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The feeding habit of the Cyprinidae *Rastrineobola argentea* in its new habitat, lakes Bulera and Ruhondo, two Rwandan lakes (Eastern Africa)

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ABSTRACT

Key-words: *feeding habits, invasive species,* Rastrineobola argentea*,* *great lakes, East Africa*

Rastrineobola argentea Pellegrin 1904, a small pelagic endemic cyprinid from lake Victoria was introduced into lake Bulera (Rwanda) in 1991 in order to develop a fishery. From there, it accidentally colonized lake Ruhondo. To study its biology in its new habitat, samples were collected in 2007 and size and the feeding habits of the fish were analyzed. *R. argentea* is smaller in lake Bulera (41.8 ± 6 mm) than in lake Ruhondo (mean total body length: 72.6 ± 15 mm). The mean total body length in lake Bulera is less than its size at the first maturity in lake Victoria (47 mm). Differences in size structure of fish between lakes Bulera and Ruhondo is attributed mainly to the food availability in the two lakes. In lake Bulera, the fish feeds on six food items with plant remnants dominant. In lake Ruhondo, *R. argentea* is a zooplanktivorous feeder like in lake Victoria. The dominant prey is a cladoceran species, *Daphnia* sp. which has not been observed in lake Bulera during the sampling period.

RÉSUMÉ

Habitude alimentaire de *Rastrineobola argentea* (Cyprinidae) dans son nouvel habitat, les lacs Bulera et Ruhondo, deux lacs du Rwanda (Afrique de l'Est)

Mots-clés : *habitudes alimentaires, espéces invasives, Rastrineobola argentea, grands lacs, Afrique de l'Est*

Rastrineobola argentea Pellegrin 1904, un petit cyprinidé pélagique, endémique du lac Victoria a été introduit dans le lac Bulera (Rwanda) en 1991 en vue d'y permettre le développement de la pêcherie. De là, il a accidentellement colonisé le lac Ruhondo. Dans le but d'étudier sa biologie dans son nouvel habitat, les échantillons pour l'analyse de sa taille et de son habitude alimentaire ont été collectés en 2007. Les résultats indiquent que ce poisson est plus petit dans le lac Bulera (41,8 ± 6 mm) que dans le lac Ruhondo (72,6 ± 15 mm). La longueur moyenne totale du corps dans le lac Bulera est plus petite que sa taille à la première maturité dans le lac Victoria (47 mm). La différence observée entre les deux lacs est attribuable principalement à la disponibilité alimentaire. En effet, dans le lac Bulera, six proies constituent la ration alimentaire de *R. argentea* avec une dominance de débris végétaux. Dans le lac Ruhondo par contre, *R. argentea* est zooplanctonophage comme au lac Victoria. La proie dominante est un cladocère, *Daphnia* sp., qui n'a pas été observé dans le lac Bulera durant la période d'échantillonnage.

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INTRODUCTION

Rastrineobola argentea Pellegrin 1904 is a small endemic zooplanktivorous cyprinid fish (maximum standard length of 9.0 cm in Lake Victoria; Eccles, 1992), from Lake Victoria, East Africa. In this lake, it is one of the most abundant fish species and of high commercial interest (*e.g.* Mwebaza-Ndawula, 1998; Wanink, 1999; Wanink and Witte, 2000).

To enhance the fish production and thus develop a flourishing fishery, *R. argentea* (locally called "Indagala"), was introduced into Lake Bulera (Rwanda) in 1991. Its fishery developed and, since 2006, this fish was curiously found in lake Ruhondo, supposing the later was accidentally colonized from Lake Bulera. The estimation of the exploitable stock of the fish in these lakes has not been achieved but catches from fishermen are estimated at about 40 t/year from Lake Bulera and about 20 t/year in lake Ruhondo.

