Aquatic Ecosystem Health and Management Society

Taylor & Francis
Taylor & Francis Group

The introduction of the endemic fish species, *Lamprichthys Tanganicanus* (Poeciliidae), from Lake Tanganyika into Lake Kivu: Possible causes and effects

Nshombo Muderhwa[1]* and Lushombo Matabaro[2]

[1]*Centre de Recherche en Hydrobiologie-CRH/Uvira/Section of Zoology, Department of Biology (Democratic Republic of Congo) via B.P. 254 Bujumbura, Burundi*

[2]*Université Officielle de Bukavu–UOB, Faculty of Science, Section of Hydrobiology, Department of Biology, Bukavu, Democratic Republic of Congo*

**Corresponding author: mnshombo@yahoo.fr*

In the present study we compared morphological characteristics of the endemic fish species Lamprichthys tanganicanus *(Poeciliidae) from Lake Tanganyika to those of similar fish samples which have appeared in Lake Kivu since 2006 to assess: (1) the taxonomic status of fish samples from Lake Kivu fisheries; (2) the food habits and fecundity of this fish and (3) the way by which this fish may have been introduced into this lake. Fish samples from Lake Kivu were collected in the bay of Bukavu and in Lake Tanganyika at Uvira. Metrics and meristics of* Lamprichthys tanganicanus *samples collected from Tanganyika were similar to those of fish collected in Lake Kivu indicating that recent fish samples caught together with* Limnothrissa miodon *in this lake indeed belong to* Lamprichthys tanganicanus*, a non-cichlid fish well known to be endemic to Lake Tanganyika. Genetic studies carried out on samples of this fish from both lakes support those conclusions. Moreover, mixed schools of* Lamprichthys tanganicanus *and* Limnothrissa miodon *fry were collected in the littoral zone of Lake Tanganyika suggesting that fry of the former species may have been accidentally introduced in Lake Kivu together with that of* Limnothrissa miodon *fifty years ago. Late appearance of this Tanganyikan non-cichlid species thirty years after* Limnothissa miodon *is discussed in relation to the biological characteristics of these two species.*

Keywords: morphology, mixed schools, late appearance

Introduction

The Great Lakes of Africa are inhabited by many cichlid and non cichlid fish species; cichlid species especially are among the best examples of explosive speciation (Fryer and Iles, 1972). Lake Tanganyika, the oldest lake in the African rift valley, is well known for its exceptional dimensions, its great age and its incredible biological diversity with a high percentage of endemic fish genera or species. Endemic fish species make up a high proportion of the fish fauna: 56% in the non-cichlids and 98% in the cichlids occupying diverse habitats like muddy, sandy or rocky bottoms in the littoral zone (Poll, 1953, 1956; Brichard, 1989; Coulter et al., 1991). The pelagic waters of this lake are inhabited by two endemic species of the clupeid family, *Stolothrissa tanganicae* and

Aquatic Ecosystem Health & Management, 13(2):203–213, 2010. Copyright © 2010 AEHMS. ISSN: 1463-4988 print / 1539-4077 online
DOI: 10.1080/14634981003800733

Limnothrissa miodon and their predators, *Lates mariae*, *L. angustifrons*, *L.microlepis* and *L. stappersii* (Poll, 1953; Coulter et al., 1991; Patterson and Makin, 1998).

Lake Kivu, situated 130 km north of Lake Tanganyika, is one of the smaller lakes of the East African lakes region and only 28 species are known from this lake, of which 19 are cichlids (Snoeks et al., 1997; De Vos et al., 2001; Worthington and Lowe-McConnell, 1994; Verheyen at al., 2003). The non-cichlids belong to four families: Clupeidae (one introduced species), Cyprinidae (five species), Amphiliidae (one species) and Clariidae (two species). Among the cichlids found in this lake, apart from the 15 endemic haplochromine species, *Oreochromis macrochir, Tilapia rendalli* and *Oreochromis leucosticus*, were introduced to this lake. The two former species, collected in 1979, probably escaped from fish ponds around Lake Kivu and the third species, which is also a result of an introduction into the lake, was first noticed in 1986. *Oreochromis niloticus* is the only autochthonous tilapia in this lake (Snoeks et al., 1997).

