

## Contemporary spatial distribution pattern, breeding status and habitat suitability criteria for the African skimmer, *Rynchops flavirostris* Vieillot, 1816 (Aves Laridae) in the Zambezi Valley, Zimbabwe

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### ABSTRACT

Reports indicate a decline in spatial distribution, reproduction and population size of the African Skimmer, *Rynchops flavirostris* Vieillot, 1816 (Aves Laridae) in the Zambezi Valley, Zimbabwe following construction of Lake Kariba. The objective of the present study was to assess contemporary distribution and breeding status of *R. flavirostris* in Lake Kariba and upstream and downstream of the lake in Zimbabwe. The study also developed habitat suitability criteria for Habitat Risk Index (Ri) and established the dominant substrates, soil moisture levels, soil temperature and food abundance for *R. flavirostris* in lentic and lotic environs of the Zambezi Valley, in order to establish the appropriate habitat conditions for the species. A survey method was used to determine *R. flavirostris* distribution and breeding status within the valley. Soil moisture level was measured by categorising levels into wet, damp, and dry soils and the category with the highest frequency was used to define habitat substrate moisture levels. Dominant substrate was visually estimated basing on proportion of soil particle sizes. Habitat risk was assessed on the basis of potential risk from anthropogenic and natural factors. Seine net fishing was conducted to estimate food abundance at sampling sites in Lake Kariba. Significant differences in sample means of measured habitat attributes between sites occupied by *R. flavirostris* and those unoccupied by the species were tested by two sample t tests with separate variance. One-way ANOVA was used to test for significant differences in habitat conditions among sampling sites. Three-way ANOVA was used to test for significant interactions of habitat conditions on *R. flavirostris* abundance in lentic and lotic environs. Preference ratios for habitat conditions were used to develop habitat suitability criteria. Results revealed that *R. flavirostris* was inhabiting and breeding in Lake Kariba and upstream and downstream of the lake. The species tolerance of habitat risk was observed to vary significantly ( $p < 0.05$ , One-way ANOVA) among the three sections of the valley. Within the lake, *R. flavirostris* mostly preferred sandbars of moderate Habitat Risk Index ( $0.4 < R < 0.7$ ). Contrary, *R. flavirostris* showed absolute preference to sandbars with low Habitat Risk Index ( $R < 0.4$ ) in habitats upstream and downstream of the lake. Significant differences ( $p < 0.05$ ; One-way ANOVA) in *R. flavirostris* abundance among sites of varying substrates were observed. Habitat Suitability Indices showed that *R. flavirostris* preferentially selected predominantly silty and sandy habitats in both lentic and lotic environs. Significant difference ( $p < 0.05$ ; One-way ANOVA) was also observed on *R. flavirostris* abundance among sites with different soil moisture content in the valley. *R. flavirostris* showed low preference for dry habitats in both lentic and lotic environs. No significant difference ( $p > 0.05$ ; One-way ANOVA) in temperature was observed on sandbars occupied by *R. flavirostris* within the lake and upstream and downstream of the lake. *R. flavirostris* preferentially selected sandbars with food abundances greater than 0.15 fish/m<sup>2</sup> within Lake Kariba. This study conclusively revealed that food availability, dominant substrate, soil moisture level and habitat risk emanating from both natural and anthropogenic factors at sandbars were important determinants of habitat suitability criteria for *R. flavirostris* in the Zambezi Valley.

**KEY WORDS** *Rynchops flavirostris*; spatial distribution; breeding status; habitat suitability.

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## INTRODUCTION

River obstruction and hydrological alterations are commonly associated with habitat changes for lotic species (Bunn & Arthington, 2002). The damming of the Zambezi River during construction of Lake Kariba in the 1950s resulted in habitat alterations for riverine avian species. One species that was profoundly affected by the construction of the lake was the African Skimmer (*Rynchops flavirostris*), an endemic, intra-African migrant species that inhabited large emergent sandbars on the Zambezi River channel (Irwin, 1981; Coppinger et al., 1988).

*Rynchops flavirostris* is one of the Important Bird Area (IBA) trigger species that inhabits the Zambezi Valley whose spatial distribution, breeding status and population size were reportedly severely affected by the construction of Lake Kariba (Irwin, 1981; Donnelly & Donnelly, 1983; Coppinger et al., 1988; Tree, 1988; Wood & Tree, 1992; Hockey et al., 2005). The species then ultimately disappeared from the Lake Kariba environs after inundation of the river channel in 1968 (Irwin, 1981; Donnelly & Donnelly, 1983; Coppinger et al., 1988; Tree, 1988; Wood & Tree, 1992; Hockey et al., 2005). Elliott (1982) reported an estimate of *R. flavirostris* on this part of the Zambezi River at 100 birds in 1981. Fishpool & Evans (2001) subsequently gave an estimate of 136 birds as of 1986. *Rynchops flavirostris* breeding was reported to have completely ceased in the entire Mid-Zambezi Valley following the inundation. This led to severe decline of the species population within the valley (Wood & Tree, 1992). Most of the emergent sandbars which used to be special breeding grounds for *R. flavirostris* disappeared along the Zambezi River channel following construction of Lake Kariba (Irwin, 1981; Donnelly & Donnelly, 1983). Tree (1989) noted that Mozambique could be the only remaining breeding stronghold for *R. flavirostris* in the entire Zambezi Valley. The species is thus listed as near threatened (BirdLife International, 2012) owing to its small population and ongoing population decline.

Although the construction of the lake could have been the most significant factor in population decline of *R. flavirostris* in the Zambezi Valley, an amalgamation of habitat factors could have played a part. Studies have shown that a multiplicity of habitat factors simultaneously determine habitat suitability criteria for species (Brooks et al., 2005).

Avian species distribution is influenced by species functional requirements in relation to a range of biotic and abiotic factors within the ecosystem. Species habitat preferences are often a function of habitat stability. Sand bars are prone to natural and human disturbances. They are ideal sites for docking and for fishing. Derelict gillnets account for high mortalities of birds in aquatic systems (Zydelis et al., 2009). Sandbars are also foraging, drinking and resting sites for a number of herbivores and predators. Decline in reproduction success of *R. flavirostris* within the Zambezi valley and the subsequent species population crush could have been a result of human fisheries, predation of the species by crocodiles and Nile monitors as well as trembling of nests by large herbivores at sandbars (Coppinger et al., 1988). Erratic flooding of sand bars from opened flood gates is among possible habitat factors that determine habitat suitability for *R. flavirostris* in the Zambezi Valley (Coppinger et al., 1988). Climate change is another possible factor. So far, no comprehensive studies have been carried out to investigate effects of these various factors on habitats of *R. flavirostris* in the Zambezi Valley. An assessment of these factors is important, especially in lentic and lotic ecosystems where habitat conditions tend to flux as a result of natural events and anthropogenic activities.

The present study assessed contemporary spatial distribution pattern and breeding status of *R. flavirostris*, and developed habitat suitability criteria for the species within lentic and lotic habitats of the Zambezi Valley, Zimbabwe, about half a century after construction of Lake Kariba. Most recent studies on *R. flavirostris* are those by Coppinger et al. (1988) who studied distribution and breeding

biology of the species in the Upper and Middle Zambezi Valley, and reported on possible absence of the species within the Lake Kariba environs some two decades after construction of the lake. Habitat suitability criteria for Habitat Risk Index (R) that included dominant substrate, soil moisture level and soil temperature were developed for sandbars utilised by *R. flavirostris* for perching and feeding in Lake Kariba and in riverine habitats upstream and downstream of the lake. Habitat suitability function was also developed for food abundance within the lake.

Habitat selection is often in pursuit of food, breeding, as well as for provision of refuge from predation and other risks. Due to scarcity of nesting sites within the study area, the study was confined to the development of habitat suitability criteria for *R. flavirostris* for perching and feeding, but not for nesting. Effects of land use, river flow rate and climate on habitats of *R. flavirostris* within the Zambezi Valley were also not considered in the current study.

## MATERIAL AND METHODS

### *Study area*

The study was conducted in the mid-Zambezi Valley, in Zimbabwe and within Lake Kariba and its environs. The mid-Zambezi Valley is situated in northern Zimbabwe and part of Zambia and Mozambique. The Zambezi River is one of Africa's four largest rivers, and flows from north western Zambia to the Indian Ocean (Fishpool & Evans, 2001). The river drains from a catchment area that extends over eight countries, namely Zambia, Angola, Namibia, Botswana, Zimbabwe, Malawi, Tanzania and Mozambique. Its valley consists of unique terrestrial and aquatic habitats that support a diversity of flora and fauna. Timberlake (2000) estimated the biodiversity of the entire Zambezi basin to be between 6000 and 7000 plant species, about 195 mammalian species, 700 avian species, 165 fresh water fish species, 200 reptilian species and around 90 amphibian species.

Despite its importance as an area of high biodiversity, the Zambezi River and its catchment have experienced extensive anthropogenic pressure

within the second half of the twentieth century. Construction of Lake Kariba in the 1950s, and the subsequent drastic shifting of land use in the mid-Zambezi Valley following the impoundment, altered the valley ecosystems. Impacts were particularly severe in submerged areas surrounding the lake. The present study covered three sections of the valley: (i) Lake Kariba, (ii) the Zambezi River channel upstream of Lake Kariba whose flow regime was presumed unaltered by the dam construction and (iii) the Zambezi River channel downstream of the lake whose flow regime was altered by the construction the lake.

### *Selection of sampling sites and sampling effort*

A survey method, in conjunction with habitat recognition protocol, was employed in selecting sampling sites. Access of sampling sites was either by road or by boat, depending on accessibility and land owner permission. Basing on the assumption that all sandbars associated with lentic and lotic environs were potential habitats for *R. flavirostris*, identification of sampling sites was primarily based on presence of sandbars. For development of habitat suitability criteria, equal sampling effort was expended in the three sections of the Zambezi Valley, with a total of one hundred and eight surveys conducted on nine sandbars in each section over the period of July, August and October of 2014 and 2015.

Upstream of Lake Kariba, sampling was conducted along the river channel on the Zimbabwean side on nine sandbars situated between Kazungula Boarder Post and Victoria Falls, between geographical locations 17°48'14.82"S 025°16'6.99"E and 17°55'29.60"S 025° 51'1.85"E. Downstream of the lake, sampling was also carried out on nine sandbars along the Zambezi River channel on the Zimbabwean side. Downstream sites were situated between Vundu and Nyamatutsi, between geographical locations 15° 73.487'S 029° 34.965'E and 15° 70.327'S 029° 41.666'E. In Lake Kariba, sampling was conducted on nine sandbars along Kariba Town shoreline, stretching from the dam wall (16°32.199'S 28°45.459'E) to Charara River mouth (16°33.583'S 28°57.047'E). Sampling was also conducted on thirteen additional sites spanning across the entire Lake Kariba shoreline during two lake-wide surveys to establish presence or absence of *R. flavirostris* on other sections of the lake.

Sampling was conducted during the breeding season of *R. flavirostris*. The species is an inter-African migrant that breeds from July to October in Zimbabwe (Irwin, 1981). Surveys therefore coincide with species presence and breeding. Lake wide surveys to investigate presence of *R. flavirostris* on other sections of Lake Kariba were conducted from 28 August 2014 to 11 September 2014 and from 6 to 18 August 2015.

