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Pollution and Foraging Behavior of Pied Kingfisher *Ceryle rudis* in Bujumbura Bay of Lake Tanganyika, Burundi: Conservation Implications

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Abstract-- *Lake Tanganyika is threatened by overfishing, deforestation, climate change and water pollution. Very few studies have investigated the effects of pollution on semi-aquatic communities such as aquatic birds. This study investigates the effects of pollution on the foraging behavior of pied Kingfisher Ceryle rudis in the Bujumbura bay of Lake Tanganyika. We use data on foraging behavior of this bird species collected in 2002 as background and data collected over two periods during which we assessed change in water environmental parameters. The sampling site is located in the littoral zone next to the channel mouths that collect rainfall and wastewater from Bujumbura city. The results show a change in the number of observations of foraging pied kingfishers during the course of the day with a significantly lower number of observations in the morning than in the study carried out in 2002. The most frequent foraging behavior also changed from direct dives in 2002 to repeated hovering before diving in 2016. These changes could be accounted for by pollution as the water parameters data collected during the same time periods reveal an increase in turbidity while dissolved oxygen levels dropped. Increased turbidity may have caused reduction of visibility of these visual predatory birds. Attention should be given to measures toward alleviation of pollution of Lake Tanganyika for the conservation of semi-aquatic communities which are members of this deep and ancient lake ecosystem.*

Keywords— Lake Tanganyika, pied kingfisher, piscivorous, pollution, semi-aquatic communities.

I. INTRODUCTION

As one of Africa's great lakes, Lake Tanganyika is described as an extraordinary reservoir of freshwater biodiversity (Salzburger *et al*. 2014). It has more than two thousand species of aquatic plants and animals and over 1200 faunal species (vertebrates and invertebrates) recorded within only 10% of the explored lake shore (Patterson and Makin, 1998). Among animal groups, fish show extraordinary diversity; 289 endemic species makes up 89% of fish diversity of the lake (Snoeks, 2000). The lake is also a source of income, animal proteins and drinking water for an estimated 10 million inhabitants of its catchment area (Mölsä *et al*. 1999). However, Lake Tanganyika is threatened by overfishing, deforestation, climate change and water pollution (West 2001, Odada *et al*. 2003, Nkotagu 2008, Kashaigili and Majaliwa 2010, O'reilly *et al*. 2003, Verburga and Hecky 2009).

Numerous studies have documented the response of the lake communities to pollution, mainly sedimentation (Cohen *et al*. 1993; Alin *et al*. 1999; Eggermont and Verschuren 2003; Donohue *et al*. 2003; Cohen *et al*. 2005; Donohue and Irvine 2004; McIntyre *et al*. 2005; Marijnissen *et al*. 2009). However, these studies have focused on benthic and fish communities mostly in rocky habitats and took diversity and abundance into account. On the other hand, there are very few, if any studies that investigated the effect of pollution on other aquatic and semi-aquatic communities. Semi aquatic communities such as aquatic birds can be influenced by the same lacustrine environmental features which affect fish and invertebrates (Paszkowski and Tonn 2000). They are therefore part of the lake ecosystem although they are rarely integrated in studies of Lake Tanganyika ecosystem.

Located in the northeastern and most populated part of the lake, Bujumbura, the capital of Burundi, is the largest city around the lake. It is regarded as the main source of pollution for the lake (Yu *et al*. 2017). Several rivers and water channels discharging into the Bujumbura bay of Lake Tanganyika cross the city. Their contaminating effect is presumably increasing with growing urbanization and the lack of wastewater treatment facilities (Yu *et al*. 2017). This pollution affects the lake communities including semi-aquatic communities and its effect needs to be investigated.

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The pied kingfisher, *Ceryle rudis* Linné 1758, is an aquatic bird occurring in Bujumbura bay of Lake Tanganyika (Hakizimana *et al*. 2011). It mostly feeds on fish by diving. Their distribution and foraging can be influenced by environmental parameters such as turbidity and alkalinity (Reyer *et al*. 1988). Increased pollution with higher turbidity at Bujumbura bay may have affected pied kingfisher's foraging behavior and efficiency since turbidity causes light reduction and leads to reduced sight of this piscivorous predator (Abrahams and Kattenfeld 1997; Strod *et al*. 2004). In this study we investigate the effect of pollution on the foraging behavior of pied Kingfisher in the Bujumbura bay of Lake Tanganyika. We exploited data collected by Hakizimana *et al*. (2011) for background information. Data collected during these two studies times were used to assess change in water environmental parameters.

