z Value	*p* Value
Intercept	−0.8718	0.2483	−3.511	0.0004
Diet body length 11–50 mm	1.3418	0.378	3.55	0.0004
Diet body length > 50 mm	−0.109	0.4631	−0.235	0.8139

The species that feed on small and large prey (diet body length classes one and three) had higher probabilities of declining (0.17 and 0.26, respectively) compared to those feeding on class two (0.08). Although the diet generality indices were slightly higher for species feeding on large prey items (Figure 2), this did not significantly affect the likelihood of decline.

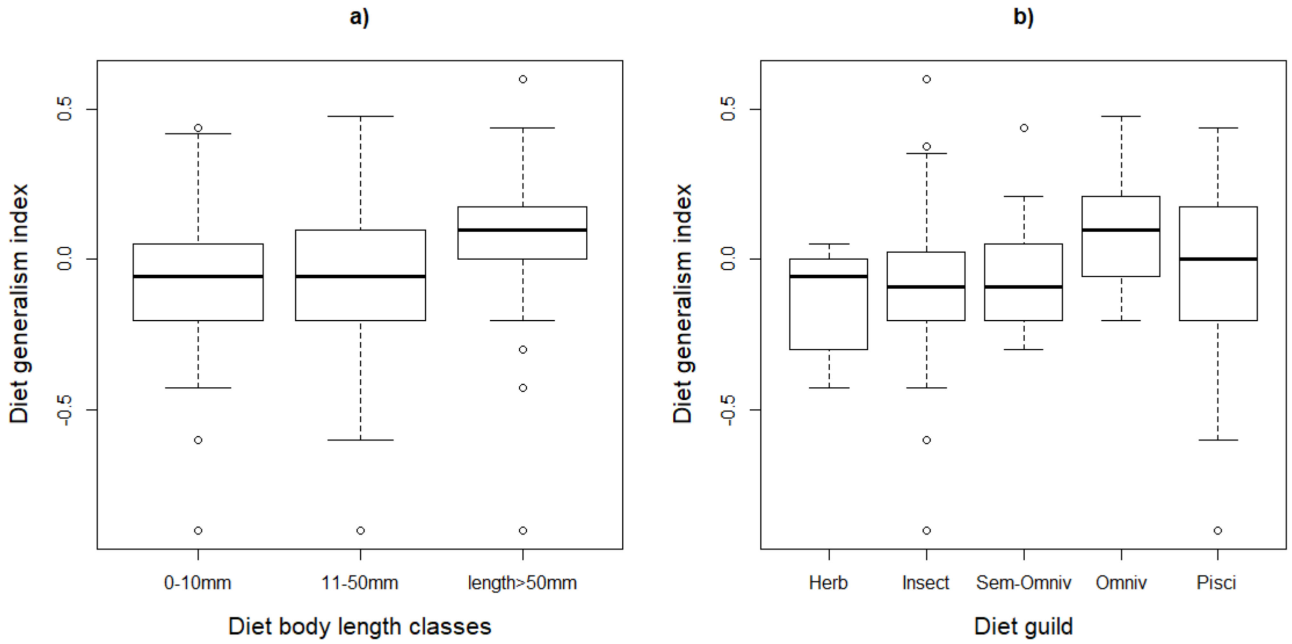

Figure 2. Variation of the diet generality index for waterbirds of southern Africa across their (**a**) diet body length classes and (**b**) diet guilds. The lines and bars represent the median and the quartiles. In plot (**b**), Herb = herbivores, Insect = insectivores, Omniv = omnivores and Pisci = piscivores.

4. Discussion

Analysis of reproduction based life history traits of waterbirds in southern Africa resulted in four clusters of species. Contrary to this study's hypothesis, there was no significant relationship between waterbird population trends and the clusters integrating reproduction based life history traits. Many waterbird species have declining population trends globally and in all clusters described in this study, at least 50% of the members had declining population trends. It is important to highlight implications for specific guilds. This study illustrated that not only species with small diet items have higher proportions of decline, but also those with large diet items (despite them having higher indices of diet generalism). Due to the sensitivity of most waterbird prey species to changes in water levels, pollution and vegetation attributes [28,29], the waterbirds relying on these species may be at greater risk of decline. It can be argued that the species consuming larger prey items have higher proportions of decline because such species are mostly large-bodied [30], and therefore, more prone to disturbances and habitat fragmentation [31] when compared to small ones. Large bodied waterbird species are also targeted by hunters [32].