### ***Distribution and breeding status of Rynchops flavirostris***

In all three sections of the Zambezi Valley, Global Positioning System (GPS) readings were recorded at all sampling sites. Surveys involved the use of the point count protocol conducted from the water edge at the middle of each sandbar with limited distance of 100 m. A single point count (one contact) was performed at each sampling site per visit, and two visits were made per sampling site per sampling month. Observations were made with the aid of pairs of binoculars (Dialyt 8X30B). Point counts were conducted with the aim of establishing abundances of *R. flavirostris* at sampling sites. Surveys were conducted at sunrise and preceded for three hours. Counting lasted for 15 minutes per sampling site, and all *R. flavirostris* seen flying or resting at sampling site were recorded. Distances of resting birds from the water edge were estimated using a range finder and classified into four categories as follows: 0–5 m, 5–10 m, 10–15 m, and >15 m. Avian species occupying sandbars in company with *R. flavirostris* were recorded as associate species. Reporting rates ( $r_{yi}$ ) were used to describe frequency of occurrence of associate species at each sampling site during the entire sampling period. Avian species at sandbars unoccupied by *R. flavirostris* were also recorded and their frequency of occurrence ( $r_{zi}$ ) at the sites during the entire sampling period calculated. Species richness (S) was used to describe the number bird species at the sampling site. Following point counts, breeding status was investigated by walking and searching for nests and chicks on the entire sandbar.

### ***Habitat characterisation***

To establish habitat suitability criteria at sites

utilised by *R. flavirostris* for perching and feeding, sandbars occupied by the species were characterised and compared with attributes from sandbars unoccupied by the species. Differences in sample means for all numerical data were tested by two sample t tests with separate variance. At each of the sampling sites, habitat characteristics were defined by soil moisture content, soil temperature, dominant substrate, and Habitat Risk Index ( $R_i$ ). In Lake Kariba, habitat characterisation also included estimating food abundance for *R. flavirostris* at different sampling sites along Kariba Town shoreline.

### ***Measuring soil temperature, soil moisture content and dominant substrate***

Basing on observations that all *R. flavirostris* encountered in this study rested very close to water edges (within distance of 0–5 m from water mark) in both lentic and lotic ecosystems, species perching territory was set at 5 m from the water mark. Soil surface temperature, soil moisture level and dominant substrate were measured within the species perching territory at all sampling sites in order to characterise species habitat preferences for perching and feeding. Measurements were taken lengthwise across sandbars by laying 100 m tape on either side of the centre of the sandbar at a distance of 2.5 m from the water mark. At each observation point, measurements were taken from a 0.5625 m<sup>2</sup> quadrant. Soil temperature (°C) and soil moisture content were measured at a depth of 1 cm below the surface. Soil temperature was measured using a mercury thermometer. Mean surface temperature across the sandbar was used to describe substrate temperature. Soil moisture level was estimated by categorising moisture levels into three classes namely, wet, damp, and dry. The category with the highest frequency of occurrence was used to define substrate moisture levels at sampling sites. Dominant substrate was visually estimated based on proportion of soil particle size within the quadrant. Soil particle size category with the highest frequency of occurrence across the sandbar was used to describe dominant substrate at the sandbar. For sandbars with lengths less than 200 m, measurements were taken across the entire length of the sandbar.

Section of Zambezi Valley	Site	<i>Rynchops flavirostris</i> abundance			<i>Rynchops flavirostris</i> breeding status and flock size		
		July	August	September	July	August	September
Lake Kariba: Kariba Town Shoreline	K1	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K2	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K3	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K4	0;18*	19;13*	11;0*	0;0*	0;0*	0;0*
	K5	0;15*	16;17*	9;0*	0;0*	0;0*	0;0*
	K6	0;33*	34;23*	29;0*	0;0*	0; B3*	B2;N*
	K7	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K8	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K9	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
Lake Kariba: Lake-wide shoreline	K10	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K11	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K12	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K13	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K14	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K15	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K16	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K17	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K18	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K19	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K20	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	K21	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*

Table 1/1. *Rynchops flavirostris* abundances and breeding status at sampling sites in the lentic and lotic environs of the Zambezi Valley, Zimbabwe. Observations made in 2015 are denoted by \* and B represents breeding observed on site e.g. B3\*= breeding and 3 young ones observed in 2015.



Section of Zambezi Valley	Site	<i>Rynchops flavirostris</i> abundance			<i>Rynchops flavirostris</i> breeding status and flock size		
		July	August	September	July	August	September
<b>Zambezi River: upstream habitats</b>	<b>V1</b>	3;2*	5;4*	9;7*	0;0*	0;0*	0;0*
	<b>V2</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>V3</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>V4</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>V5</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>V6</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>V7</b>	13;11*	17;15*	28;18*	0;0*	0;0*	B5;0*
	<b>V8</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>V9</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
<b>Zambezi River: downstream habitats</b>	<b>M1</b>	14;12*	15;13*	17;15*	0;0*	0;0*	0;0*
	<b>M2</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>M3</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>M4</b>	0;13*	16;12*	13;0*	0;0*	0;0*	0;0*
	<b>M5</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>M6</b>	17;8*	19;11*	26;17*	0;0*	0;0*	B3;0*
	<b>M7</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>M8</b>	0;0*	0;0*	0;0*	0;0*	0;0*	0;0*
	<b>M9</b>	12;14*	17;14*	12;18*	0;0*	0;0*	0;0*

Table 1/2. *Rynchops flavirostris* abundances and breeding status at sampling sites in the lentic and lotic environs of the Zambezi Valley, Zimbabwe. Observations made in 2015 are denoted by \* and B represents breeding observed on site e.g. B3\*= breeding and 3 young ones observed in 2015.

Common Name	Scientific Name	Kariba Town Shoreline								
		K1 $r_{zi}$	K2 $r_{zi}$	K3 $r_{zi}$	K4 $r_{ji}$	K5 $r_{ji}$	K6 $r_{ji}$	K7 $r_{zi}$	K8 $r_{zi}$	K9 $r_{ji}$
African Skimmer	<i>Rynchops flavirostris</i>	0	0	0	0.67	0.67	0.67	0	0	0.33
African Fish Eagle	<i>Haliaeetus vocifer</i>	0.17	0.33	0	0.33	0.17	0	0.33	0.67	0.33
African Jacana	<i>Actophilornis africanus</i>	0	0	0	0.17	0	0	0	0	0.33
African Pied Wagtail	<i>Motacilla aguimp</i>	0	0	0	0	0	0	0	0	0
African Spoonbill	<i>Platalea alba</i>	0	0	0	0	0	0	0	0	0
Black Smith Plover	<i>Vanellus armatus</i>	0.33	0.17	0.33	0.83	0.67	0.33	0.17	0.33	0.83
Black-headed Heron	<i>Ardea melanocephala</i>	0	0	0	0	0	0	0	0	0
Black-winged Stilt	<i>Himantopus himantopus</i>	0	0	0	0	0	0	0	0	0
Bohm's Spinetail	<i>Neafrapus boehmi</i>	0	0	0	0	0	0	0	0	0
Cattle Egret	<i>Bubulcus ibis</i>	0.33	0.67	0.33	1	1	1	0.67	0.83	1
Common Sand piper	<i>Actitis hypoleucos</i>	0	0	0	0.33	0	0.67	0	0	0.83
Darter	<i>Anhinga melanogaster</i>	0	0	0	0	0	0	0	0	0
Egyptian Goose	<i>Alopochen aegyptiacus</i>	0.5	0.17	0	1	1	1	0.17	0.17	1
Glossy Ibis	<i>Plegadis falcinellus</i>	0.17	0	0	1	1	1	0	0.17	1
Goliath Heron	<i>Ardea goliath</i>	0	0	0	0.17	0	0.33	0	0.33	0
Great White Egret	<i>Egretta alba</i>	0	0	0	0	0	0	0	0	0
Green-Backed Heron	<i>Butorides striatus</i>	0	0	0	0	0	0	0	0	0
Greenshank	<i>Tringa nebularia</i>	0	0	0	0	0	0	0	0	0
Grey Heron	<i>Ardea cinerea</i>	0.17	0	0	0.33	0	0.17	0	0.33	0.67
Grey-headed Gull	<i>Larus cirrocephalus</i>	0	0.17	0	1	1	1	0.33	0	1
Hadedda Ibis	<i>Bostrychia hagedash</i>	0	0	0	0	0	0	0	0	0
Hammerkop	<i>Scopus umbretta</i>	0.17	0	0	0.33	0	0	0.17	0.33	0
Knob-billed Duck	<i>Sarkidiornis melanotos</i>	0	0	0	0	0	0	0	0	0
Little Egret	<i>Egretta garzetta</i>	0	0	0	0	0	0	0	0	0
Longtoed Plover	<i>Vanellus crassirostris</i>	0	0	0	0	0	0	0	0	0
Marabou Stork	<i>Leptoptilos crumeniferus</i>	1	1	0.83	0.5	1	0.83	1	0.33	0.5
Open-billed Stork	<i>Anastomus lamelligerus</i>	0	0.33	0.5	0	0.17	0.33	0	0.67	0.17
Pied Kingfisher	<i>Ceryle rudis</i>	0	0	0	0.33	0	0.5	0	0	0.67
Reed Cormorant	<i>Phalacrocorax africanus</i>	1	0	1	1	0.83	1	0.67	1	1
Rock Pratincole	<i>Glareola nuchalis</i>	0	0	0	0	0	0	0	0	0
Sacred Ibis	<i>Threskiornis aethiopicus</i>	0	0	0	1	1	1	0	0	1
Saddle-billed Stork	<i>Ephippiorhynchus senegalensis</i>	0	0.33	0	0.17	0.33	0	0.17	0	0.67
Spurwing Goose	<i>Plectropterus gambensis</i>	0	0	0	0	0	0	0	0	0
Squacco Heron	<i>Ardeola ralloides</i>	0	0	0	0	0	0	0	0	0
Water Dikkop	<i>Burhinus vermiculatus</i>	0	0	0	0	0	0	0	0	0
White Stork	<i>Ciconia ciconia</i>	0	0	0	0	0.33	0	0	0	0.17
White-crowned Plover	<i>Vanellus albiceps</i>	0	0	0	0	0	0	0	0	0
White-faced Duck	<i>Charadrius marginatus</i>	0.5	0	0.17	1	0.83	0.5	0.5	0.33	0
White-fronted Plover	<i>Charadrius marginatus</i>	0.5	0.33	0.17	1	1	1	0.3	0	1
Woolly-necked Stork	<i>Ciconia episcopus</i>	0	0	0	0	0	0	0	0	0
Yellow-billed Stork	<i>Mycteria ibis</i>	0.17	0	0.33	0.5	0.17	0.33	0.17	0	0.33
<b>Cumulative number of species (S)</b>		12	9	8	20	16	17	12	12	19

Table 2/1. *Rynchops flavirostris* associate species and their respective reporting rates  $r_{yi}$  and  $r_{zi}$  (defined in text) at sampling sites during the sampling period in the lentic and lotic environs of the Zambezi Valley, Zimbabwe.