Until now, nothing was known about the biology and ecology of this fish in its new habitat whereas its fishery is expected to become flourishing. Therefore, this study aims at (i) reporting a preliminary investigation on the feeding habits of *Rastrineobola argentea* in these two lakes, using the stomach contents analysis, and at (ii) understanding how this species copes to exploit different resources available in these ecosystems.

MATERIALS AND METHODS

> (I) SITES LOCATION AND SAMPLING PERIOD

Lake Bulera (1° 26′ S and 29° 46′ E) and lake Ruhondo (1° 30′ S and 29° 44′ E) are the two highest lakes of Rwanda, situated at 1862 and 1764 m a.s.l., respectively (Van den Bossche and Bernascek, 1990). The surface and catchments area of lake Bulera (51.8 and 563 km^2, respectively) are about twice of that of lake Ruhondo (26.6 and 198 km^2, respectively) (Figure 1). The water volume is also about four times higher in lake Bulera (4.5 km^3) than in lake Ruhondo (1 km^3). The two lakes differ also by their depths (max. 179 m in lake Bulera and 68 m in lake Ruhondo). These lakes are close to each other and connected. Lake Ruhondo is situated downstream lake Bulera, with a hydroelectric dam between the two.

Water and fish samples were collected in 5 stations from each lake, in both open and littoral waters, during a programme of scientific investigations aimed at a better understanding of their biotopes.

> (II) LIMNOLOGICAL VARIABLES MEASUREMENTS

Limnological variables [dissolved oxygen (DO), temperature, conductivity and pH] were measured using a Hydrolab DS4a multiprobe (Loveland, USA). Euphotic depth (Zeu, depth at which light is 1% of subsurface light) was derived from estimates of the vertical light attenuation coefficient from Secchi depth, using a coefficient (k = 1.34/(Secchi disk depth in m)) obtained by calibration with measurement of PAR (photosynthetic attenuation rate) attenuation with LICOR quantum sensors at each sampling site. Depth of the mixed layer (*Zm*) was estimated from the depth of the top of the thermocline, as shown by the temperature, oxygen and pH vertical profiles.

> (III) FISH SAMPLING

Fish samples for Length frequency distribution analysis were collected from catches of fishermen who operate night-time lift-nets in deep waters. Samples of large fish were caught with experimental gill-nets of various mesh sizes (10 to 30 mm knot to knot) in the shallow littoral zones. The maximum depth exploited by lift-nets is 15 to 20 m in these two lakes, but