Although the probability of a species having a declining population status was unrelated to its index of diet generalism, all the species that grouped in cluster four are waterfowl (dominated by ducks and geese that feed on small food items). This finding is important, as the diet of waterfowl is limited to water bodies [2,33] and they also face pressure from harvesting by humans [34,35], disease risk [36] and other global climate and habitat change mediated challenges [10,37]. For example, some people involved in waterfowl hunting insist on sustaining this activity [38] despite the conservation risks to the populations globally. Additionally, most of these species (90%) are herbivorous, having lower indices of diet generalism, and hence, could be less able to cope with environmental stochasticity [12]. Conservationists, therefore, need to strengthen mitigative efforts against the main drivers such as habitat destruction and hunting [10].

Cluster one contained species from all the diet guilds (a "mixed bag" representing all the prey items reviewed in this study). Insectivore and omnivorous species were predominant in this mixed bag, a description fitting waders [39]. Since most waders are migratory [40], they face different constraints on the flyway [41] and this possibly explains the high proportion (68%) of those with declining populations. Additionally, waders may have the ability to exploit various prey items at different stopping sites [42], thus, explaining the tendency of being omnivorous.

This study revealed that tunicates, crustacea, amphibians, molluscs and coleopterans are constantly at the top of the diet of all the allocated waterbird clusters. With the current global declines in these prey items [43,44], this study also emphasizes the threat warnings particularly in relation to the species that feed on small items and those with low indices of diet generalism (cluster three). It is acknowledged that these listed food items do not necessarily imply the importance of their biomass in the diet, particularly for species in cluster three, which are large-bodied (as waterbirds may make meals from fewer but larger prey items). Additionally, the challenges associated with segregating diet items are acknowledged, since most published materials classify them in very broad taxonomic groupings and each item can vary in size from half a millimetre to several centimetres within a given taxon [11].

5. Conclusions

This study has shown that the size (lengths) of prey items is important in explaining population trends of waterbirds, and exposes the immediate risks faced by wildfowl species and those feeding on large prey in southern Africa if wetland conditions continue to deteriorate. The study also illustrated the importance of distinguished waterbird prey items such as tunicates, crustacea, amphibians and molluscs in the diet of species included in this study. It is possible that this study failed to detect some differences in population trends across specific guilds because the waterbird guild is already a specialised class of birds [45]. There is a need for united efforts in mitigating wetland disturbances, chiefly habitat destruction and hunting as these directly affect the prey base.

Author Contributions: Conceptualization, T.T. and T.M.; methodology, T.T., H.F. and I.M.; software, H.F.; validation, T.T., P.M. and I.M.; formal analysis, T.T.; investigation, I.M. and T.T.; resources, H.F. and T.T.; data curation, H.F., T.T. and I.M.; writing—original draft preparation, T.T.; writing—review and editing, H.F.; visualization, T.T. and T.M.; supervision, H.F. and P.M.; project administration, H.F.; funding acquisition, T.T. All authors have read and agreed to the published version of the manuscript.

Funding: This work was funded by the Ministère Français des Affaires Etrangères through the FSP-RenCaRe project, grant number CC04.

Institutional Review Board Statement: Not applicable.

Data Availability Statement: The waterbird trends data presented in this study are openly available on the birdlife international website on www.datazone.birdlife.org/species (accessed on 4 February 2018).

Acknowledgments: We thank the framework of the Research Platform 'Production and Conservation in Partnership' (RP-PCP) for supporting the student with administration of the grant. We also thank the Zone Atelier Hwange—Hwange LTSER for hosting the lead author during the course of study.

Conflicts of Interest: The authors declare no conflict of interest. The funders had no role in the design of the study; in the collection, analyses, or interpretation of data; in the writing of the manuscript, or in the decision to publish the results.

Appendix A

Table A1. Groups of southern African waterbird species from life-history based cluster analysis alongside their re-categorised ecological guilds and codes as used in Figure 1. Semi-omn = semi-omnivores, Dec = declining.