Common Name	Scientific Name	Site								
		V1 r <sub>yi</sub>	V2 r <sub>zi</sub>	V3 r <sub>zi</sub>	V4 r <sub>zi</sub>	V5 r <sub>zi</sub>	V6 r <sub>zi</sub>	V7 r <sub>yi</sub>	V8 r <sub>zi</sub>	V9 r <sub>zi</sub>
African Skimmer	<i>Rynchops flavirostris</i>	1	0	0	0	0	0	1	0	0
African Fish Eagle	<i>Haliaeetus vocifer</i>	0.17	0.17	0.33	0	0	0.17	0.33	0	0
African Jacana	<i>Actophilornis africanus</i>	0.33	0	0.33	0	0.17	0	0.67	0.67	0.5
African Pied Wagtail	<i>Motacilla aguimp</i>	0	0.17	0	0	0.33	0	0	0	0.17
African Spoonbill	<i>Platalea alba</i>	0	0	0	0	0	0	0	0	0
Black Smith Plover	<i>Vanellus armatus</i>	0.67	0	0	0	0	0	0.5	0	0
Black-headed Heron	<i>Ardea melanocephala</i>	0	0	0	0	0	0	0	0	0
Black-winged Stilt	<i>Himantopus himantopus</i>	0.5	0	0	0	0	0	0.3	0	0
Bohm's Spinetail	<i>Neafrapus boehmi</i>	0	0	0	0	0	0	0	0	0
Cattle Egret	<i>Bubulcus ibis</i>	1	0.17	0.33	0.67	0.5	0.33	1	0.5	0.33
Common Sand piper	<i>Actitis hypoleucos</i>	0	0.17	0	0.33	0.33	0	0	0.17	0.33
Darter	<i>Anhinga melanogaster</i>	0.17	0	0.17	0	0	0	0	0	0
Egyptian Goose	<i>Alopochen aegyptiacus</i>	1	0.5	0.67	0.17	0.33	0.17	1	0.33	0.17
Glossy Ibis	<i>Plegadis falcinellus</i>	1	0.33	0.5	0.17	0	0.17	1	0.17	0.33
Goliath Heron	<i>Ardea goliath</i>	0	0	0	0	0	0	0	0	0
Great White Egret	<i>Egretta alba</i>	0	0	0	0	0	0	0	0	0
Green-Backed Heron	<i>Butorides striatus</i>	0	0.17	0	0	0.33	0	0	0.17	0
Greenshank	<i>Tringa nebularia</i>	0	0	0	0	0	0	0	0	0
Grey Heron	<i>Ardea cinerea</i>	0	0	0	0	0	0	0	0	0
Grey-headed Gull	<i>Larus cirrocephalus</i>	1	0	0	0	0	0	1	0	0
Hadedda Ibis	<i>Bostrychia hagedash</i>	0	0	0	0	0	0	0.17	0	0
Hammerkop	<i>Scopus umbretta</i>	0	0.33	0	0.17	0	0.33	0	0.17	0
Knob-billed Duck	<i>Sarkidiornis melanotos</i>	0	0.17	0.33	0.17	0	9	0	0	0
Little Egret	<i>Egretta garzetta</i>	0.17	0	0	0	0	0	0.33	0	0
Longtoed Plover	<i>Vanellus crassirostris</i>	0	0	0	0	0	0	0	0	0
Marabou Stork	<i>Leptoptilos crumeniferus</i>	0	0	0	0	0	0	0	0	0
Open-billed Stork	<i>Anastomus lamelligerus</i>	0.5	0.33	0.67	0.17	0	0	0.17	0	0.33
Pied Kingfisher	<i>Ceryle rudis</i>	0	0.67	0.17	0.5	0	0.5	0	0	0.17
Reed Cormorant	<i>Phalacrocorax africanus</i>	0.17	0.5	0.33	0.17	0.5	0.83	0.17	0.33	0.5
Rock Pratincole	<i>Glareola nuchalis</i>	0	0.17	0	0	0.33	0	0	0.17	0
Sacred Ibis	<i>Threskiornis aethiopicus</i>	1	0	0	0	0	0	1	0	0
Saddle-billed Stork	<i>Ephippiorhynchus senegalensis</i>	0	0.17	0.33	0.17	0	0	0	0.33	0
Spurwing Goose	<i>Plectropterus gambensis</i>	0.33	0	0	0.17	0	0	0	0.17	0
Squacco Heron	<i>Ardeola ralloides</i>	0	0	0	0	0	0	0	0	0
Water Dikkop	<i>Burhinus vermiculatus</i>	0	0	0	0	0	0	0	0	0
White Stork	<i>Ciconia ciconia</i>	0	0	0	0	0	0	0	0	0
White-crowned Plover	<i>Vanellus albiceps</i>	0.5	0.33	0.67	0.33	0.17	0.5	0.5	0.33	0.67
White-faced Duck	<i>Charadrius marginatus</i>	0	0	0	0	0	0	0	0	0
White-fronted Plover	<i>Charadrius marginatus</i>	1	0	0	0	0	0	1	0	0
Woolly-necked Stork	<i>Ciconia episcopus</i>	0	0	0	0	0	0	0	0	0
Yellow-billed Stork	<i>Mycteria ibis</i>	0	0	0	0	0	0	0	0	0
<b>Cumulative number of species (S)</b>		17	15	12	12	9	9	16	12	10

Table 2/2. *Rynchops flavirostris* associate species and their respective reporting rates r<sub>yi</sub> and r<sub>zi</sub> (defined in text) at sampling sites during the sampling period in the lentic and lotic environs of the Zambezi Valley, Zimbabwe.



Common Name	Scientific Name	Site								
		M1 r <sub>yi</sub>	M2 r <sub>zi</sub>	M3 r <sub>zi</sub>	M4 r <sub>yi</sub>	M5 r <sub>zi</sub>	M6 r <sub>yi</sub>	M7 r <sub>zi</sub>	M8 r <sub>zi</sub>	M9 r <sub>yi</sub>
African Skimmer	<i>Rynchops flavirostris</i>	1	0	0	0.67	0	1	0	0	1
African Fish Eagle	<i>Haliaeetus vocifer</i>	0.5	0.67	0.33	0.67	0.17	0.33	0.5	0.67	0.67
African Jacana	<i>Actophilornis africanus</i>	0.5	0.67	0.33	0.17	0.67	0.33	0.17	0.5	0.5
African Pied Wagtail	<i>Motacilla aguimp</i>	0	0	0	0	0	0	0	0	0
African Spoonbill	<i>Platalea alba</i>	0.17	0.17	0.33	0.5	0.17	0.33	0.33	0	0.17
Black Smith Plover	<i>Vanellus armatus</i>	0.5	0.33	0.67	0.83	0.5	0.33	0.17	0.5	0.33
Black-headed Heron	<i>Ardea melanocephala</i>	0.33	0	0	0.17	0	0.17	0	0	0.33
Black-winged Stilt	<i>Himantopus himantopus</i>	0.5	0.33	0.67	0.83	0.5	0.33	0.17	0.5	0.33
Bohm's Spinetail	<i>Neafrapus boehmi</i>	0.17	0	0	0	0	0.17	0	0	0
Cattle Egret	<i>Bubulcus ibis</i>	1	0.33	0.83	1	0.67	1	0.83	0.5	1
Common Sand piper	<i>Actitis hypoleucos</i>	0.17	0	0.33	0	0	0.17	0.33	0	0.17
Darter	<i>Anhinga melanogaster</i>	0	0	0	0	0	0	0	0	0
Egyptian Goose	<i>Alopochen aegyptiacus</i>	1	0.83	0.33	1	0.33	1	0.17	0.33	1
Glossy Ibis	<i>Plegadis falcinellus</i>	1	0.83	0.17	1	0.33	1	0.33	0	1
Goliath Heron	<i>Ardea goliath</i>	0	0.17	0.33	0	0	0	0.17	0	0
Great White Egret	<i>Egretta alba</i>	0.5	0.67	0.33	0	0	0.17	0	0.33	0.17
Green-Backed Heron	<i>Butorides striatus</i>	0	0	0	0	0	0	0	0	0
Greenshank	<i>Tringa nebularia</i>	0.17	0.33	0	0	0	0.17	0	0.33	0
Grey Heron	<i>Ardea cinerea</i>	0.17	0	0	0	0	0.33	0	0	0
Grey-headed Gull	<i>Larus cirrocephalus</i>	1	0.33	0.17	1	0.17	1	0.33	0.17	1
Hadeda Ibis	<i>Bostrychia hagedash</i>	0.17	0	0.33	0	0	0.17	0	0	0.33
Hammerkop	<i>Scopus umbretta</i>	0	0.17	0.33	0	0	0	0.33	0.17	0
Knob-billed Duck	<i>Sarkidiornis melanotos</i>	0	0	0	0	0	0	0	0	0
Little Egret	<i>Egretta garzetta</i>	0	0	0	0.33	0	0.17	0	0	0
Longtoed Plover	<i>Vanellus crassirostris</i>	0.33	0	0	0.17	0	0	0	0	0.33
Marabou Stork	<i>Leptoptilos crumeniferus</i>	0	0	0	0	0	0	0	0	0
Open-billed Stork	<i>Anastomus lamelligerus</i>	0.33	0	0	0.17	0	0.33	0	0	0
Pied Kingfisher	<i>Ceryle rudis</i>	0	0	0	0	0	0	0	0	0
Reed Cormorant	<i>Phalacrocorax africanus</i>	0.5	0.67	0.33	0.67	0.83	0.67	0.5	0.5	0.67
Rock Pratincole	<i>Glareola nuchalis</i>	0	0	0	0	0	0	0	0	0
Sacred Ibis	<i>Threskiornis aethiopicus</i>	1	0	0	1	0	0.5	0	0	0.67
Saddle-billed Stork	<i>Ephippiorhynchus senegalensis</i>	0.33	0	0	0.17	0	0	0	0	0.17
Spurwing Goose	<i>Plectropterus gambensis</i>	0	0	0	0	0.33	0	0.17	0	0
Squacco Heron	<i>Ardeola ralloides</i>	0.17	0	0	0.33	0	0.67	0	0	0.33
Water Dikkop	<i>Burhinus vermiculatus</i>	0	0.17	0.33	0.33	0.17	0.17	0	0	0.33
White Stork	<i>Ciconia ciconia</i>	0	0	0	0	0	0	0	0	0
White-crowned Plover	<i>Vanellus albiceps</i>	0.33	0.17	0	0.17	0.33	0	0.17	0.33	0.5
White-faced Duck	<i>Charadrius marginatus</i>	0.5	0	0	0.33	0	0.33	0	0	0.33
White-fronted Plover	<i>Charadrius marginatus</i>	1	0	0	1	0	1	0	0	1
Woolly-necked Stork	<i>Ciconia episcopus</i>	0.17	0	0	0.33	0	0.33	0	0	0.17
Yellow-billed Stork	<i>Mycteria ibis</i>	0.5	0.33	0.17	0.5	0.17	0.33	0.17	0.33	0.5
<b>Cumulative number of species (S)</b>		28	17	17	24	14	27	16	13	25

Table 2/3. *Rynchops flavirostris* associate species and their respective reporting rates r<sub>yi</sub> and r<sub>zi</sub> (defined in text) at sampling sites during the sampling period in the lentic and lotic environs of the Zambezi Valley, Zimbabwe.

Site	K4	K5	K6	K8	V1	V7	M1	M4	M6	M9
First count July 2014	14	12	13	15	9	10	21	19	20	19
Second count July 2014	14	13	12	13	9	9	18	18	17	17
First count July 2015	13	10	10	8	6	6	16	14	16	15
Second count July 2015	11	11	10	11	7	7	17	16	13	11
Mean ± SD	13±1.41	11.5±1.29	11.3±1.5	11.8±2.99	7.8±1.5	8±1.83	18±2.16	16.8±2.22	16.5±2.89	15.5±3.42
First count August 2014	16	13	15	12	9	10	22	20	19	20
Second count August 2014	15	14	13	16	8	9	23	18	17	19
First count August 2015	12	10	12	10	8	8	21	16	13	15
Second count August 2015	10	9	11	11	7	8	20	17	15	13
Mean ± SD	13.3±2.75	11.5±2.38	12.8±1.7	12.3±2.63	8±0.82	8.8±0.96	21.5±1.29	18±2.16	16±2.58	16.8±3.3
First count October 2014	20	16	17	19	12	16	28	24	27	25
Second count October 2014	18	15	16	19	9	9	27	22	23	21
First count October 2015	18	13	16	17	7	11	25	20	21	20
Second count October 2015	17	13	15	18	10	8	23	21	20	20
Mean ± SD	18.3±1.25	14.3±1.5	16±0.8	18.3±0.96	9.5±2.08	6±8.57	25.8±2.22	21.8±1.71	22.8±3.1	21.5±2.38

Table 3. Avian associate species richness (S), mean ± SD at sandbars occupied by *Rynchops flavirostris* in Lake Kariba (K4, K5, K6 and K9), and along the Zambezi River upstream of Lake Kariba (VI and V7) and downstream of Lake Kariba (M1, M4, M6, and M9).