There have been a great many introductions of fishes to inland waters in Africa (Worthington and Lowe-McConnell, 1994) and most of those introductions were made with the hope of improving the fisheries, although this view still remains controversial (De Vos et al., 2001; Snoeks et al., 1997). *Limnothrissa miodon* (Clupeidae) was introduced from Lake Tanganyika to Lake Kivu in 1959 because of the absence of a zooplanktivorous fish in Lake Kivu to fill the apparent vacant niche and create a pelagic fishery similar to that of Lake Tanganyika (Capart, 1959; Collart, 1960; Hauser, 1996). The success of this introduction could not be evaluated before 1976 when an investigative mission found that the clupeid *Limnothrissa miodon* had colonized all waters of Lake Kivu, instead of the targeted clupeid *Stolothrissa tanganicae* (Frank, 1989).

The presence of an alien fish species in a lake is often noticed late, especially when it is not appearing in the catch. Although an intensive sampling programme was carried out between 1979 and 1988, no other alien species had been found in Lake Kivu (Snoeks at al., 1997). However, since 2006, an alien species was caught in commercial gill nets together with the pelagic clupeid *Limnothrissa miodon* around Lake Kivu. This fish is *Lamprichthys tanganicanus* (Poeciliidae), well known as an endemic species from Lake Tanganyika (Poll, 1953). Experimental fishing carried out between December 2006 and February 2007 in the Bay of Bukavu, at the southern end of Lake Kivu by the Laboratory of Zoology of the Centre de Recherche en Hydrobiologie/C.R.H.-Uvira and the Laboratory of Hydrobiology of the Université Officielle de Bukavu/UOB confirmed the presence of this fish species as yet unknown to the lake's ichthyofauna.

This study presents the results of metrics and meristics of *Lamprichthys tanganicanus* collected at Uvira in the littoral zone of Lake Tanganyika, and those collected with gill nets in the Bay of Bukavu in Lake Kivu. In order to identify the relationship between these two populations, this comparison was completed by a genetic analysis of fish samples from both lakes. Finally, three hypotheses are discussed to explain the presence and late appearance of this Tanganican non-cichlid fish in Lake Kivu based on the biological characteristics of *Lamprichthys tanganicanus* and *Limnothrissa miodon* in their original habitat in Lake Tanganyika.

Material and methods

Study sites

Lake Kivu was formed by volcanic eruptions in the late Pleistocene about 25,000–20,000 BP according to Beadle (1981), or 14,000–11,000 BP according to Pouclet (1978), which cut off the northward drainage in the Rift Valley (Hauser, 1996; Snoeks et al., 1997). The lake has a stable stratification and is permanently influenced by three factors: the relatively constant surface temperature (23.1°C to 24.5°C), the salinity (1.115 g l^{-1}) which increases with depth and the conductivity (1240 μS cm^{-1} at 20°C). The deep water is rich in potassium, methane and phosphorus, probably due to an inflow of warm saline water indicating some volcanic activity continuing to this day (Beadle, 1981; Hauser, 1996). This lake is distinguished from other great lakes of the East African Rift by the presence of great quantities of dissolved gas in its deep water, particularly methane, of which this lake is the largest natural reservoir on earth with an estimated volume of 63 billion cubic meters (Kaningini et al., 1999).

Lake Tanganyika which is the second deepest lake in the world (1470 m) has a surface temperature varying between 23.2°C and 27.3°C, a salinity (0.53 g l^{-1}) and a conductivity (560–610 μS cm^{-1} at 20°C) twice as low as that of Lake Kivu.