Cluster	Code	Local Name	Scientific Name	Diet Guild	Global Status
1	3	African Crake	*Crex egregia*	Semi-omn	Not Dec
	4	African Darter	*Anhinga rufa*	Piscivores	Dec
	6	African Jacana	*Actophilornis africanus*	Insectivores	Not Dec
	10	African Rail	*Rallus caerulescens*	Omnivores	Not Dec
	12	African Snipe	*Gallinago nigripennis*	Insectivores	Dec
	15	Allen's Gallinule	*Porphyrio alleni*	Omnivores	Dec
	17	Baillon's Crake	*Porzana pusilla*	Insectivores	Dec
	19	Bar-tailed Godwit	*Limosa lapponica*	Omnivores	Dec
	20	Black Crake	*Zapornia flavirostra*	Omnivores	Dec
	21	Black Heron	*Egretta ardesiaca*	Piscivores	Not Dec
	23	Black Tern	*Chlidonias niger*	Piscivores	Dec
	26	Black-necked Grebe	*Podiceps nigricollis*	Insectivores	Dec
	28	Black-tailed Godwit	*Limosa limosa*	Omnivores	Dec
	30	Black-winged Pratincole	*Glareola nordmanni*	Insectivores	Dec
	31	Black-winged Stilt	*Himantopus himantopus*	Insectivores	Not Dec
	32	Bronze-winged Courser	*Rhinoptilus chalcopterus*	Insectivores	Not Dec
	33	Buff-spotted Flufftail	*Sarothrura elegans*	Semi-omn	Not Dec
	37	Caspian Plover	*Charadrius asiaticus*	Semi-omn	Dec
	39	Cattle Egret	*Bubulcus ibis*	Insectivores	Not Dec
	40	Chestnut-banded Plover	*Charadrius pallidus*	Insectivores	Not Dec
	42	Common Greenshank	*Tringa nebularia*	Insectivores	Not Dec
	43	Common Moorhen	*Gallinula chloropus*	Omnivores	Not Dec
	44	Common Redshank	*Tringa totanus*	Insectivores	Dec
	45	Common Ringed Plover	*Charadrius hiaticula*	Insectivores	Dec
	46	Common Sandpiper	*Actitis hypoleucos*	Omnivores	Dec
	47	Common Snipe	*Gallinago gallinago*	Omnivores	Dec
	49	Common Whimbrel	*Numenius phaeopus*	Insectivores	Dec
	51	Crowned Cormorant	*Microcarbo coronatus*	Piscivores	Not Dec
	53	Curlew Sandpiper	*Calidris ferruginea*	Insectivores	Not Dec
	54	Damara Tern	*Sternula balaenarum*	Piscivores	Dec
	55	Dimorphic egret	*Egretta garzetta dimorpha*	Piscivores	Not Dec
	56	Dwarf Bittern	*Ixobrychus sturmii*	Piscivores	Dec
	58	Eurasian Curlew	*Numenius arquata*	Omnivores	Dec
	61	Glossy Ibis	*Plegadis falcinellus*	Insectivores	Dec
	65	Great Snipe	*Gallinago media*	Insectivores	Dec
	69	Greater Painted Snipe	*Rostratula benghalensis*	Omnivores	Dec
	70	Greater Sandplover	*Charadrius leschenaultii*	Insectivores	Not Dec
	71	Green Sandpiper	*Tringa ochropus*	Omnivores	Not Dec
	72	Green-backed Heron	*Butorides striata*	Piscivores	Dec
	74	Grey Phalarope	*Phalaropus fulicarius*	Semi-omn	Not Dec
	75	Grey Plover	*Pluvialis squatarola*	Insectivores	Dec
	83	Kitlitz Plover	*Charadrius pecuarius*	Insectivores	Dec
	89	Lesser Jacana	*Microparra capensis*	Insectivores	Dec
	90	Lesser Moorhen	*Gallinula angulata*	Semi-omn	Dec
	91	Lesser Sandplover	*Charadrius mongolus*	Insectivores	Not Dec
	92	Little Bittern	*Ixobrychus minutus*	Piscivores	Dec
	93	Little Egret	*Egretta garzetta*	Piscivores	Not Dec
	94	Little Grebe	*Tachybaptus ruficollis*	Insectivores	Dec
	95	Little Ringed Plover	*Charadrius dubius*	Insectivores	Dec
	96	Little Stint	*Calidris minuta*	Omnivores	Dec