### Estimating Potential Habitat Risk

Potential habitat risk for *R. flavirostris* was assessed from sandbars on the basis of potential risk from anthropogenic and natural factors. A 100 m lengthwise protocol, with standard width of 15 m from water mark on either side of the middle of the sandbar, was used to quantify risk from boat traffic, human traffic, as well as presence and activity of crocodiles, Nile monitors, herbivores and derelict gillnets at sampling sites. The protocol assumed an extended zone of risk influence of 10 m outside the species perching territory. Habitat Risk Indices ( $R_i$ ) at sampling sites were derived from Habitat Risk Ratios ( $H_{r1}$ ) defined by Anthropogenic Risk Ratio

( $H_A$ ) and Natural Risk Ratio ( $H_N$ ).  $H_A$  and  $H_N$  for each sampling site were derived by summing the proportional contributions of individual Habitat Risk Ratios for each risk component as follows:

$$H_A = H_{r1} + H_{r2} + H_{r3} + H_{r4}; \text{ and}$$

$$H_N = H_{r5} + H_{r6} + H_{r7} + H_{r8} + H_{r9} + H_{r10} + H_{r11} + H_{r12}$$

Where  $H_{r1}$  = likelihood of presence of people at sampling site during the entire sampling period;  $H_{r2}$  = likelihood of presence of boats at sampling site during the entire sampling period;  $H_{r3}$  = likelihood of presence of derelict fishing nets at sampling site during the entire sampling period;  $H_{r4}$  = likelihood of encountering entangled birds by derelict fishing

nets at sampling site during the entire sampling period;  $H_{r5}$  = likelihood of encountering crocodiles at sampling site during the entire sampling period;  $H_{r6}$  = likelihood of encountering Nile monitors at sampling site during the entire sampling period;  $H_{r7}$  = likelihood of encountering active predation of *R. flavirostris* by crocodiles at sampling site during the entire sampling period;  $H_{r8}$  = likelihood of encountering active predation of *R. flavirostris* by Nile monitors at sampling site during the entire sampling period;  $H_{r9}$  = likelihood of encountering elephants at sampling site during the entire sampling period;  $H_{r10}$  = likelihood of encountering hippopotami at sampling site during the entire sampling period;  $H_{r11}$  = likelihood of encountering buffalos at sampling site during the entire sampling period; and  $H_{r12}$  = likelihood of observing trembled nests by herbivores at sampling site during the entire sampling period.

Habitat Risk Index ( $R_i$ ) for each sampling site was then defined by the joint effect of habitat risk from anthropogenic factors and natural factors, and was arrived at by multiplying  $H_A$  and  $H_N$  for each sampling site, followed by normalising the values by dividing each by the highest to get  $R_i$  ranging between 0 and 1 as follows:

$$R_i = (H_{Ai})(H_{Ni})/f$$

Where  $R_i$  = Habitat Risk Index for sampling site  $i$ ;  $H_{Ai}$  = Anthropogenic Risk Ratio at sampling site  $i$ ;  $H_{Ni}$  = Natural Risk Ratio at sampling site  $i$ ; and  $f$  = highest product of  $H_{Ai}$  and  $H_{Ni}$  among the sampling sites.

### Estimating Food Abundance

Estimation of food abundance for *R. flavirostris* was conducted only in Lake Kariba along Kariba Town shoreline. Due to risks associated with seine net fishing in large rivers no estimates on food abundances for *R. flavirostris* along the Zambezi River channel both upstream and downstream of the lake were conducted. Presence of hippopotami and crocodiles compromised safety along the Zambezi River. Estimation of Food Abundance (F) for *R. flavirostris* along Kariba Town Shoreline was carried out in August of 2014 and in 2015. Seine net fishing was conducted using the encircling manoeuvre to estimate food abundance at sites occupied

and those unoccupied by *R. flavirostris* along the shoreline. Three catches were conducted at each sampling site. The first catch was conducted at the midpoint of the sandbar, and the other two some 100 m away from the first position, on either side of the midpoint along the shoreline. Fish caught in the three catches were combined to form a composite sample, identified to species level, and their lengths measured to the nearest cm using a tape measure. For each catch, radius of the circle was measured in metres using GPS, and the surface area ( $m^2$ ) for the catch was calculated using the formula of a circle ( $\pi r^2$ ).

*R. flavirostris* feeds on non-cichlids 6 cm long or less (Coppinger et al., 1988). Mean catch of non-cichlids 6 cm long or less  $m^{-2}$  was used to describe food abundance for *R. flavirostris* at each sampling site.

### Developing habitat suitability criteria for *Rynchops flavirostris*

Development of species habitat suitability criteria has been done in numerous studies but there has been no clear consensus on a single standard method (Jowett, 2002). In this study, monthly variable data for dominant substrate, soil moisture level, soil temperature, Habitat Risk Index ( $R_i$ ) and food abundance were categorised and used to derive habitat suitability criteria for *R. flavirostris* within the three sections of the Zambezi Valley. Habitat suitability functions were derived from measures of strength of selection for a particular habitat category as defined by Heath et al. (2015). Preference Ratios ( $Z_a$ ) for individual habitat categories were calculated and used to develop habitat suitability criteria for *R. flavirostris* in the three sections of the Zambezi Valley. Preference ratios were computed by dividing mean abundance of *R. flavirostris* encountered in a given habitat category by mean abundance of the species in all habitat categories in relation to sampling effort within the study area.  $Z_a$  measured species preference levels of particular habitat condition in relation to sampling effort as follows:

$$Z_a = (\bar{a}/\bar{A})/(S_a/\sum S_{aj})$$

Where  $Z_a$  = Preference ratio for habitat condition  $a$ ;  $\bar{a}$  = average abundance of *R. flavirostris*

within habitat category  $a$ ; and  $\bar{A}$  = average abundance of the species in all habitat categories;  $S_a$  = number of samples in category  $a$ ;  $\sum S_{aj}$  = total number of samples in all categories.

Habitat Preference ratios were then normalised by dividing them with the largest  $Z_a$  value to get Habitat Suitability Indices ( $Y_a$ ) ranging between 0 and 1. Optimum range of a habitat condition was therefore assigned a weighting factor of 1, and the least suitable ranges assumed values near zero. To express habitat suitability functions, function fitting models were performed on habitat variables and correlations were considered significant at the 0.05 level.

## RESULTS

### *Distribution and breeding status of Rynchops flavirostris*

*Rynchops flavirostris* was recorded and its breeding sites observed in Lake Kariba and upstream and downstream of the lake (Fig. 1). Although no nesting behaviour and/or nesting scraps were observed with incubating eggs during the entire sampling period, flocks of *R. flavirostris* with their young were observed in the upstream and downstream of the lake. This suggested that the species was breeding in the three sections of the Zambezi valley. In Lake Kariba, a single nest with two unfledged chicks was recorded in August 2015, indicating resumption of breeding by *R. flavirostris* in the Kariba area. However, no nesting grounds were observed within the lentic and lotic habitats of the valley throughout the sampling period.

*Rynchops flavirostris* was observed on four of the nine sandbars sampled along Kariba Town shoreline (Fig. 1), where the species occupied sandbars with predominantly silty or sandy substrate. Within the lake environs the species occupied sandbars with high avian species richness (Table 2), and moderate to high levels of risk (Figs. 15–17). Flock sizes ranged between 9 and 34 within the Lake Kariba environs (Table 1), with highest flock sizes recorded at sites with food availability greater than 0.15 fish/m<sup>2</sup> (Figs. 24, 25).

In October 2014, two fledged juveniles were observed standing in shallow water with adults on the lake shoreline at Site K6. Further observations of

juveniles were made at site K6 in August 2014, where three fledged juveniles were also observed resting with adult birds within a distance of less than 5 m from the water mark. In August 2015, two unfledged chicks were observed at Site K9 in damp sand some 9.6 m away from the water edge.

In upstream habitat, within the lotic environs of the Zambezi Valley, *R. flavirostris* was observed on two of the nine sandbars sampled (Fig. 1; Table 1), where it also occupied sandbars with predominantly silty or predominantly sandy substrate. In the upstream habitat *R. flavirostris* also occupied sandbars with high avian species richness (Table 2). However, contrary to the lake environs, the species preferred sandbars of low risk levels within the lotic habitat, upstream of Lake Kariba (Figs. 15–17).

Flock size ranged between 2 and 28 within the upstream habitat (Table 1). Five fledged juveniles were observed upstream in October 2014 on sampling site V7. The juveniles were resting with adult birds on the silty sandbar along the edges of the river within a distance of less than 5 m from the water.

In downstream environs *R. flavirostris* was observed on four of the nine sandbars sampled with flock size ranging between 8 and 26. The species also occupied sandbars with predominantly silty or predominantly sandy substrate with high associate avian species richness (Table 2). The species also showed selective preference of low risk levels within the lotic environs of the Zambezi River downstream of Lake Kariba (Figs. 15–17).

Breeding was observed only at one site (M6) out of the nine sites sampled (Table 1) downstream of Lake Kariba. Three fledged juveniles were observed at Site M6 resting with adult birds within a distance of less than 5 m from the water mark in October 2015.

### *Rynchops flavirostris avian species association*

Common avian associate species of *R. flavirostris* in both the lentic and lotic environs of the Zambezi Valley were Cattle Egret *Bubulcus ibis* Linnaeus, 1758, Egyptian Goose *Alopochen aegyptiacus* (Linnaeus, 1758), Glossy Ibis *Plegadis falcinellus* (Linnaeus, 1758), Grey-headed Gull *Larus cirrocephalus* Vieillot 1818, Sacred Ibis *Threskiornis aethiopicus* Latham, 1790 and White-fronted Plover *Charadrius marginatus* Vieillot 1818. These species were al-