Fish sampling was carried out at Uvira at the northern end of Lake Tanganyika and in the Bay

of Bukavu, in the southern part of Lake Kivu. Fifty specimens of *Lamprichthys tanganicanus* (30 males and 20 females) between 107, 8 mm and 54, 5 mm standard length (SL) were sampled in Lake Kivu, Bay of Bukavu near the brewery between December 2006 and February 2007. This sampling site is a coastal rocky habitat of 2 m depth. All adult fish of *Lamprichthys tanganicanus* were collected with a gill net (1 cm mesh, measured between knots), while a hand net was used to collect juveniles and larvae which were hovering near the water surface under a shaded metallic structure. This artificial structure is apparently a spawning site of this species. A two hour observation with a diving mask in December 2006 showed the presence not only of different-sized *Lamprichthys tanganicanus*, but also of various species of the haplochromine group which were foraging near the rocky bottom. In Lake Tanganyika, 48 specimens of this species (26 males and 22 females) between 89.8 mm and 59.5 mm in standard length (SL) were caught at Uvira in the littoral zone at Action Kusaidia and Mulongwe. These sandy/rocky sites are characterized by the presence of *Phragmites mauritianus* reeds. A gill net of 1 cm mesh was also used for collecting adult fish and a special mosquito net for juveniles and larvae.

Each specimen was photographed and its colors were noted. All samples were preserved in 10% formalin and later transferred to 95.5% ethanol in the Laboratory of Zoology in the Centre de Recherche en Hydrobiologie (CRH-Uvira) and in the Universite Officíelle de Bukavu (UOB). For each fish, the metric and meristic characteristics were noted and a multivariate analysis (Principal Component Analysis) was done with the assistance of the Past programme. In addition, 60 tissue samples from the two lakes (12 males and 18 females for Lake Kivu and 24 males and 6 females for Lake Tanganyika) between 64.9–109.2 mm. standard length (SL) for males and 64.3–94.3 mm SL for females were sent to the molecular laboratory of the Department of Vertebrates of the Institut Royal des Sciences Naturelles in Belgium to examine the *Lamprichthys tanganicanus* samples from the two lakes genetically. Finally, to assess the moment of appearance of this fish in the catch, a survey was carried out between 2006 and 2007 among fishermen of Lake Kivu in: Bukavu, Minova, Sake and Goma for the Democratic Republic of Congo and Gisenyi, Kibuye and Cyangugu for Rwanda (Figure 1).

Results

Coloration of fish samples collected in Lake Kivu

The coloration of male and female individuals of *Lamprichthys tanganicanus* from Lake Kivu is similar to those found in Lake Tanganyika (for detailed description see Poll, 1953). Compared to males, females generally have a less conspicuous coloration with few blue spots only limited to the dorsal fin and with little yellow color on the fins (Figure 2).

Fish measurements in the two lakes

Forty eight samples of *Lamprichthys tanganicanus* (26 males and 22 females) from Lake Tanganyika and 50 from Lake Kivu were measured and used in a principal component analysis for 18 biometric characteristics (Tables 1A–D).

This analysis showed the existence of two main groups, composed of males and females from both lakes. Females sampled in Lake Kivu were in the same group as *L. tanganicanus* females from Lake Tanganyika. Similarly, males from Lake Kivu belong to the same group as the males from Lake Tanganyika (Figure 3). These results indicate that samples collected in both lakes are of the same species, which naturally only occurred in Lake Tanganyika. The sexual dimorphism observed mainly concerns the length of the anal fin base, which is greater in males than in females (33.8–38.8% vs 25.5–29.9% for Lake Tanganyika and 33.9–40.4% vs 25.7–29.5% for Lake Kivu) as shown in Tables 1A–D).

In addition, genetical analysis showed that the 12 examined tissue samples (6 for each lake) share the same sequence of the mitochondrial DNA (mtDNA) for 16s of rARN (Verheyen, pers.comm.). This indicates that the specimens from the two lakes form a single species *Lamprichthys tanganicanus* and confirms the conclusions from the analysis of metric characteristics. Females are smaller than males and their longer preanal distance is the only distinguishing morphological character between the sexes.