Table A1. *Cont.*

Cluster	Code	Local Name	Scientific Name	Diet Guild	Global Status
	97	Little Tern	*Sternula albifrons*	Piscivores	Dec
	98	Long-tailed Cormorant	*Microcarbo africanus*	Piscivores	Dec
	100	Maccoa Duck	*Oxyura maccoa*	Omnivores	Dec
	102	Madagascar Jacana	*Actophilornis albinucha*	Semi-omn	Dec
	103	Madagascar Pond Heron	*Ardeola idae*	Piscivores	Dec
	104	Madagascar Snipe	*Gallinago macrodactyla*	Semi-omn	Dec
	106	Marsh Sandpiper	*Tringa stagnatilis*	Insectivores	Dec
	110	Pacific Golden Plover	*Pluvialis fulva*	Insectivores	Dec
	112	Pied Kingfisher	*Ceryle rudis*	Piscivores	Dec
	115	Red Knobbed Coot	*Fulica cristata*	Semi-omn	Dec
	116	Red Knot	*Calidris canutus*	Omnivores	Dec
	118	Red-chested Flufftail	*Sarothrura rufa*	Omnivores	Dec
	119	Red-necked Phalarope	*Phalaropus lobatus*	Omnivores	Dec
	120	Red-tailed Flufftail	*Sarothrura affinis*	Semi-omn	Dec
	121	Red-winged Pranticole	*Glareola pratincola*	Insectivores	Dec
	122	Rock Pratincole	*Glareola nuchalis*	Insectivores	Dec
	124	Ruddy Turnstone	*Arenaria interpres*	Omnivores	Dec
	125	Ruff	*Philomachus pugnax*	Omnivores	Dec
	126	Rufous-bellied Heron	*Ardeola rufiventris*	Piscivores	Dec
	128	Sanderling	*Calidris alba*	Insectivores	Not Dec
	135	Spotted Crake	*Porzana porzana*	Omnivores	Not Dec
	138	Spur-winged Lapwing	*Vanellus spinosus*	Semi-omn	Not Dec
	139	Squacco Heron	*Ardeola ralloides*	Piscivores	Dec
	140	Staty Egret	*Egretta vinaceigula*	Piscivores	Dec
	141	Streaky-breasted Flufftail	*Sarothrura boehmi*	Herbivores	Dec
	142	Stripped Crake	*Amaurornis marginalis*	Insectivores	Dec
	143	Temminck Courser	*Cursorius temminckii*	Semi-omn	Not Dec
	144	Terek Sandpiper	*Xenus cinereus*	Omnivores	Dec
	146	Three-banded Plover	*Charadrius tricollaris*	Insectivores	Dec
	151	White Winged Tern	*Chlidonias leucopterus*	Insectivores	Not Dec
	158	White-throated Rail	*Dryolimnas cuvieri*	Omnivores	Not Dec
	159	Wiskered Tern	*Chlidonias hybrida*	Piscivores	Not Dec
	160	Wood Sandpiper	*Tringa glareola*	Omnivores	Not Dec
2	2	African Black Oystercatcher	*Haematopus moquini*	Insectivores	Not Dec
	5	African Finfoot	*Podica senegalensis*	Insectivores	Dec
	7	African Openbill Stork	*Anastomus lamelligerus*	Piscivores	Dec
	8	African Purple Swamphen	*Porphyrio porphyrio*	Omnivores	Dec
	11	African Skimmer	*Rynchops flavirostris*	Piscivores	Dec
	13	African Spoonbill	*Platalea alba*	Insectivores	Not Dec
	14	African Wattled Lapwing	*Vanellus senegallus*	Semi-omn	Not Dec
	16	Arctic Tern	*Sterna paradisaea*	Piscivores	Dec
	18	Bank Cormorant	*Phalacrocorax neglectus*	Piscivores	Dec
	24	Black-crowned Night Heron	*Nycticorax nycticorax*	Omnivores	Dec
	25	Black-headed Heron	*Ardea melanocephala*	Insectivores	Not Dec
	27	Blacksmith Lapwing	*Vanellus armatus*	Insectivores	Not Dec
	29	Black-winged Lapwing	*Vanellus melanopterus*	Insectivores	Dec
	34	Cape Cormorant	*Phalacrocorax capensis*	Piscivores	Dec
	38	Caspian Tern	*Hydroprogne caspia*	Piscivores	Dec
	41	Common Bittern	*Botaurus stellaris*	Piscivores	Dec
	48	Common Tern	*Sterna hirundo*	Piscivores	Not Dec
	59	Franklin's Gull	*Larus pipixcan*	Insectivores	Not Dec
	62	Goliath Heron	*Ardea goliath*	Piscivores	Not Dec
	64	Great Egret	*Ardea alba*	Piscivores	Dec
	67	Greater Crested Tern	*Thalasseus bergii*	Piscivores	Not Dec
	73	Grey Heron	*Ardea cinerea*	Piscivores	Dec
	76	Grey-hooded Gull	*Chroicocephalus cirrocephalus*	Piscivores	Not Dec
	77	Gull-billed Tern	*Gelochelidon nilotica*	Insectivores	Dec