II. MATERIAL AND METHODS

2.1 Study area

Data was collected at former "Cercle Nautique" (-3.38996°, 29.35023°), a partially protected small bay in Bujumbura, Burundi the north-eastern part of Lake Tanganyika (Fig. 1). Bujumbura has a tropical Climate of Aw type according to Köppen-Gierger classification; the mean monthly temperature ranges from 28.6°C and 31.9°C and the mean monthly precipitation is between 0 and 136.4 mm. The rain season covers the period between October and April whereas the dry season, with monthly rainfall below 50 mm, runs from May to September.

The study site is located in the littoral zone of Lake Tanganyika next to the mouths of channels that collect rainfall and domestic water from Bujumbura City and the surrounding hills (Ndikumana *et al.* 2013). The water from these channels consists mainly of rainwater runoff, household and industrial effluent and sediment discharge as well as nutrients loads from deforested areas.

2.2 Data collection

This study is based on the comparison of our results with data collected by Hakizimana *et al*. (2011). Therefore, data have been collected partially following the methodology in Hakizimana *et al*. (2011). We recorded the number of observations of pied kingfishers, time of the observations and foraging behaviors namely single hovering, repeated hovering prior to dive and direct dive without hovering. Data was collected from 8 to 11 am and 3 to 5 pm in September and October 2016.

We used data on physico-chemical parameters to compare environmental conditions in 1988 (Gasana, unpublished data), the period of Hakizimana *et al*'s (2011) study and data collected during our study period in 2016 (Nduwayezu, unpublished data). Collected parameters are pH, dissolved oxygen and turbidity.

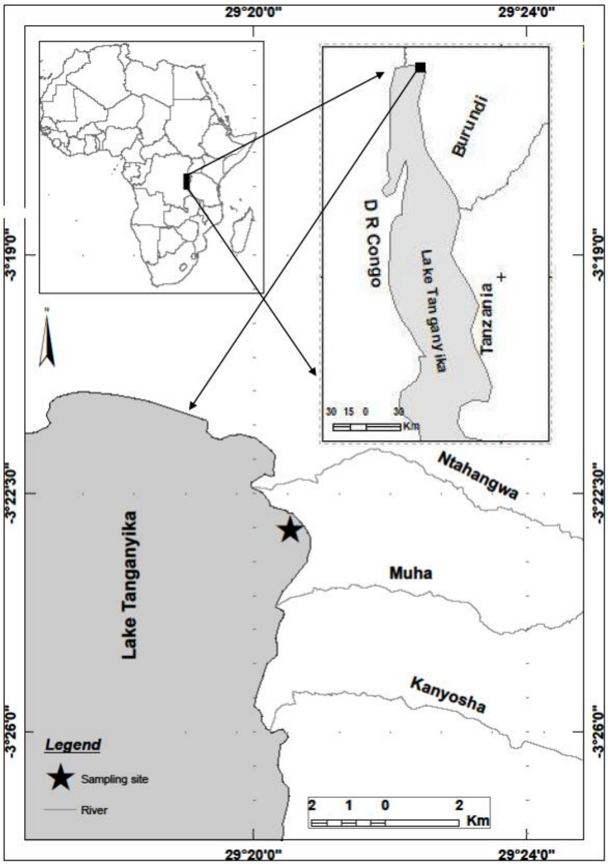


Figure 1: Study area showing the sampling site location

2.3 Data analysis

Statistical analyses were performed using ANOVA test in RStudio version 1.0.143 (R Development Core Team 2013) and graphs were generated using SigmaPlot version 11.0 (SigmaPlot, Systat Software Inc., Erkrath, Germany).

III. RESULTS

The number of observations of foraging kingfishers at the site during our study period tended to change in the course of the day with the highest values during midday and late in the afternoon. These values showed no remarkable change for the data from the 2002 study (Table 1, Fig. 2). Mean number of observations comparison from ANOVA show that there is a significant difference in all numbers of observations of foraging kingfishers at the site except for the time span from 15h-16h (Table 2). The number of observations was significantly higher for the 2002 study for the period between 8 am and 10 am in the morning.