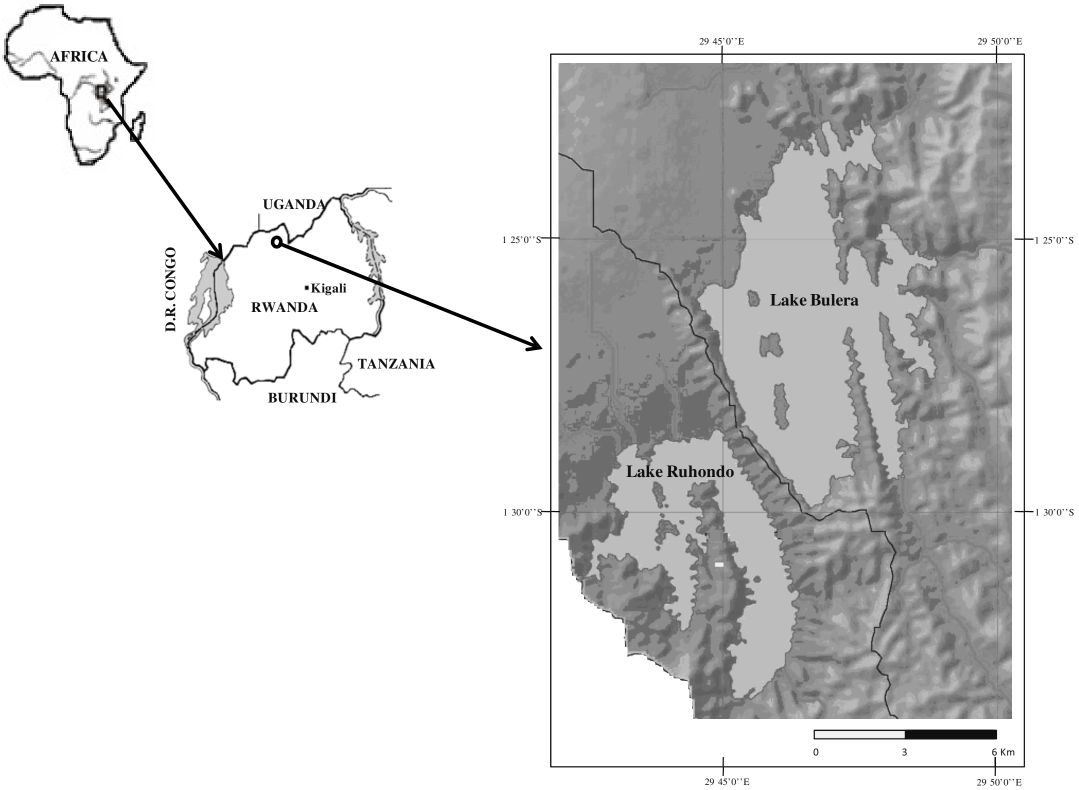

Figure 1
Geographic situation of lakes Bulera and Ruhondo.

echosounding measurements implemented during the study showed that *R. argentea* colonizes deeper waters in both lakes (about 30 m). The gill-nets were set in waters at < 4 m and left overnight, while the fishers cast their lift-net every 3 h, from around 10 p.m. until dawn. Stomach contents were taken from fish caught by both lift-nets and gill nets.

> *(IV) FISH BODY LENGTH MEASUREMENT AND STOMACH CONTENTS ANALYSIS*

The total fish body length (TL in mm) was measured using a Calipers square. A total of 921 and 357 *R. argentea* from lakes Bulera and Ruhondo, respectively, were measured. The data recorded were used for length frequency analysis using a one way ANOVA to compare the two sets of data distribution.

Only 100 and 83 stomachs, preserved in 5% buffer formalin from fish from lakes Bulera and Ruhondo, respectively, were examined under a binocular microscope in the laboratory. Depending on the extent of the digestion, the different items were determined with variable taxonomic accuracy. Occurrence index (*Io* %) and volumetric index (*Iv* %), using the point estimation method developed by Hynes (1950), were used to describe the diet of *R. argentea* and were combined into the synthetic Lauzanne's alimentary index Ia (Lauzanne, 1976).

In order to characterize the diet by identifying the importance of common prey items consumed by *R*. *argentea*, the contribution of each prey item to the total diet was quantified using its Ia percentage estimated as:

$$\%Ia_{\mathrm{i}} = \frac{IA_i}{\sum\limits_{i=1}^{n} IA_i} \times 100.$$

With $Ia = 0.01 \times Io \times Iv$ (Lauzanne, 1976) and n the number of different prey items (i).

RESULTS

> (I) LIMNOLOGICAL VARIABLES IN THE WATER COLUMN OF BULERA AND RUHONDO LAKES

Physicochemical parameters measured during the sampling period are presented in Table I. The mixed zone was 10 m in lake Bulera, four times deeper that of Ruhondo (2.5 m). Maximum measured water transparency was 5 m in lake Bulera and 2.1 m in lake Ruhondo while the euphotic depth was about twice (12 m) in Bulera than in Ruhondo (5.2 m). The water is less mineralized (conductivity: 102 $\mu S \cdot cm^{-1}$) in lake Bulera than in lake Ruhondo (253 $\mu S \cdot Cm^{-1}$). The mean dissolved oxygen concentration, temperature and pH in the mixed zone were, respectively, 6.3 $mg \cdot L^{-1}$ (about 80% of saturation), 21.1 °C and 9.7 in lake Bulera and 7.0 $mg \cdot L^{-1}$ (about 95% of saturation), 22.6 °C and 10.4 in Ruhondo. The oxygen depletion in the water column was observed at about 35 m depth in lake Bulera, and 8 m in Ruhondo (Figure 2).