Table A1. *Cont.*

Cluster	Code	Local Name	Scientific Name	Diet Guild	Global Status
	78	Hadeda Ibis	*Bostrychia hagedash*	Insectivores	Not Dec
	79	Hamerkop	*Scopus umbretta*	Piscivores	Not Dec
	80	Hartlaub's Gull	*Chroicocephalus hartlaubii*	Piscivores	Not Dec
	82	Intermediate Egret	*Ardea intermedia*	Piscivores	Dec
	85	Lesser Black-backed Gull	*Larus fuscus*	Piscivores	Not Dec
	86	Lesser Black-winged Plover	*Vanellus lugubris*	Semi-omn	Not Dec
	87	Lesser Crested Tern	*Thalasseus bengalensis*	Piscivores	Not Dec
	99	Long-toed Lapwing	*Vanellus crassirostris*	Semi-omn	Dec
	101	Madagascar Heron	*Ardea humbloti*	Piscivores	Dec
	105	Madagascar Teal	*Anas bernieri*	Insectivores	Dec
	111	Pied Avocet	*Recurvirostra avosetta*	Omnivores	Dec
	114	Purple Heron	*Ardea purpurea*	Piscivores	Dec
	123	Roseate Tern	*Sterna dougallii*	Piscivores	Not Dec
	127	Sacred Ibis	*Threskiornis aethiopicus*	Insectivores	Dec
	129	Sandwich Tern	*Thalasseus sandvicensis*	Piscivores	Not Dec
	132	Southern Bald Ibis	*Geronticus calvus*	Insectivores	Dec
	133	Southern Black-backed Gull	*Larus dominicanus*	Piscivores	Not Dec
	136	Spotted Thickknee	*Burhinus capensis*	Insectivores	Not Dec
	145	Three-banded Courser	*Rhinoptilus cinctus*	Insectivores	Not Dec
	147	Eurasian Oystercatcher	*Haematopus ostralegus*	Insectivores	Dec
	148	Water Thickknee	*Burhinus vermiculatus*	Omnivores	Dec
	153	White-backed Night Heron	*Gorsachius leuconotus*	Piscivores	Not Dec
	154	White-breasted Cormorant	*Phalacrocorax carbo*	Piscivores	Not Dec
	155	White-crowned Lapwing	*Vanellus albiceps*	Semi-omn	Not Dec
	157	White-fronted Plover	*Charadrius marginatus*	Insectivores	Dec
	163	Yellow-billed Stork	*Mycteria ibis*	Piscivores	Dec
3	22	Black Stork	*Ciconia nigra*	Insectivores	Dec
	52	Crowned Crane	*Balearica regulorum*	Semi-omn	Dec
	66	Great White Pelican	*Pelecanus onocrotalus*	Piscivores	Dec
	68	Greater Flamingo	*Phoenicopterus roseus*	Piscivores	Not Dec
	88	Lesser Flamingo	*Phoeniconaias minor*	Insectivores	Dec
	113	Pink-backed Pelican	*Pelecanus rufescens*	Piscivores	Not Dec
	130	Shoebill	*Balaeniceps rex*	Piscivores	Dec
	149	Wattled Crane	*Grus carunculate*	Omnivores	Dec
	150	White Stork	*Ciconia ciconia*	Piscivores	Not Dec
	161	Woolly necked Stork	*Ciconia episcopus*	Insectivores	Dec
4	1	African Black Duck	*Anas sparsa*	Omnivores	Dec
	9	African Pygmy Goose	*Nettapus auritus*	Herbivores	Dec
	35	Cape Shoveler	*Spatula smithii*	Omnivores	Not Dec
	36	Cape Teal	*Anas capensis*	Omnivores	Not Dec
	50	Corn Crake	*Crex crex*	Semi-omn	Not Dec
	57	Egyptian Geese	*Alopochen aegyptiaca*	Herbivores	Dec
	60	Fulvous Duck	*Dendrocygna bicolor*	Herbivores	Dec
	63	Great Crested Grebe	*Podiceps cristatus*	Insectivores	Not Dec
	81	Hottentot Teal	*Spatula hottentota*	Omnivores	Dec
	84	Knob-billed Duck	*Sarkidiornis melanotos*	Herbivores	Dec
	107	Meller's Duck	*Anas melleri*	Herbivores	Dec
	108	Northern Mallard	*Anas platyrhynchos*	Omnivores	Not Dec
	109	Northern Shoveler	*Spatula clypeata*	Insectivores	Not Dec
	117	Red-billed Teal	*Anas erythrorhyncha*	Omnivores	Dec
	131	South African Shelduck	*Tadorna cana*	Herbivores	Not Dec
	134	Southern Pochard	*Netta erythrophthalma*	Herbivores	Dec
	137	Spur-winged Goose	*Plectropterus gambensis*	Herbivores	Not Dec
	152	White-backed Duck	*Thalassornis leuconotus*	Herbivores	Dec
	156	White-faced Duck	*Dendrocygna viduata*	Semi-omn	Not Dec
	162	Yellow-billed Duck	*Anas undulata*	Omnivores	Not Dec