Fin ray and scale counts of *Lamprichthys tanganicanus* from both lakes

Five characteristic counts were performed on each individual: the numbers of dorsal, anal and

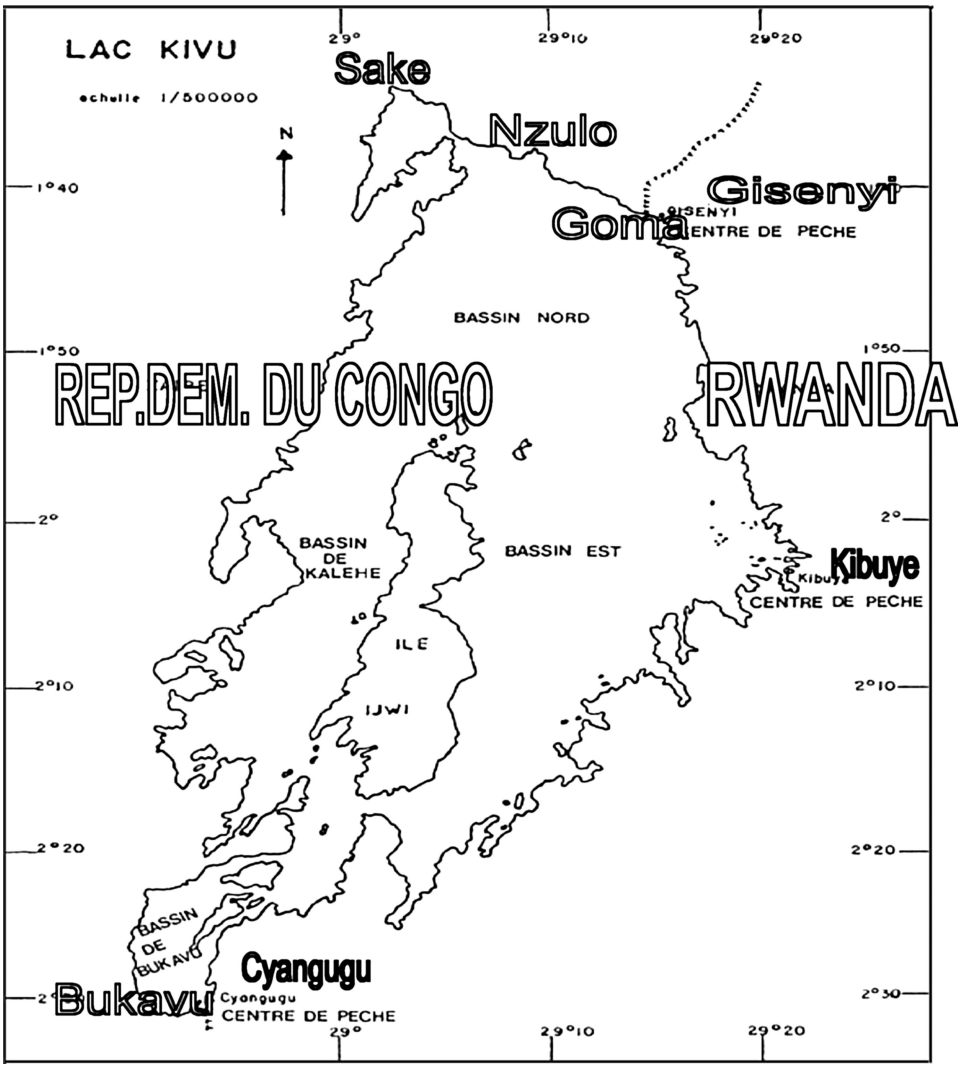

Figure 1. Visited fishing sites (Bukavu, Sake, Nzulo and Goma for Dem. Rep. of Congo and Gisenyi, Kibuye and Cyangugu for Rwanda) where *Lamprichthys tanganicanus* samples were found in Lake Kivu between 2006 and 2007.