Table I
Limnological variables (average values for Zm) and other physics parameters of lakes Bulera and Ruhondo (Van den Bossche and Bernascek, 1990, except (*): data collected during the present study).

Parameter	Lake Bulera	Lake Ruhondo
Catchments area (km^2)	563	198
Altitude (m)	1862	1764
Surface (km^2)	51.8	26.6
Volume (km^3)	4.5	1
Maximum depth (m)	179	68
Average depth (m)	80	40
Mixing zone: *Zm* (m) (*)	10	2.5
Temperature (°C) (*)	21.1	22.6
Dissolved oxygen ($mg \cdot L^{-1}$) (*)	6.3	7.0
Conductivity ($\mu S \cdot cm^{-1}$) (*)	102.1	253.0
Transparency Secchi (m) (*)	5.0	2.1
Euphotic depth: *Zeu* (m) (*)	12	5.2
pH (*)	9.7	10.4

> (II) SIZE FREQUENCIES DISTRIBUTIONS IN THE TWO LAKES

The difference in the average total body length of *R. argentea* (41.8 ± 6 mm in lake Bulera and 72.6 ± 15 mm in lake Ruhondo) was highly significant ($P < .0001$, Fisher PLSD) during the sampling period. The range of sizes from experimental fishing nets was from 25 to 65 mm in lake Bulera and from 34 to 99 mm in Lake Ruhondo (Figure 3). The size frequencies for the fish of the two lakes show also an important difference (Figure 3). During the sampling period, only one modal size class (between 40 and 44 mm) was observed in lake Bulera, while in Lake Ruhondo, two modal classes were evident, with the most abundant between 80 and 84 mm.

> (III) COMPOSITION OF THE DIET AND IMPORTANCE OF DIFFERENT PREYS FOR R. ARGENTEA IN LAKES BULERA AND RUHONDO

The composition of the diet of *R. argentea* is different in the two lakes (Table II). In lake Bulera, six categories of prey were found: phytoplankton (mainly Diatoms and *Microcystis* spp.), zooplankton (cyclopoid copepods), insects (larvae of *Chaoborus* spp.), scales of fish, nematods