Habitat Variable	Section	Month	Correlation Coefficient & function
Boat traffic	Kariba	July	*0.015 (polynomial)
Boat traffic	Kariba	August	*0.068 (polynomial)
Boat traffic	Kariba	October	*0.371 (polynomial)
Boat traffic	upstream	July	*0.126 (polynomial)
Boat traffic	upstream	August	not derived
Boat traffic	upstream	October	*0.029 (polynomial)
Boat traffic	downstream	July	*0.047 (polynomial)
Boat traffic	downstream	August	not derived
Boat traffic	downstream	October	not derived
Human traffic	Kariba	July	*0.148 (polynomial)
Human traffic	Kariba	August	*0.195 (polynomial)
Human traffic	Kariba	October	*0.074 (polynomial)
Human traffic	upstream	July	*0.037 (polynomial)
Human traffic	upstream	August	*0.126 (polynomial)
Human traffic	upstream	October	*0.059 (polynomial)
Human traffic	downstream	July	*0.036 (polynomial)
Human traffic	downstream	August	*0.037 (polynomial)
Human traffic	downstream	October	*0.035 (polynomial)
Derelict gillnets	Kariba	July	*0.160 (polynomial)
Derelict gillnets	Kariba	August	*0.2519 (polynomial)
Derelict gillnets	Kariba	October	*0.104 (polynomial)
Derelict gillnets	upstream	July	not derived
Derelict gillnets	upstream	August	not derived
Derelict gillnets	upstream	October	not derived
Derelict gillnets	downstream	July	not derived
Derelict gillnets	downstream	August	not derived
Derelict gillnets	downstream	October	not derived
Elephant density	Kariba	July	*0.741 (polynomial)
Elephant density	Kariba	August	*0.246 (polynomial)
Elephant density	Kariba	October	*0.867 (polynomial)
Elephant density	upstream	July	*0.663 (polynomial)
Elephant density	upstream	August	*0.879 (polynomial)
Elephant density	upstream	October	*0.947 (polynomial)
Elephant density	downstream	July	0.116 (polynomial)
Elephant density	downstream	August	0.026 (polynomial)
Elephant density	downstream	October	*0.858 (polynomial)
Crocodile density	Kariba	July	0.046 (polynomial)
Crocodile density	Kariba	August	0.093 (polynomial)
Crocodile density	ariba	October	*0.132(polynomial)
Crocodile density	upstream	July	0.024 (polynomial)
Crocodile density	upstream	August	*0.124 (polynomial)
Crocodile density	upstream	October	0.05 (polynomial)
Crocodile density	downstream	July	0.024 (polynomial)
Crocodile density	downstream	August	0.016 (polynomial)
Crocodile density	downstream	October	0.032 (polynomial)
Hippopotamus density	Kariba	July	0.022 (linear)
Hippopotamus density	Kariba	August	0.025 (linear)
Hippopotamus density	Kariba	October	0.016 (linear)
Hippopotamus density	upstream	July	0.022 (linear)
Hippopotamus density	upstream	August	0.008 (linear)
Hippopotamus density	upstream	October	0.04 (linear)
Hippopotamus density	downstream	July	0.04 (linear)
Hippopotamus density	downstream	August	0.171 (linear)
Hippopotamus density	downstream	October	0.009 (linear)

Table 4. Function fitting and correlation coefficients ( $r^2$ ) of *Rynchops flavirostris* abundance and habitat variables at sampling sites in the lentic and lotic environs of the Zambezi Valley, Zimbabwe. \* $p < 0.05$ . Correlation is significant at the 0.05 level.  $r^2$  for habitat variable data with mean=0 were not derived.



Temperature (°C)	20-22	22-24	24-26	26-28	28-30	30-32	32-34	>34
Kariba July	1	0.2	0	0	0	0	0	0
Kariba Aug	0	0	0	0.2	1	0	0	0
Kariba Oct	0	0	0	0	0	1	0.5	0
Upstream Jul	1	0.5	0	0	0	0	0	0
Upstream Aug	0	0	0	0.3	1	0	0	0
Upstream Oct	0	0	0	0	0	1	0.9	0
Downstream Jul	0.3	0.1	1	0	0	0	0	0
Downstream Aug	0	0	0	0.2	1	0	0	0
Downstream Oct	0	0	0	0	0	1	0.2	0

Table 5. Substrate temperature suitability index for *Rynchops flavirostris* in the lotic and lentic environs of the Zambezi Valley, Zimbabwe.

ways in association with *R. flavirostris* during the sampling period and scored reporting rate  $r_{yi} = 1$  in all the three sections of the Zambezi Valley (Table 2).

Two sample t test indicated that there were significant differences ( $p < 0.05$ ) in avian associate species richness and species reporting rates between sites occupied by *R. flavirostris* and those unoccupied by *R. flavirostris* in all the three sections of the Zambezi Valley sampled in this study. Avian associate species richness and reporting rates were significantly higher at sandbars occupied by *R. flavirostris* than at sandbars unoccupied by *R. flavirostris* in all the three sections of the Zambezi Valley.

Number of avian associate species at sandbars occupied by *R. flavirostris* varied significantly ( $p < 0.05$ ; One-way ANOVA) among the three sections of the Zambezi Valley. Tukey's pair wise comparisons showed significant difference ( $p < 0.05$ ) in associate avian species richness between the lentic and lotic habitats. Lake Kariba had significantly higher avian associate species richness ( $p < 0.05$ ) than the upstream habitat. However, downstream habitat had significantly higher associate avian species richness ( $p < 0.05$ ) than the lake environs. During all sampling months, number of avian associate species (S) was highest downstream, followed by Lake Kariba.

The least S was observed in upstream habitat (Figs. 2–4, Table 3).

#### ***Rynchops flavirostris* Habitat Characteristics and Habitat Suitability Criteria**

The principal component analysis (PCA) results revealed that Principal Component 1 explained 43% of the observed variation on sampling sites, while Principal Component 2 explained 28.6% and Principal Component 3 explained 9% of the observed variation among the sampling sites. Principal component biplot showed that *R. flavirostris* abundance and habitat risk factors accounted for most of the variance among the sampling sites (Fig. 5).

#### **Habitat Risk**

Weak, but significant, correlations were observed between *R. flavirostris* abundance and most of the habitat risk variables in all the three sampling months (Table 4). Except for elephant density, negative correlations were observed between *R. flavirostris* abundance and each of the individual habitat risk factors (human traffic, boat traffic, derelict gillnets, hippopotamus density and crocodile density) in all the three sections of the Zambezi Valley. Positive correlation was observed between elephant density and *R. flavirostris* abundance in all



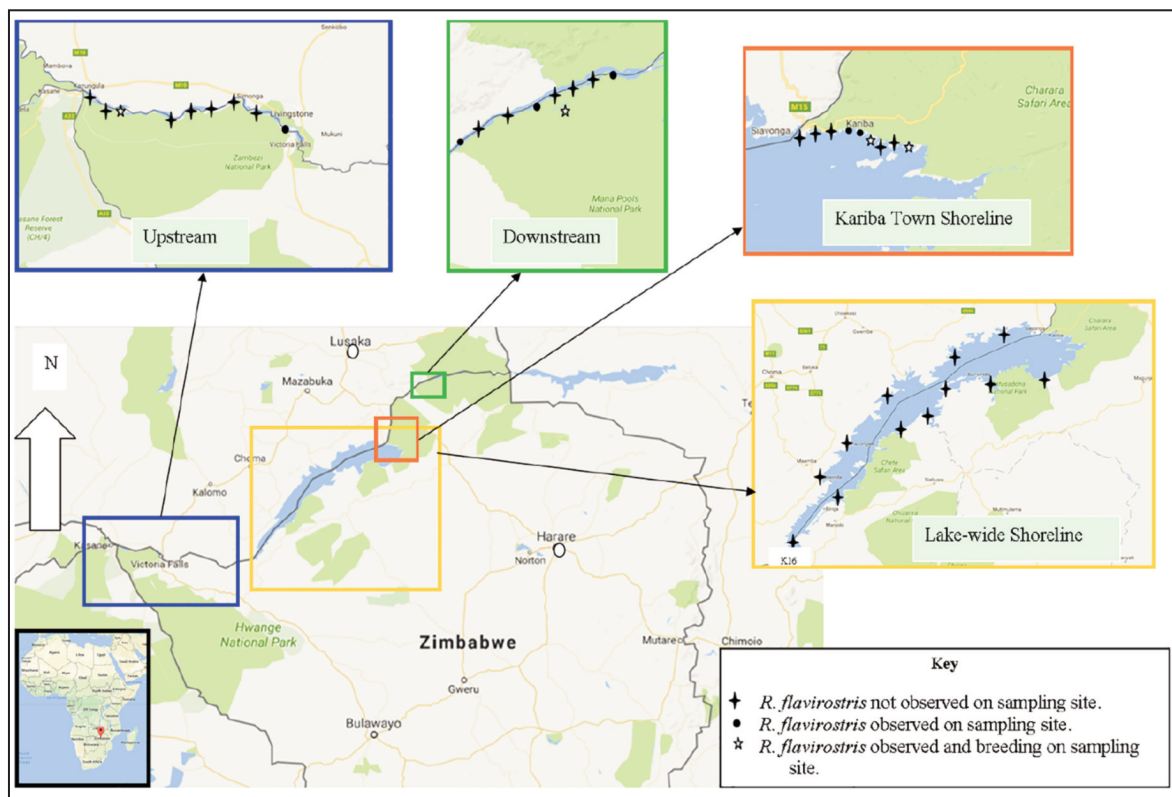


Figure 1. *Rynchops flavirostris* distributional pattern and breeding status at sampling sites in the lentic and lotic environs of the Zambezi Valley, Zimbabwe.

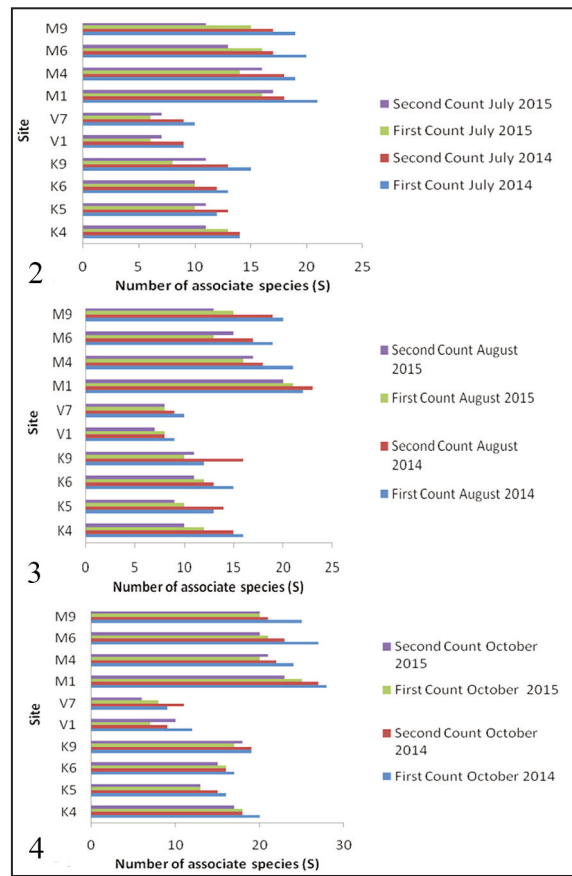
three sampling months in Lake Kariba, as well as in upstream and downstream habitats in October (Figs. 6–14). However, elephant density negatively correlated with *R. flavirostris* abundance in lotic habitats of the Zambezi Valley in July and August (Figs. 6–14).

*Rynchops flavirostris* tolerance to risk levels varied significantly ( $p < 0.05$ , One-way ANOVA) among the three sections of the Zambezi Valley. In Lake Kariba, the species showed highest preference to sandbars of moderate risk index ( $0.4 < R < 0.7$ ) and no preference to sandbars with low habitat risk index ( $R < 0.4$ ) (Figs. 15–17). Preference to sandbars of high habitat risk index ( $R > 0.7$ ) was low in Lake Kariba (Figs. 15–17). On the contrary, *R. flavirostris* showed preferential occupation of sandbars with low risk index ( $R < 0.4$ ) in habitats upstream and downstream of the lake on the Zambezi River (Figs. 15–17). The species showed no preference of sandbars of medium or high risk indices in upstream and downstream habitats along the lotic environs of the Zambezi River (Figs. 15–17).

Anthropogenic factors accounted for higher habitat risk at sampling sites in Lake Kariba than upstream and downstream of the lake. In Lake Kariba, risk contributed by anthropogenic factors (human traffic, boat traffic, presence of derelict gillnets, derelict gillnet activity) at sampling sites was significantly higher ( $p < 0.05$ ; two sample t test) than from natural factors (risk from crocodiles, elephants and hippopotami). On the contrary, risk from anthropogenic factors was significantly lower ( $p < 0.05$ ; two sample t test) than risk from natural factors within the lotic habitats of the Zambezi River both upstream and downstream of Lake Kariba. Among the natural risk factors, presence of elephants contributed most to habitat risk followed by presence of hippopotami at sampling sites in both lentic and lotic environs. Presence and action of crocodiles scored the least risk indices in all the three sections of the valley. Nile monitors, buffaloes, carnivory incidences, and nest trembling by herbivores were not encountered at any of the sampling sites within all the three sections.