Table.1: Number of observations for sampled hour spans during the study period at former "Cercle Nautique", Bujumbura in 2016

Date	8h-9h	9h-10h	10h-11h	15h-16h	16h-17h	Total
01 September	1	2	8	4	7	22
03 September	0	4	9	2	5	20
04 September	1	3	8	4	6	22
15 September	2	4	7	5	8	26
17 September	0	3	6	4	12	25
18 September	1	2	5	3	6	17
06 October	0	2	6	6	8	22
08 October	0	5	9	8	10	32
09 October	0	3	6	4	7	20
20 October	1	4	7	2	5	19
22 October	0	3	6	5	2	16
23 October	1	4	7	7	5	24
Average	**0.58**	**3.25**	**7**	**4.5**	**6.75**	**22.08**
Total	**7**	**39**	**84**	**54**	**81**	**265**

However, the mean number of daily observations was not significantly different between the two studies (Table 2). Results on comparison of relative importance of fishing behavior of foraging pied kingfishers show these aquatic birds performed more direct dives in 2002 than in 2016 whereas they performed single hovering and repeated hovering more often in 2016 than in 2002. We found direct diving to be its largely dominant behavior in 2002 with a double percentage compared to other fishing behaviors (Fig. 3).

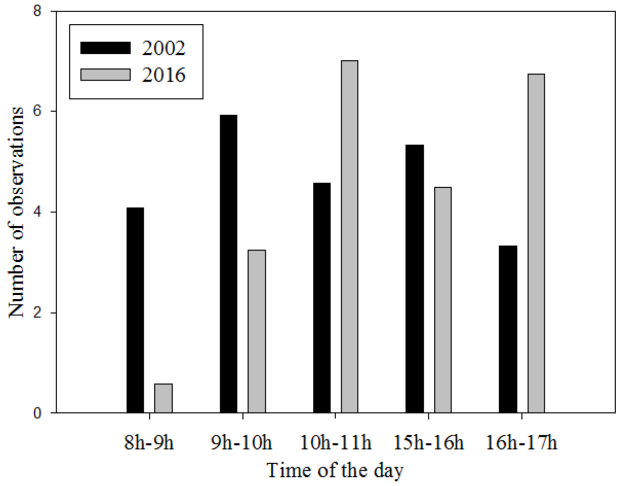


Fig.2: Comparison of observations of foraging kingfishers from 2002 and 2016 data for one-hour intervals along the day.

Tableau 2: ANOVA summary table of mean observations comparison for sampled hour span between results from 2002 and 2016.

	8h-9h	9h-10h	10-11h	15h-16h	16h-17h	Total observation
Mean sum of square	73.5	42.667	35.042	4.167	70.042	225.417
F	13.06	12.83	11.88	1.096	16.95	55.816
p-value	0.002*	0.002*	0.002*	0.307	0.0005*	0.313

*: significantly different

Comparison of the physico-chemical parameters of water in the study site between the two studies periods reveals major change in two measured water parameters. Turbidity has considerably increased while dissolved oxygen value has decreased from 1987 to 2016. On the other hand, between the same time periods pH value showed a slight decrease (Fig. 4).

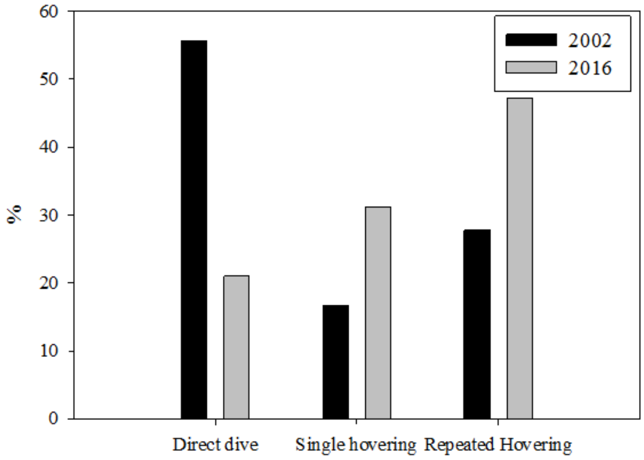
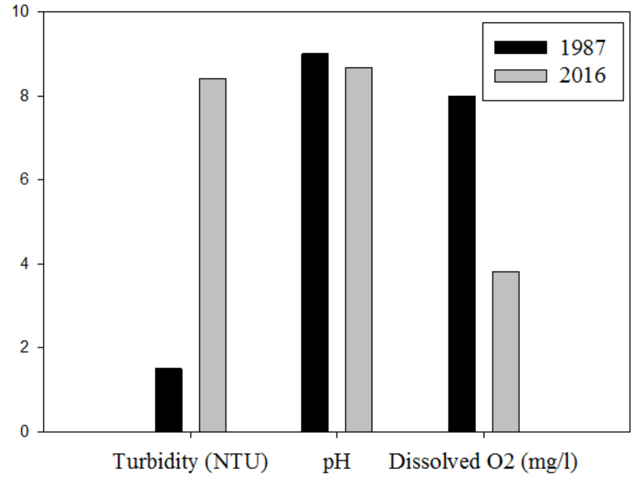