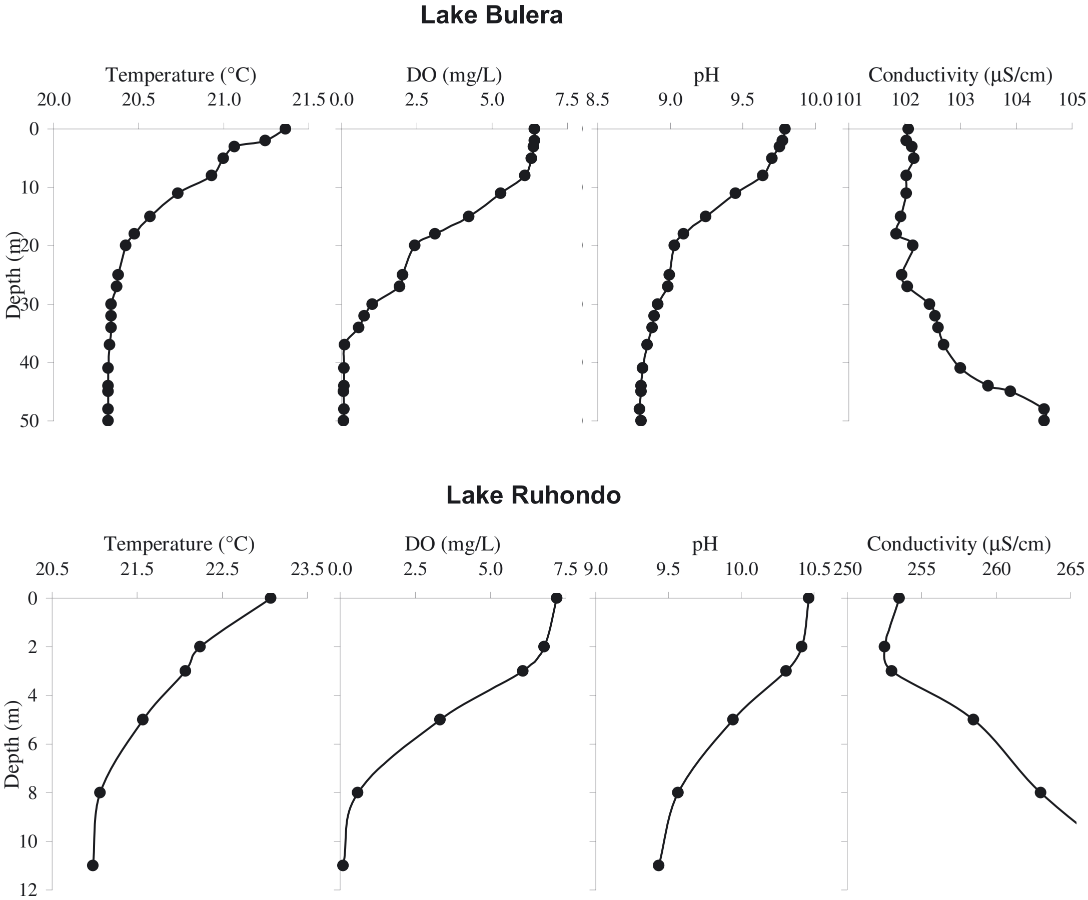

Figure 2
Temperature, DO, pH and water conductivity vertical profiles in the water column of lakes Bulera and Ruhondo.

and plant remnants. In lake Ruhondo, only three prey categories were found: Phytoplankton (mostly *Microcystis* spp.), zooplankton (cyclopoid copepods and a cladoceran *Daphnia* sp.) and insects (*Chaborus* larvae).

Quantitatively, the difference is also important (Table II). In lake Bulera, *R. argentea* showed a preference for plant remnants, with more than 70% of stomachs full of this item (*Io* = 72.7%). Only 27% of stomachs analysed contained zooplankton (*Io* = 27.3%) while phytoplankton (*Io* = 18.2%), scales of fish (*Io* = 18.2%) and nematods (9.1%) were observed in less than 20% of stomachs. In lake Ruhondo, *R. argentea* consumes mainly zooplankton. Practically all stomachs analysed contained *Daphnia* sp. (*Io* = 100%) and 45% contained copepods (*Io* = 45.5%). Phytoplankton was consumed by about 28% (*Io* = 27.8%) and the insects by only 9% of fishes analysed.

The relative contribution of the different preys to the total volume of the diet consumed by the fish in the two lakes reveals the same trend (Figure 4). In lake Bulera, plant remnants were the major volumetric proportion of the diet (*Iv* = 58%). Zooplankton and Phytoplankton constituted, respectively, 18.9% and 10% of the total volume of food consumed. Volumetric proportions of other prey items were negligible. In lake Ruhondo, zooplankton occupied at least 98% of the volume of the diet consumed by *R. argentea* (*Iv* = 98.4%).

When examining the alimentary Lauzanne's index (*Ia*) for each prey item, the difference in the feeding habit of the fish is very clear (Table II). In each lake, only one prey item was dominant while others were accessories.