Natural habitat risk factors (presence of elephants, hippopotami, crocodiles) were observed in both the lentic and lotic environs. One-way ANOVA showed that across the three months sampled, elephant density varied significantly ( $p < 0.05$ ) among the three sections of the valley. Tests for effects of interactions revealed that there was no statistically significant three way interaction between section of the Zambezi Valley, sampling month and elephant density on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). There was also no statistically significant interaction between elephant density and sampling month, as well as section of the Zambezi Valley and elephant density ( $p > 0.05$ ; Three-way ANOVA) on *R. flavirostris* abundance. Tukey's pair wise comparisons showed significant difference ( $p < 0.05$ ) in elephant density between the lentic environs of Lake Kariba and lotic environs of the Zambezi River. However, significant difference was not observed ( $p > 0.05$ ) in elephant density between upstream and downstream environs of the Zambezi Valley. Two sample t test also showed no significant differences ( $p > 0.05$ ) in elephant density between sites occupied by *R. flavirostris* and those unoccupied by the species in all the three sections of the Zambezi Valley throughout all the sampling months.

One-way ANOVA showed that across the three months sampled, hippopotamus density varied significantly ( $p < 0.05$ ) among the three sections of the valley. Tests for effects of interactions revealed that



Figures 2–4. Monthly variation of number of avian associate species (S) at sandbars occupied by *Rynchops flavirostris* in Lake Kariba (K4, K5, K6 and K9), in the Zambezi River upstream of Lake Kariba (V1 and V7) and in the Zambezi River downstream of Lake Kariba (M1, M4, M6, and M9) in Fig. 2 (July), Fig. 3 (August) and Fig. 4 (October).

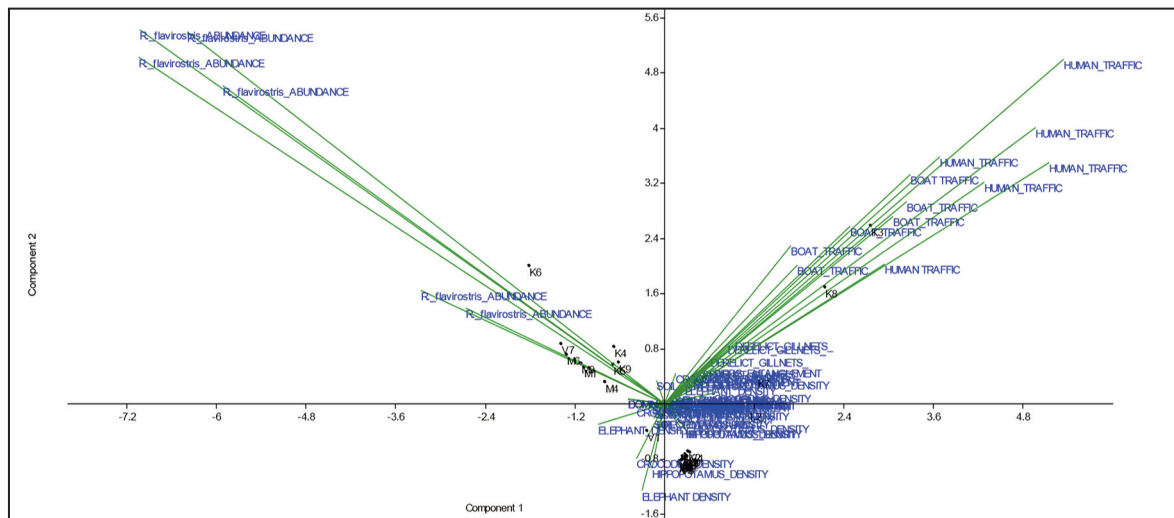
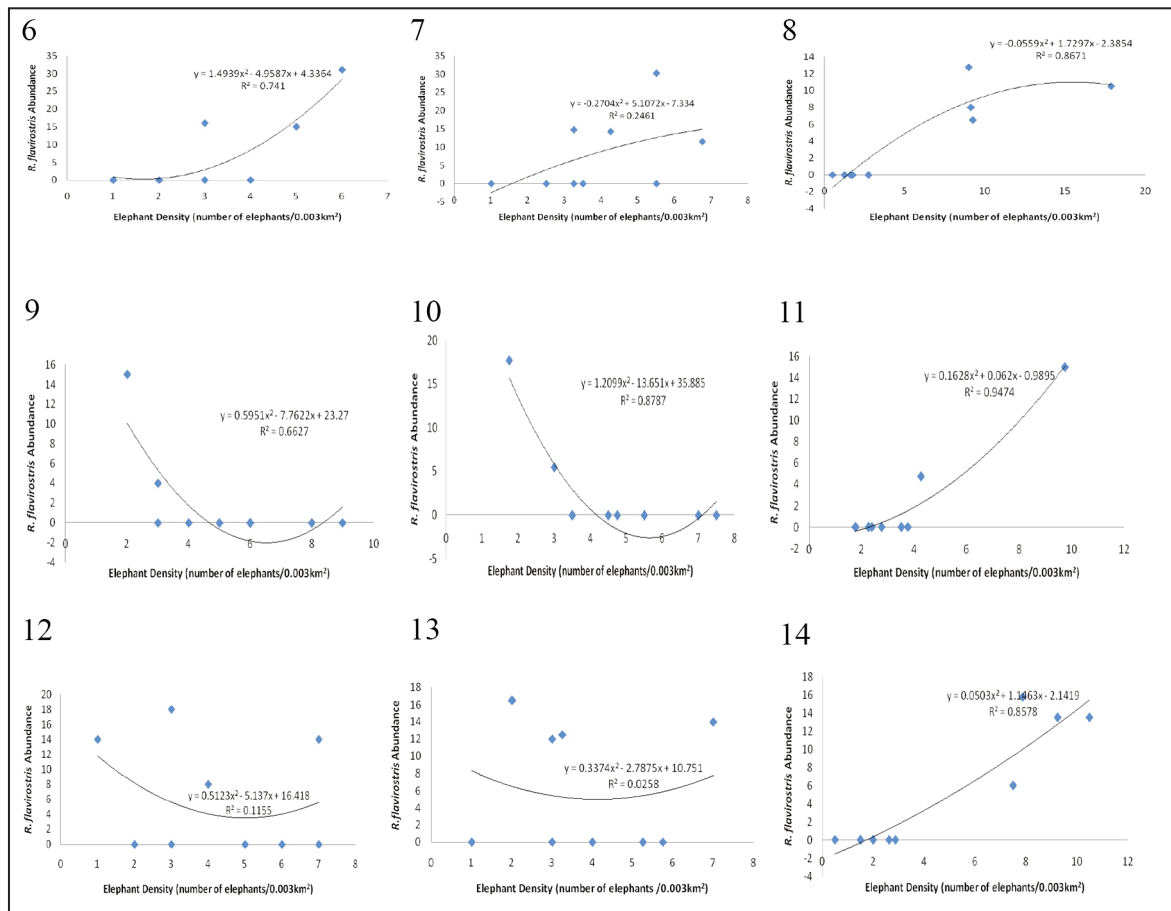


Figure 5. Principal Component Analysis (PCA) biplot of habitat factors on sandbars in Lake Kariba, and along the Zambezi River upstream and downstream of Lake Kariba.



Figures 6–14. Polynomial function fitting of the relationship between elephant density and *Rynchops flavirostris* abundance at sampling sites in the lentic and lotic habitats of the Zambezi Valley, Zimbabwe (Fig. 6: Lake Kariba sites in July; Fig. 7: Lake Kariba sites in August; Fig. 8: Lake Kariba sites in October; Fig. 9: Upstream sites in July; Fig. 10: upstream sites in August; Fig. 11: upstream sites in October; Fig. 12: downstream sites in July; Fig. 13: downstream sites in August; and Fig. 14: downstream sites in October).

there was no statistically significant three way interaction between section of the Zambezi Valley, sampling month and hippopotamus density on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). There was also no statistically significant interaction between hippopotamus density and sampling month, as well as between hippopotamus density and section of the Zambezi Valley ( $p > 0.05$ ; Three-way ANOVA). Tukey's pair wise comparisons showed significant difference ( $p < 0.05$ ) in hippopotamus density between Kariba and the upstream habitat. However, no significant difference was observed in hippopotamus density between Lake Kariba and downstream environs. Significant difference ( $p < 0.05$ ) in hippopotamus density was also observed between upstream and downstream habi-

tats. Two sample t test showed no significant differences ( $p > 0.05$ ) in hippopotamus density between sites occupied by *R. flavirostris* and those unoccupied by the species in all three sections of the Zambezi Valley throughout all the sampling months.

In all the sampling months, crocodile density did not vary significantly ( $p > 0.05$ ; One-way ANOVA) among the three sections of the Zambezi Valley. There was also no statistically significant three way interaction between crocodile density, section of the Zambezi Valley, and sampling month on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). No statistically significant interaction was observed between crocodile density and sampling month, as well as crocodile density and sec-

tion of the Zambezi Valley ( $p > 0.05$ ; Three-way ANOVA). Tukey's pair wise comparisons showed no significant difference ( $p > 0.05$ ) in crocodile density between habitats within the Zambezi Valley. Two sample t test also showed no significant differences ( $p > 0.05$ ) in crocodile density between sites occupied by *R. flavirostris* and those unoccupied by the species in all the three sections of the Zambezi Valley throughout all the sampling months.

Derelict gillnets were not encountered within the lotic habitats of the Zambezi Valley throughout the sampling period, but were present at all sampling sites in Lake Kariba. Derelict monofilament gillnets were observed at all sampling sites in Lake Kariba throughout the sampling period. These were associated with artisanal fishing that was prominent along the Kariba Town Shoreline. Significant strong positive correlation ( $r > 0.6$ ;  $p < 0.05$ ) was observed between human traffic and density of derelict gillnet within the lake. Significant strong positive correlation ( $r > 0.6$ ;  $p < 0.05$ ) was also observed between boat traffic and density of derelict gillnet within the lake. Two sample t test showed significant differences ( $p < 0.05$ ) in density of derelict gillnet between sites occupied by *R. flavirostris* and those unoccupied by the species in Lake Kariba across the sampling months. Sites occupied by *R. flavirostris* had significantly higher density of derelict gillnet and human traffic than those unoccupied by the species.

One-way ANOVA showed that across the three months sampled, human traffic varied significantly ( $p < 0.05$ ) among the three sections of the Zambezi Valley. Artisanal fishing was the most common human activity at sampling sites in Lake Kariba. On the contrary artisanal fishing was rare at sampling sites upstream and downstream of Lake Kariba. Scenic viewing by tourists was the most common human activities along the Zambezi River both in the upstream and downstream habitats of Lake Kariba. Tests for effects of interactions revealed absence of statistically significant three way interaction between human traffic, section of the Zambezi Valley, and sampling month on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). There was also no statistically significant interaction between human traffic and sampling month on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). However, significant effect on *R. flavirostris* abundance ( $p < 0.05$ ; Three-way

ANOVA) was observed on interaction between human traffic and section of the Zambezi Valley. Tukey's pair wise comparisons showed significant difference ( $p < 0.05$ ) in human traffic between the lentic and lotic environs of the Zambezi Valley. Lake Kariba had significantly higher human traffic compared to the lotic environs. However, human traffic did not vary significantly ( $p < 0.05$ ) between upstream and downstream environs of the Zambezi Valley. Two sample test also showed no significant differences ( $p > 0.05$ ) in human traffic between sites occupied by *R. flavirostris* and those unoccupied by the species in upstream and downstream environs throughout all sampling months. Significant differences ( $p < 0.05$ ) were observed in human traffic between sites occupied by *R. flavirostris* and those unoccupied by the species only in Lake Kariba throughout the sampling months.