Fig.3: Comparison of fishing behavior ratio from data for observations from 2002 and 2016



Fig,4: Variation in water environmental parameters between 1987 (Gasana, unpublished data) and 2016 (Nduwayezu unpublished data).

IV. DISCUSSION

The number of observations of foraging kingfishers at the site seemed to change in the course of the day while there was no remarkable change in the number of observations for the study carried out in 2002. The number of observations was significantly lower in the morning compared to the results from the 2002 study and was significantly higher from 10 am and at the end of the afternoon. However, the difference in the number of observations between the two studies from 15 to 16 h was not significant. According to EPA (United States Environmental Protection Agency) guidance, turbidity is due to suspended matter (Kumari *et al*. 2014) and causes light attenuation leading to reduced visual range of sighted organisms (Vogel and Beauchamp 1999). Piscivorous birds are visual predators and their foraging efficiency is affected by turbidity (Abrahams and Kattenfeld 1997; Strod *et al*. 2004). The reduced number of observations of foraging pied kingfishers in our study site may have resulted from reduced visibility. This in turn could be due to increased turbidity as the number of observations of foraging kingfishers increased at midday when high sunlight contributed to more visibility. In fact, data on turbidity showed a remarkable increase from 1987 to 2016. However, the mean number of daily observations has not changed significantly between the two surveys, suggesting that pied kingfishers are still using this site for foraging but with an obvious shift in foraging timing.

Pied kingfishers fishing behavior differed from our study and the study carried out by Hakizimana *et al*. (2011) in 2002. The most frequent foraging behavior in 2002 was direct diving which is remarkably high in proportion compared to our survey where it is less frequent. The other foraging behaviors, single hovering and repeated hovering are less in proportion in 2002 but are dominant behaviors in 2016 with repeated hovering being the most frequent. Like the change in foraging timing, this change in foraging behavior could be explained by the increase in turbidity of the water at the study site. Hovering before diving is a behavior that allows the bird to hunt over large water surfaces and locate prey; thus hovering takes more time when water is more turbid. Previous studies have reported changes in the dominant foraging behavior of pied kingfishers from dives from perches to dives from hovering positions when the waters became turbid (Douthwaite 1976; Laudelout and Libois 2003).

Water parameter values measured in 1987 and 2016 have remarkably changed except pH. Turbidity has remarkably increased whereas dissolved oxygen has sensibly decreased during that period. This trend suggests that the studied littoral zone of Lake Tanganyika has undergone pollution. Our results are corroborated by a recent study that reported that rivers crossing Bujumbura city and inflowing Lake Tanganyika have become more contaminated over the past two decades (Yu *et al*. 2017). Although the nutrient loading depends on availability of nutrients in the drainage basin, Yu *et al*. (2017) argued that this change was primarily intensified by the human activity across the watershed. Another study conducted at our study site showed that there was a significant pollution by nutrient loads from water collectors discharging into the lake (Ndikumana *et al*. 2013).

Although the north-eastern part of Lake Tanganyika has been described the most polluted part of the lake, few studies have assessed the effect of this pollution on organisms. Our study shows that foraging behavior of pied kingfisher at littoral zone of Lake Tanganyika near Bujumbura city may have been affected by pollution. Foraging timing and behavior of pied kingfisher has changed in the past fourteen years but the site near

Bujumbura city is still used by this piscivorous species as a foraging site. Our study suggests that despite the detrimental effect of pollution on the ecology and behavior of pied kingfisher, the study site still offers a foraging habitat for this species. Therefore attention should be given to measures toward alleviation of pollution of Lake Tanganyika especially by anthropogenic activities from Bujumbura city not only for preservation of human health and aquatic animals but also for conservation of semi-aquatic communities which are members of Lake Tanganyika ecosystem. Since our study didn't take into account all the hour-intervals of the day due to logistic reasons, we recommend a more complete investigation and studies assessing the effects of pollution on communities of this deep and ancient lake.

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