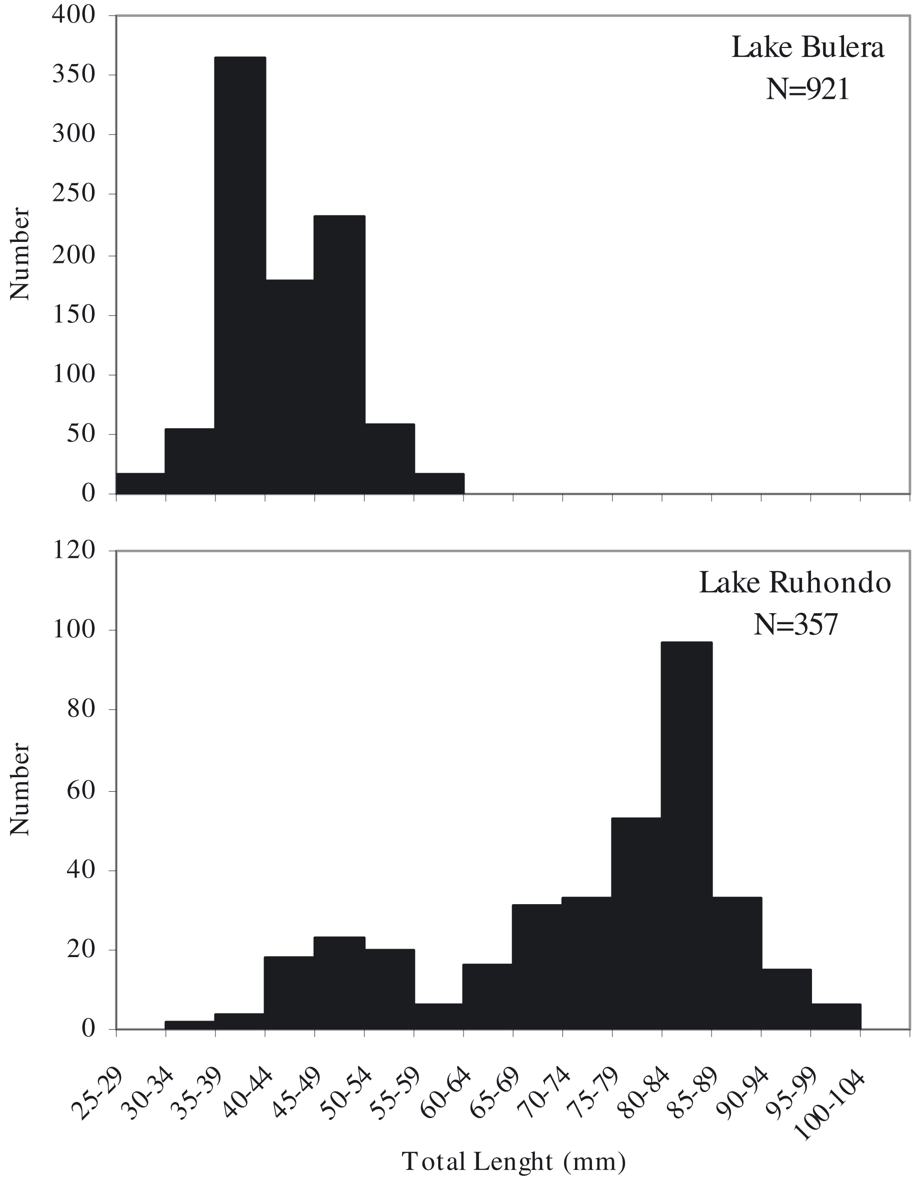

Figure 3
Length frequency distributions of R. argentea in lakes Bulera and Ruhondo as obtained from lift nets operated by fishermen.

DISCUSSION

The introduction of the zooplanktivorous cyprinid *R. argentea* in 1991 in lake Bulera aimed at exploiting a vacant pelagic ecological niche in order to enhance fish productivity. The accidental colonization of lake Ruhondo by *R. argentea* from lake Bulera is similar to that of Cahora Bassa by *Limnothrissa miodon* (Boulenger, 1906) from lake Kariba (Marshall, 1991).