Appendix B

Table A2. Results of the Akaike information criteria for the top candidate models used to model the global population trends of waterbirds in southern Africa.

Model	K	AICc	ΔAICc	W_i
Global trend~Diet body size	3	208.724	0	0.788
Global trend~Waterbird cluster + diet Body size	6	212.534	3.81	0.117
Global trend~Waterbird guild + number of prey items consumed + diet body size	8	213.024	4.299	0.092

References

1. Hockey, P.; Dean, W.; Ryan, P. *Roberts Birds of Southern Africa*, 7th ed.; Trustees of the John Voelcker Bird Book Fund: Cape Town, South Africa, 2005.
2. Henry, D.A.; Cumming, G.S. Can waterbirds with different movement, dietary and foraging functional traits occupy similar ecological niches? *Landsc. Ecol.* **2017**, *32*, 265–278. [CrossRef]
3. Végvári, Z.; Borza, S.; Juhász, K. The role of phylogeny and life history of migratory waterbirds in designing fishpond management plans. *Ecol. Eng.* **2015**, *85*, 288–295. [CrossRef]
4. Thackeray, S.J.; Henrys, P.A.; Hemming, D.; Bell, J.R.; Botham, M.S.; Burthe, S.; Helaouet, P.; Johns, D.G.; Jones, I.D.; Leech, D.I. Phenological sensitivity to climate across taxa and trophic levels. *Nature* **2016**, *535*, 241. [CrossRef] [PubMed]
5. Blueweiss, L.; Fox, H.; Kudzma, V.; Nakashima, D.; Peters, R.; Sams, S. Relationships between body size and some life history parameters. *Oecologia* **1978**, *37*, 257–272. [CrossRef] [PubMed]
6. Pianka, E.R. On r-and K-selection. *Am. Nat.* **1970**, *104*, 592–597. [CrossRef]
7. Sæther, B.-E.; Lande, R.; Engen, S.; Weimerskirch, H.; Lillegård, M.; Altwegg, R.; Becker, P.H.; Bregnballe, T.; Brommer, J.E.; McCleery, R.H. Generation time and temporal scaling of bird population dynamics. *Nature* **2005**, *436*, 99–102. [CrossRef] [PubMed]
8. Dingle, H. Animal migration: Is there a common migratory syndrome? *J. Ornithol.* **2006**, *147*, 212–220. [CrossRef]
9. Okes, N.C.; Hockey, P.A.R.; Cumming, G.S. Habitat use and life history as predictors of bird responses to habitat change. *Conserv. Biol.* **2008**, *22*, 151–162. [CrossRef]
10. Dodman, T.; Diagana, C.H. Conservation dilemmas for intra-African migratory waterbirds. *Waterbirds World* **2006**, *218*, 223–230.
11. Brochet, A.L.; Dessborn, L.; Legagneux, P.; Elmberg, J.; Gauthier-Clerc, M.; Fritz, H.; Guillemain, M. Is diet segregation between dabbling ducks due to food partitioning? A review of seasonal patterns in the Western Palearctic. *J. Zool.* **2012**, *286*, 171–178.
12. Julliard, R.; Clavel, J.; Devictor, V.; Jiguet, F.; Couvet, D. Spatial segregation of specialists and generalists in bird communities. *Ecol. Lett.* **2006**, *9*, 1237–1244. [CrossRef]