Boat traffic also varied significantly ( $p < 0.05$ ; One-way ANOVA) among the three sections of the Zambezi Valley over the entire sampling period. Turkey's pair wise comparisons showed significant difference ( $p < 0.05$ ) in boat traffic between the lentic and lotic habitats. Lake Kariba had significantly higher boat traffic than the lotic environs of the Zambezi River, both upstream and downstream of the lake. However, no significant difference ( $p > 0.05$ ) was observed in boat traffic between upstream and downstream habitats. Tests for effects of interactions revealed absence of statistically significant three way interaction between boat traffic, section of the Zambezi Valley and sampling month on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). There was also no statistically significant interaction between boat traffic and sampling month, as well as boat traffic and section of the Zambezi Valley ( $p > 0.05$ ; Three-way ANOVA). Two sample t test showed no significant differences ( $p > 0.05$ ) in boat traffic between sites occupied by *R. flavirostris* and those unoccupied by the species in upstream and downstream habitats throughout all the sampling months. Boat traffic also showed no significant difference ( $p > 0.05$ ) between sites occupied by *R. flavirostris* and those unoccupied by the species in Kariba in July. However, significant differences ( $p < 0.05$ ) were observed in boat traffic between sites occupied by *R. flavirostris* and those unoccupied by the species in Lake Kariba environs in August and October.



### **Dominant Habitat Substrate**

Three types of dominant habitat substrate, namely predominantly sandy substrate, predominantly silty substrate, and predominantly sandy with pebbles substrate were observed at sandbars in Lake Kariba and along the Zambezi River channel. Predominantly sandy substrate had the highest frequency of occurrence at sampling sites (45% in Lake Kariba and in upstream habitats; 56% in down-stream habitats).

Significant difference ( $p < 0.05$ , One-way ANOVA) was observed on *R. flavirostris* abundance among the three types of dominant habitat substrate in all the three sections of the Zambezi Valley. In both the lentic and lotic habitats of the Zambezi Valley, *R. flavirostris* showed most preference of predominantly silty substrate at perching sandbars to the other two habitat substrates. In all the three months sampled, predominantly silty sandbars scored the highest suitability indices in Lake Kariba and in habitats upstream and downstream of the lake (Figs. 18–20). However, *R. flavirostris* also showed to a lesser extent some preferential selection of predominantly sandy substrate in all the three sections of the Zambezi Valley (Figs. 18–20). No *R. flavirostris* was observed on predominantly sandy with pebbles substrate in all the three sections of the Zambezi Valley (Figs. 18–20) implying no preference of this habitat within the entire valley.

Tests for effects of interaction revealed that there was no statistically significant three way interaction between section of the Zambezi Valley, sampling month and dominant substrate on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). However, significant effect of interactions on *R. flavirostris* abundance ( $p < 0.05$ ; Three-way ANOVA) were observed between sampling month and dominant substrate as well as between section of the Zambezi Valley and dominant substrate.

### **Substrate Moisture Content**

Significant difference ( $p < 0.05$ ; One-way ANOVA) was observed on *R. flavirostris* abundance among sites with different soil moisture content in all the three sections of the Zambezi Valley. Results revealed that *R. flavirostris* showed no preference of dry habitat substrate for perching in all

the three sections of the Zambezi Valley. The species preferred wet and/or moist substrate in all the three sections of the Zambezi Valley (Figs. 21–23).

There was no statistically significant three way interaction between section of the Zambezi Valley, sampling month and soil moisture content on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). No significant interaction was also observed between sampling month and soil moisture content on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). However, significant interaction effect on *R. flavirostris* abundance ( $p < 0.05$ ; Three-way ANOVA) was observed between section of the Zambezi Valley and soil moisture content. In Lake Kariba environs, the species showed most preference of moist habitat substrate for perching. However, the species also utilised wet habitat substrate within the lentic environs of Lake Kariba. A similar pattern was observed in upstream habitat where the species showed most preference to moist substrate. Preference levels for wet habitat substrate were low in upstream environs and varied across the three sampling months in the three sections of the Zambezi Valley (Figs. 21–23). On the contrary, although *R. flavirostris* utilised moist habitat substrate for perching downstream of Lake Kariba and upstream environs, the species showed highest preference of wet habitat substrate throughout the three sampling months downstream of the lake. Habitat suitability index was low ( $Y_a < 0.5$ ) for moist habitat substrate throughout the three sampling months in downstream habitat and was high ( $Y_a > 0.5$ ) for wet habitat substrate (Fig. 24).

### **Substrate Temperature**

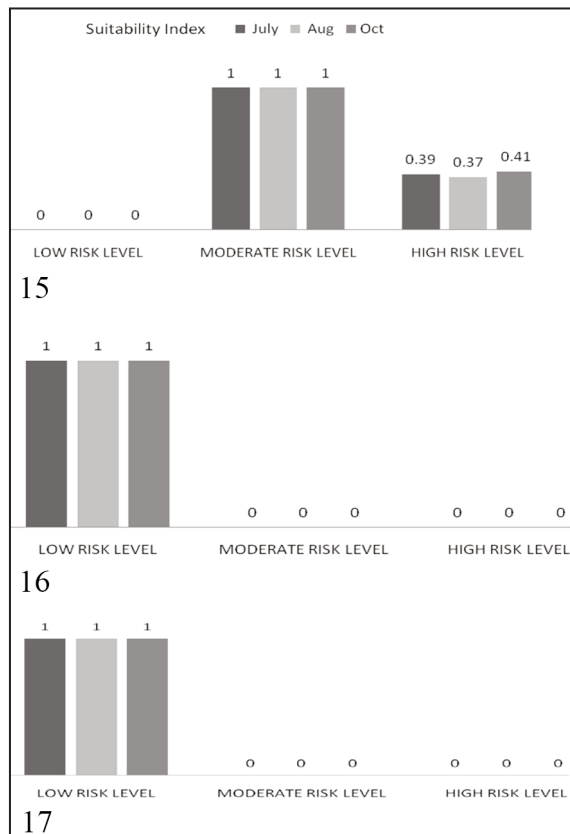
In all the three sections of the Zambezi Valley *R. flavirostris* displayed narrow preference of temperature ranges throughout the sampling months. No significant difference ( $p > 0.05$ ; One-way ANOVA) was observed in substrate temperature of sandbars occupied by *R. flavirostris* in all the three sections of the Zambezi Valley. In all the three sections of the Zambezi Valley, the species showed preference to substrate temperature below 26°C in July, with highest preference temperature index at the 22–24°C range in Lake Kariba and in upstream environs, and highest preference temperature index at the 24–26°C range in downstream environs of Lake Kariba. In August, *R. flavirostris* showed

preferential selection of the 26–30°C substrate temperature range in all the three section of the Zambezi Valley, with highest preference temperature index at the 28–30°C temperature range (Table 5). *R. flavirostris* preferentially selected 30–32°C temperature range in Lake Kariba and in habitats upstream and downstream of the lake. The species also showed tolerance to high substrate temperature range of 32–34°C in all the three sections of the Zambezi Valley during the month of October. However, *R. flavirostris* showed no preference of substrate temperatures >34°C in all the three sections of the Zambezi Valley (Table 5). Two sample t test showed no significant differences ( $p > 0.05$ ) in soil temperature between sites occupied by *R. flavirostris* and those unoccupied by the species in all the three sections of the Zambezi Valley throughout all the sampling months.

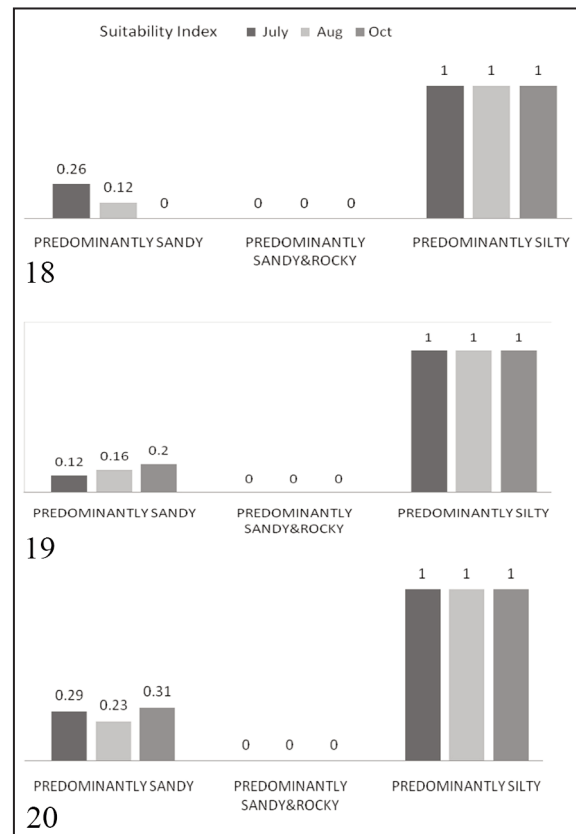
Tests for effects of interaction revealed that there was no statistically significant three way interaction between section of the Zambezi Valley, dominant substrate and soil temperature on *R. flavirostris* abundance ( $p > 0.05$ ; Three-way ANOVA). There was also no significant effect of interactions ( $p > 0.05$ ; Three-way ANOVA) observed between soil temperature and dominant substrate on *R. flavirostris* abundance within the Zambezi Valley.

**Food Availability**

In Lake Kariba, significant strong positive correlation was observed between food abundance and *R. flavirostris* abundance at sampling sites ( $r > 0.6$ ;  $p < 0.05$ ). *Rynchopus flavirostris* showed preferential selection of sandbars with high food abundance (sites K4, K5, K6 and K9). *R. flavirostris* preferen-



Figures 15–17. Habitat risk suitability criteria for *Rynchopus flavirostris* in the lotic and lentic environment of the Zambezi Valley Zimbabwe (Fig. 15: Kariba; Fig. 16: Upstream habitat; Fig. 17: Downstream habitat). See also in the text.



Figures 18–20. Dominant substrate suitability criteria for *Rynchopus flavirostris* in the lotic and lentic environment of the Zambezi Valley Zimbabwe (Fig. 18: Kariba; Fig. 19: Upstream habitat; Fig. 20: Downstream habitat). See also in the text.



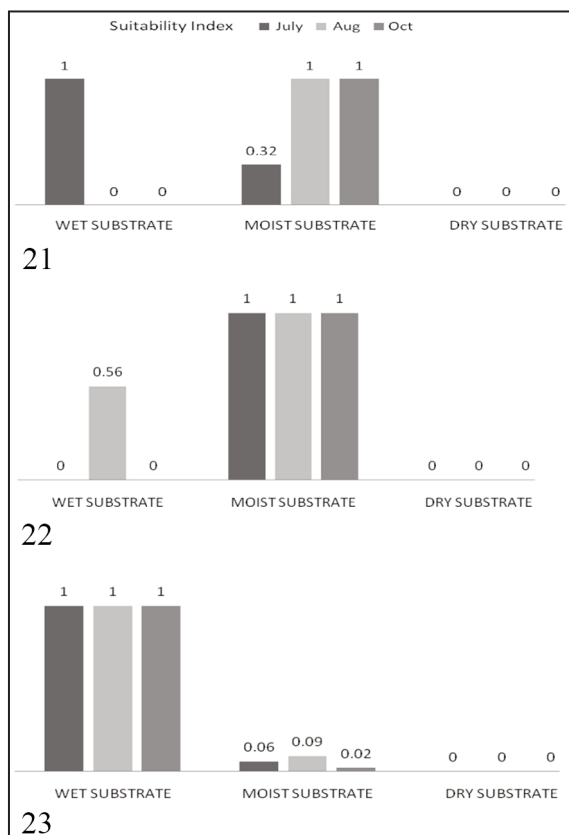
tially selected sandbars with food abundances greater than 0.15 fish/m<sup>2</sup> (Figs. 24, 25). Highest habitat suitability index was recorded at food abundance of 0.2–0.25 fish/m<sup>2</sup> category. Two sample t test showed significant differences ( $p < 0.05$ ) in food abundance between sites occupied by *R. flavirostris* and those unoccupied by the species.