It is known that introduction of exogenous species into ecosystems, which occurred quite often in the past (*e.g.* Lodge *et al.*, 1998; Pardo *et al.*, 2009), is now considered as one of the leading threats to the biodiversity of ecosystems (*e.g.* Sala *et al.*, 2000; Baxter *et al.*, 2004; Lasram and Mouillot, 2009; Leprieur *et al.*, 2009). For example, the Tanganyika sardine *L. miodon* was introduced into lake Kivu for the same reason *i.e.* to exploit the vacant pelagic feeding niche (empty niche hypothesis, Simberloff, 1995). At least within the context of the importance of fisheries for the local population, the introduction of *L. miodon* into lake

Table II
Relative importance of preys consumed by R. argentea in lakes Bulera and Ruhondo (Io = occurrence index in %, Iv = volumetric index in % and Ia (%) = the percentage of Lauzanne's index).

Food items	Lake Bulera			Lake Ruhondo		
	Io (%)	*Iv* (%)	*Ia* (%)	*Io* (%)	*Iv* (%)	*Ia* (%)
Phytoplankton	**18.2**	**10**	**3.6**	**27.8**	**0.8**	**0.2**
Diatoms	9.1	0.9	–	–	–	–
Microcystis spp.	9.1	9.1	–	27.3	0.8	–
Zooplankton	**27.3**	**18.9**	**9.6**	**100**	**98.4**	**97.7**
Copepods Cyclopoids	27.3	18.9	–	45.5	11.3	–
Daphnia sp.	–	–	–	100	87.1	–
Insects	**9.1**	**3.6**	**0.6**	**9.1**	**0.8**	**0.1**
Chaoborus larvae	9.1	3.6	–	9.1	0.8	–
Scales of fish	**18.2**	**6.8**	**2.4**	–	–	–
Nematods	**9.1**	**2.7**	**0.5**	–	–	–
Plants remnant (rubbish)	**72.7**	**58**	**83.0**	–	–	–

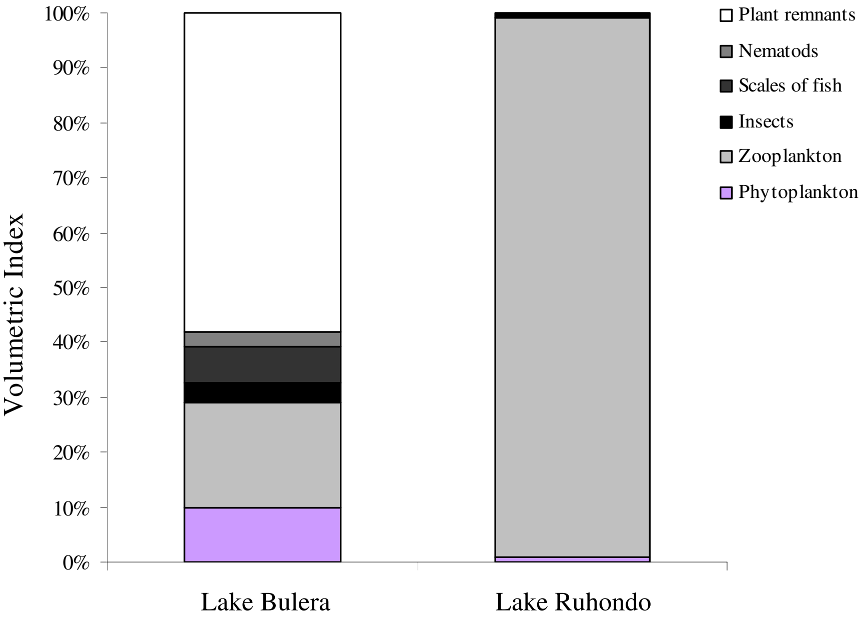

Figure 4
Volumetric importance of different prey items in the stomach contents of R. argentea in lakes Bulera and Ruhondo.

Kivu has been a success (Marshall, 1995; Roest, 1999). However, important changes in the food web were reported, particularly concerning zooplankton community: disappearance of large species, particularly *Daphnia curvirostris* Eylmann 1878 and decrease of the total zooplankton biomass (Dumont, 1986). Exotic species introductions are a global problem that deserves global attention and understanding (Halls and Mills, 2000).