13. Tripet, F.; Christe, P.; Møller, A.P. The importance of host spatial distribution for parasite specialization and speciation: A comparative study of bird fleas (Siphonaptera: Ceratophyllidae). *J. Anim. Ecol.* **2002**, *71*, 735–748. [CrossRef]
14. Dall, S.R.; Cuthill, I.C. The information costs of generalism. *Oikos* **1997**, 197–202. [CrossRef]
15. Zanchetta, C.V.; Moore, D.J.; Weseloh, D.C.; Quinn, J.S. Population trends of colonial waterbirds nesting in Hamilton Harbour in relation to changes in habitat and management. *Aquat. Ecosyst. Health Manag.* **2016**, *19*, 192–205. [CrossRef]
16. Hansen, B.D.; Menkhorst, P.; Moloney, P.; Loyn, R.H. Long-term declines in multiple waterbird species in a tidal embayment, south-east Australia. *Austral Ecol.* **2015**, *40*, 515–527. [CrossRef]
17. Cheriak, L.; Barbraud, C.; Doumandji, S.; Bouguessa, S. Diet variability in the White Stork *Ciconia ciconia* in eastern Algeria. *Ostrich* **2014**, *85*, 201–204. [CrossRef]
18. Tarakini, T.; Guerbois, S.; Wencelius, J.; Mundy, P.; Fritz, H. Integrating local ecological knowledge for waterbird conservation: Insights from Kavango-Zambezi transfrontier conservation area, Zimbabwe. *Trop. Conserv. Sci.* **2018**, *11*, 1–17. [CrossRef]
19. Halse, S. Diet, body condition, and gut size of Egyptian geese. *J. Wildl. Manag.* **1984**, *48*, 569–573. [CrossRef]
20. Stewart, K.; Matthiesen, D.; Leblanc, L.; West, J. Prey diversity and selectivity of the African fish eagle: Data from a roost in northern Kenya. *Afr. J. Ecol.* **1997**, *35*, 133–145. [CrossRef]
21. Arzel, C.; Elmberg, J.; Guillemain, M.; Legagneux, P.; Bosca, F.; Chambouleyron, M.; Lepley, M.; Pin, C.; Arnaud, A.; Schricke, V. Average mass of seeds encountered by foraging dabbling ducks in Western Europe. *Wildl. Biol.* **2007**, *13*, 328–336. [CrossRef]
22. Liordos, V. Foraging guilds of waterbirds wintering in a Mediterranean coastal wetland. *Zool. Stud.* **2010**, *49*, 311–323.
23. Tibshirani, R.; Walther, G.; Hastie, T. Estimating the number of clusters in a data set via the gap statistic. *J. R. Stat. Soc. Ser. B Stat. Methodol.* **2001**, *63*, 411–423. [CrossRef]
24. Charrad, M.; Ghazzali, N.; Boiteau, V.; Niknafs, A.; Charrad, M.M. Package 'NbClust'. *J. Stat. Softw.* **2014**, *61*, 1–36.
25. Mwedzi, T.; Zimunya, T.G.; Bere, T.; Tarakini, T.; Mangadze, T. Disentangling and ranking the influence of multiple stressors on macroinvertebrate communities in a tropical river system. *Int. Rev. Hydrobiol.* **2017**, *102*, 1–11. [CrossRef]
26. Burnham, K.P.; Anderson, D.R. *Model Selection and Multimodel Inference*; Springer: New York, NY, USA, 2002.
27. R Development Core Team. *R: A Language and Environment for Statistical Computing (Internet)*; R Foundation for Statistical Computing: Vienna, Austria, 2018.