Significant strong positive correlation ( $r > 0.6$ ;  $p < 0.05$ ) was also observed between food abundance for *R. flavirostris* and human traffic at sampling sites in Lake Kariba. Human traffic was high at sampling sites with high food abundance for *R. flavirostris* and low at sampling sites with low food abundance.

### DISCUSSION

Contrary to Coppinger et al. (1988) who re-

ported on likely absence of *R. flavirostris* within Lake Kariba some two decades after construction of the lake, contemporary investigations more than fifty years after construction of the lake revealed its presence and breeding in the lake and along the Zambezi River. These results are consistent with observations by Rost et al. (2006) who argued that although disturbance alters habitats and causes species extirpation, microenvironment modification over time may facilitate adaptation and gradual return of old species into the altered environment. Thus, the presence of *R. flavirostris* in Lake Kariba more than fifty years after construction of Lake Kariba could be attributed to re-establishment of suitable habitats for the species within the lentic environs. As highlighted by Donnelly (1984), changes in Kariba environs will continue to take place, facilitating changes in species composition in the lake



Figures 21–23. Substrate moisture level suitability criteria for *Rynchops flavirostris* in the lotic and lentic environment of the Zambezi Valley Zimbabwe (Fig. 21: Kariba; Fig. 22: Upstream habitat; Fig. 23: Downstream habitat). See also in the text.

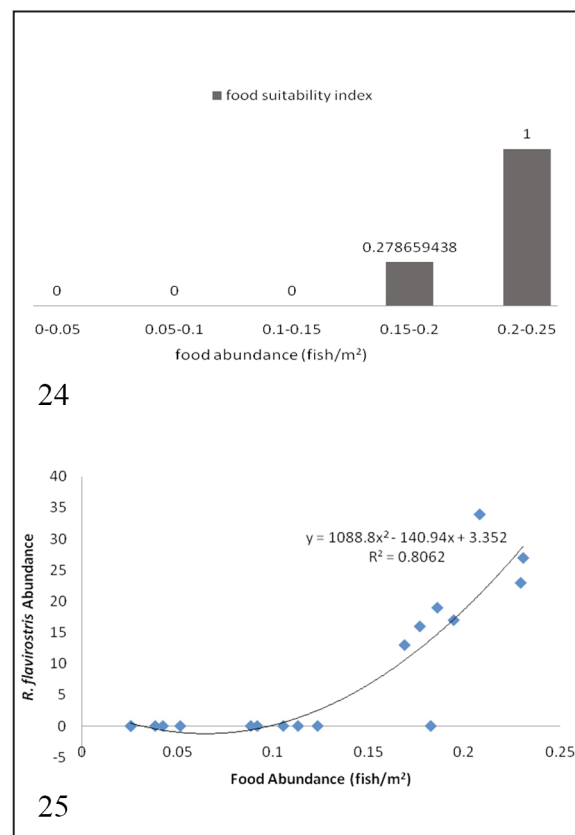


Figure 24. Food abundance suitability criteria for *Rynchops flavirostris* in Lake Kariba. Figure 25. Polynomial function fitting of *R. flavirostris* abundance across the range of food abundance at sampling sites in lentic habitat of Lake Kariba.

over time. However, contemporary distribution of *R. flavirostris* within the lake appears to be restricted to some sites along the shoreline. In the present study, *R. flavirostris* was only observed on selected sites along Kariba Town shoreline. Recent surveys were only conducted on Lake Kariba and associated islands. Thus the results may not conclusively ascertain a restricted distribution of the species within the lake.

Contemporary results reported cases of breeding of *R. flavirostris* within all three sections of the Zambezi Valley in Zimbabwe. However, only few isolated cases provided evidence of *R. flavirostris* reproduction within the three sections. This suggested that the species rarely breeds within the Zambezi valley, thus ascertaining its vulnerability in Zimbabwe. *R. flavirostris* breeds from July to October in Zimbabwe (Maclean, 1985). Thus, even if we failed to observe any nesting colonies during our surveys which coincided with the breeding season for the species, we at least should have observed a significant number of juveniles in all three sections of the Zambezi Valley. *R. flavirostris* has conspicuous nesting behavior, and failure to observe any active nesting colonies or nesting behavior indicates that breeding has not fully recovered for the species in Zimbabwe, more than fifty years after construction of Lake Kariba. Interestingly, breeding of *R. flavirostris* was also low upstream of Lake Kariba where we assumed that construction of the lake had no impact on the species habitat. In situations like this, development of habitat suitability criteria for *R. flavirostris* in different sections of the Zambezi Valley was crucial for a proper habitat assessment.

Several studies demonstrated that habitat suitability criteria may differ among different types of habitats (Jowett, 2002). This justifies our effort to develop site specific habitat suitability criteria for *R. flavirostris* within the three sections of Zambezi Valley, where the species was observed to specialise in lentic and lotic environs. Literature indicates that *R. flavirostris* breeds on broad rivers and lakes where it occupies large, dry sandbars that are largely free of vegetation (Urban et al., 1986; del Hoyo et al., 1996). Contemporary investigation showed that dominant substrate varied on sandbars in the Zambezi Valley, and this influenced habitat selection by *R. flavirostris* in the lotic and lentic environs of the valley. No comprehensive studies to develop

*R. flavirostris* substrate suitability criterion within the Zambezi Valley had ever been carried out prior to this study. Thus no baseline data were available for comparison. Our results showed that *R. flavirostris* preferentially selected predominantly silty and predominantly sandy substrates. Substrate that was predominantly sandy and rocky was not necessarily suitable for the species in all three sections of the Zambezi Valley. Significant interactions were observed between sampling month and dominant substrate as well as among sections of the Zambezi Valley and dominant substrate in influencing *R. flavirostris* abundance. This can be attributed to fluctuations in water levels in Lake Kariba, as well as fluctuations in river volume and river velocity on the Zambezi River during different sampling months. These fluctuations most likely influenced substrate deposition on sandbars in the aquatic habitats of the Zambezi Valley.

Just like all migratory species, *R. flavirostris* is an intra-African migrant whose habitat selection is influenced by habitat stability. As suggested by Pollard (1989), *R. flavirostris* can migrate and repeatedly occupy a stable sandbank for several years only to abandon the habitat when conditions become unfavourable. Changes in water level emanating from dam construction were suggested by several authors to be altering habitat quality for *R. flavirostris* in the Zambezi Valley (Pollard, 1989; Eriksson, 1990; Tree, 1988, 1992; Wood & Tree 1992). Lake Kariba, like most lentic habitats, is characterised by large fluctuations of water level (Eriksson, 1990). This influences substrate deposition at emergent sandbars and associated islands. The lake traps silt which normally ends up as sandbars that are utilised by *R. flavirostris* when water level recedes (Nugent, 1983, 1988). However, stability of these sandbars as habitat for sandbank nesters is influenced by cyclic fluctuations of water levels in Lake Kariba. Similarly, substrate deposition, formation of sandbars and stability of sandbars as suitable habitat for *R. flavirostris* along the Zambezi River are influenced by temporal and spatial fluctuations in river volume and velocity. Catchment input from the Zambezi River tributaries most likely influences river flow rate and formation of sandbars along the river upstream of Lake Kariba, while water flow controls at Kariba Dam wall influences volume and velocity of the Zambezi River downstream of the lake. Tree (1988) and Riddle

(2009) highlighted that Lake Kariba had significant effect on river velocity and structure of the Zambezi River bed downstream of the lake. Thus fluctuations in river volume and velocity upstream and downstream of the lake is likely to have significant impacts on trends in quantity and quality of sandbars as habitats for *R. flavirostris* along the Zambezi River channel. Comprehensive studies are necessary to verify this.

Our soil moisture level results contrasted with those of Urban et al. (1986) and del Hoyo et al. (1996) who stated that *R. flavirostris* occupies and breeds on dry sandbars. Our results were consistent with those of Tree (1992) who highlighted that *R. flavirostris* requires slightly damp substrate to maintain coolness around the eggs. Coppinger et al. (1988) reported on some breeding colonies situated on dry, moist and wet substrates. In the contemporary distribution, *R. flavirostris* showed preferential selection of wet and moist habitats. In the current study, no records were made of *R. flavirostris* occupying dry sandbars. In fact, within the three month sampling period of the present study, the species was frequently observed resting in water edges in both the lentic and lotic environs of the Zambezi Valley. Preference of wet substrate was highest downstream of the lake which happens to be the hottest among the three sections of the Zambezi Valley sampled. Standing in water and occupying wet and damp substrates could be the species behavioural adaptation to cope with the intense heat experienced in the Zambezi Valley. Behaviour plays an important role in thermoregulation among birds. Birds often stand in water to regulate their body temperature and to prevent hyperthermia in hot and dry environments.

*R. flavirostris* response to risk factors varied between the lentic and lotic habitats. In the lotic environs, the species preferentially selected sandbars of low risk index and completely avoided sandbars with moderate to high risk indices. This behaviour was expected given that habitat selection by organisms is also influenced by refuge from predation and other risks. Contrary to this, *R. flavirostris* occupied sandbars of moderate and high risk in Lake Kariba. The species was observed to occupy sandbars with high human traffic despite literature suggesting that the avian species is usually wary and unapproachable (Maclean, 1985). Contemporary results suggest *R. flavirostris* high tolerance for people in Lake Kariba. This association could be explained by variation in food availability at sand-

bars along the lake shoreline. Contemporary results showed that sandbars with high food abundance were also selected as human fishing grounds. Lake Kariba supports artisanal fishing, and it would be expected that fishing activities and human traffic would be high at sandbars with high fish production. In this case, optimum foraging behaviour of *R. flavirostris* in Lake Kariba was likely to be influenced by trade-offs between averting risk and starving or tolerance to human presence and gaining energy. Some degree of species tolerance to human presence was thus adopted by *R. flavirostris* in order to gain energy in the lentic environs. However, this tolerance most likely impacted negatively on breeding success of *R. flavirostris* in Lake Kariba.

In conclusion, the present study revealed that food availability, dominant substrate type, soil moisture level and habitat risk emanating from both natural and anthropogenic factors at sandbars were important determinants of vulnerability and adaptive capacity for *R. flavirostris* in the Zambezi Valley. We noted that Zambezi River volume and velocity upstream and downstream of Lake Kariba and standards of management of the lake flood gates could possibly be affecting the size and stability of suitable habitat for *R. flavirostris*. Selection of sandbars with varying habitat conditions by *R. flavirostris* highlighted the need for further research on factors influencing stability of sandbars in the entire Zambezi Valley from north western Zambia to the Indian Ocean. Such research is critical for generation of comprehensive data sets that are required for analysis of vulnerability and adaptive capacity of *R. flavirostris* in its Zambezi territory, and for proper formulation of conservation strategies for the species in the region.

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