The limnological variables suggest that lakes Bulera and Ruhondo differ in their productivity, leading to potential effects on the availability of resources exploited by *R. argentea* as, according to Hobæk *et al*. (2002), the lake area as well as its depth can influence its species richness. *Rastrineobola argentea* reaches larger sizes in lake Ruhondo than in lake Bulera. This may be due to the existence of better ecological conditions in lake Ruhondo. Regarding the temperature, Baensch and Riehl (1997) reported the range of 22 to 26 °C to be the preference for this species. During the sampling period, in the rainy season, the mean temperature in the *Zm* of lake Bulera was 21.1° C, which is lower to the minimal value of this range, compared to the situation in lake Ruhondo (22.6 °C). Given that in the region, the surface water temperature of large lakes decreases in the dry season (Isumbisho *et al*., 2006, Sarmento *et al*., 2006), it is likely that the temperature in lake Bulera remains lower (22 °C) all over the year, which is not suitable for *R. argentea.*

The reliance on plant remnants in the diet of *R. argentea* in lake Bulera is likely to be a suboptimal food. In lake Ruhondo, the diet is dominated by zooplankton as it is for *R. argentea* in lake Victoria (Wanink *et al*., 2002). Although *R. argentea* can also feed on shrimps, other plankton invertebrates and insects (Witte and de Winter, 1995), plant remnants have never been reported in its diet. In lake Ruhundo, large cladocerans, particularly *Daphina* spp., are the preferred food of *R. argentea* while the zooplankton analysis showed that biomass and abundance of copepods were greater than cladocerans ones in the two lakes (Isumbisho *et al*., unpublished).

The preferential consumption of large prey by opportunistic feeders, when they are available, is well known in freshwaters (*e.g.* Lazzaro, 1987; Marshall, 1993; Soranno *et al*., 1993). Cladocerans in general are often selected by visual predators because of their visibility and behaviour (Mookerji *et al*., 1998; Korinek, 1999). The preference of large body-size cladocerans by opportunistic visual feeders enhances their vulnerability and might even lead to their disappearance (Cochrane, 1984; Dumont, 1986; Marshall, 1991; Allison *et al*., 1996; Marshall, 1997; Mandima, 1999, 2000; Hoffman *et al*., 2001; Gliwicz, 2002; Isumbisho *et al*., 2004).

The size of *R. argentea* in lake Ruhondo, where it feeds predominantly on *Daphnia* sp., is about twice the size found in lake Bulera. Besides, its mean size (41.8 ± 6 mm; Max. 65 mm) in lake Bulera is less than its size at first maturity in lake Victoria (47 mm, according to Wandera, 1990) where it originates from. In lake Ruhondo, the fish reaches a total body length of 99 mm, which is more than in lake Victoria where individuals rarely reach a length greater than 90 mm (Eccles, 1992). This suggests that lake Ruhondo provides a very favorable habitat for *R. argentea*, whereas food resources in lake Bulera are poor.

The success of exotic species depends on their ability to establish and reproduce in invaded communities (Elton, 1958). The proficiency with which an invader avoids predators, pathogens and competitors determines, in part, its abundance and potential ecological impact on the community it has invaded (Coulas *et al*., 1998). Likewise, invasion theory predicts that invasions are most likely to succeed in systems that lack strong predators and in which native species diversity is low (Elton, 1958; Lodge, 1993). Different aspects of the biology and ecology of *R. argentea* in the two neighbouring lakes are to be investigated for a sustainable management of the fisheries. For example, in lake Victoria, the main predators of *R. argentea* are known (Wanink, 1999) but nothing about this aspect has been investigated in the two lakes of Rwanda. Finally, an important question is the reason of the absence of *Daphnia* in the samples collected from lake Bulera. The possibility that it was there before the *R. argentea* introduction remains to be considered. This should be investigated in further studies.

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