28. Bere, T.; Dalu, T.; Mwedzi, T. Detecting the impact of heavy metal contaminated sediment on benthic macroinvertebrate communities in tropical streams. *Sci. Total Environ.* **2016**, *572*, 147–156. [CrossRef]
29. Guareschi, S.; Abellán, P.; Laini, A.; Green, A.; Sánchez-Zapata, J.; Velasco, J.; Millán, A. Cross-taxon congruence in wetlands: Assessing the value of waterbirds as surrogates of macroinvertebrate biodiversity in Mediterranean Ramsar sites. *Ecol. Indic.* **2015**, *49*, 204–215. [CrossRef]
30. Emmerson, M.C.; Raffaelli, D. Predator–prey body size, interaction strength and the stability of a real food web. *J. Anim. Ecol.* **2004**, *73*, 399–409. [CrossRef]
31. Austin, V.I.; Ribot, R.F.H.; Bennett, A.T.D. If waterbirds are nocturnal are we conserving the right habitats? *Emu* **2016**, *116*, 423–427. [CrossRef]
32. Griffiths, M. Identifying Gamebird Hunting 'Hotspots': Implications for Conservation. Master's Thesis, University of Cape Town, Cape Town, South Africa, 1998.
33. Ndlovu, M.; Cumming, G.S.; Hockey, P.A.; Nkosi, M.D.; Mutumi, G.L. A study of moult-site fidelity in Egyptian geese, *Alopochen aegyptiaca*, in South Africa. *Afr. Zool.* **2013**, *48*, 240–249. [CrossRef]
34. Ramachandran, R.; Kumar, A.; Gopi Sundar, K.S.; Bhalla, R.S. Hunting or habitat? Drivers of waterbird abundance and community structure in agricultural wetlands of southern India. *Ambio* **2017**, *46*, 613–620. [CrossRef] [PubMed]
35. Gutiérrez, R.J.; Wood, K.A.; Redpath, S.M.; Young, J.C. Conservation conflicts: Future research challenges. *Curr. Trends Wildl. Res.* **2016**, *1*, 267–282.
36. Caron, A.; Abolnik, C.; Mundava, J.; Gaidet, N.; Burger, C.E.; Mochotlhoane, B.; Bruinzeel, L.; Chiweshe, N.; Garine-Wichatitsky, M.D.; Cumming, G.S. Persistence of low pathogenic avian influenza virus in waterfowl in a Southern African ecosystem. *EcoHealth* **2011**, *8*, 109–115. [CrossRef] [PubMed]
37. Haq, R.U.; Eiam-Ampai, K.; Ngoprasert, D.; Sasaki, N.; Shrestha, R.P. Changing landscapes and declining populations of resident waterbirds: A 12-year study in Bung Boraphet wetland, Thailand. *Trop. Conserv. Sci.* **2018**, *11*, 1–17. [CrossRef]
38. Holmgaard, S.B.; Eythórsson, E.; Tombre, I.M. Hunter opinions on the management of migratory geese: A case of stakeholder involvement in adaptive harvest management. *Hum. Dimens. Wildl.* **2018**, *23*, 1–9. [CrossRef]
39. Smith, R.V.; Stafford, J.D.; Yetter, A.P.; Horath, M.M.; Hine, C.S.; Hoover, J.P. Foraging ecology of fall-migrating shorebirds in the Illinois river valley. *PLoS ONE* **2012**, *7*, e45121. [CrossRef]
40. Buelow, C.; Sheaves, M. A birds-eye view of biological connectivity in mangrove systems. *Estuar. Coast. Shelf Sci.* **2015**, *152*, 33–43. [CrossRef]
41. Boere, G.C.; Galbraith, C.A.; Stroud, D.A. *Waterbirds Around the World: A Global Overview of the Conservation, Management and Research of the World's Waterbird Flyways*; The Stationery Office: Edinburgh, UK, 2006; p. 960.
42. Gerwing, T.G.; Kim, J.; Hamilton, D.J.; Barbeau, M.A.; Addison, J.A. Diet reconstruction using next-generation sequencing increases the known ecosystem usage by a shorebird. *Auk* **2016**, *133*, 168–177. [CrossRef]
43. Houlahan, J.E.; Findlay, C.S.; Schmidt, B.R.; Meyer, A.H.; Kuzmin, S.L. Quantitative evidence for global amphibian population declines. *Nature* **2000**, *404*, 752–755. [CrossRef]
44. Lydeard, C.; Cowie, R.H.; Ponder, W.F.; Bogan, A.E.; Bouchet, P.; Clark, S.A.; Cummings, K.S.; Frest, T.J.; Gargominy, O.; Herbert, D.G. The global decline of nonmarine mollusks. *BioScience* **2004**, *54*, 321–330. [CrossRef]
45. Ntiamoa-Baidu, Y.A.A.; Piersma, T.; Wiersma, P.; Poot, M.; Battley, P.; Gordon, C. Water depth selection, daily feeding routines and diets of waterbirds in coastal lagoons in Ghana. *Ibis* **1998**, *140*, 89–103. [CrossRef]