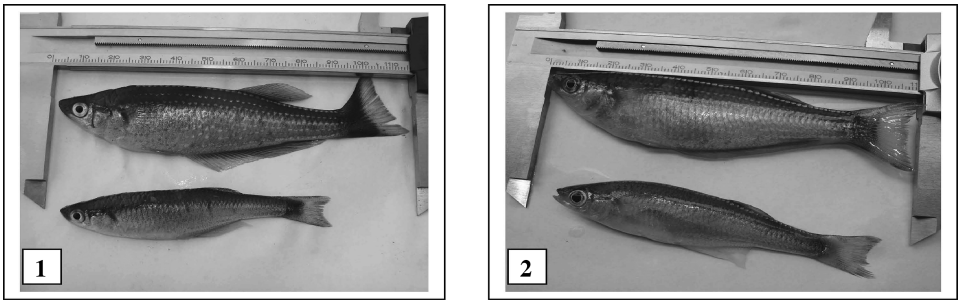

Figure 2. *Lamprichthys tanganicanus* adult male(top) and female (bottom) from lakes Kivu (1) and Tanganyika (2).

Table 1A. Measurements expressed as a percentage of *Lamprichthys tanganicanus* males from Lake Tanganyika (SD = Standard Deviation; Min = Minimum; Max = Maximum; Mn. = Mean; N = Number of samples examined; SL = Standard Length; TL = Total Length).

N		Min	Max	Mn ± SD
Standard Length (SL mm)	26	64.8	86.8	75.4 ± 5.85
Body Depth (%SL)	26	21.5	24.9	23.3 ± 0.80
Head Length (%SL)	26	19.0	22.5	21.8 ± 0.87
Head Width (%HL)	26	47.4	55.2	51.8 ± 2.21
Snout Length (%HL)	26	29.8	40.5	34.1 ± 2.14
Cheek depth (%HL)	26	11.2	16.8	14.4 ± 1.32
Eye Diameter (%HL)	26	32.5	44.8	39.8 ± 2.52
Interorbital Width (%HL)	26	37.6	50.0	45.3 ± 3.11
Dorsal Fin Base Length (%SL)	26	14.0	19.1	16.4 ± 1.14
Anal Fin Base Length (%SL)	26	33.1	38.8	35.6 ± 1.40
Preanal Distance (%SL)	26	40.8	45.9	43.1 ± 1.21
Prepelvic Distance (%SL)	26	29.3	33.4	31.7 ± 1.15
Pelvic Fin Length (%SL)	26	11.1	14.8	12.5 ± 0.89
Caudal Peduncle Length (%SL)	26	17.7	24.1	20.6 ± 1.39
Caudal Peduncle Height (%CPL)	26	45.9	58.9	52.4 ± 4.09
Caudal Peduncle Lobe Length (%SL)	26	20.7	25.2	22.8 ± 1.20
Pectoral Fin Base Length (%SL)	26	6.1	8.6	7.3 ± 0.58
Prepectoral Distance (%SL)	26	20.9	24.2	22.8 ± 0.86

Table 1B. Measurements expressed as a percentage of *Lamprichthys tanganicanus* females from Lake Tanganyika (SD = Standard Deviation; Min = Minimum; Max. = Maximum; Mn. = Mean; N = Number of samples examined; SL = Standard Length; TL = Total Length).

N		Min	Max	Mn ± SD
Standard Length (SL mm)	22	59.5	79.5	72.3 ± 4.44
Body Depth (%SL)	22	20.5	23.5	22.0 ± 0.80
Head Length (%SL)	22	20.0	22.5	21.0 ± 0.61
Head Width (%HL)	22	49.6	58.3	52.8 ± 2.16
Snout Length (%HL)	22	30.8	36.6	33.2 ± 1.68
Cheek depth (%HL)	22	10.5	18.8	15.4 ± 2.00
Eye Diameter (%HL)	22	38.9	48.2	43.3 ± 2.28
Interorbital Width (%HL)	22	39.5	53.5	46.8 ± 3.93
Dorsal Fin Base Length (%SL)	22	11.7	15.4	13.6 ± 1.02
Anal Fin Base Length (%SL)	22	25.5	29.9	28.7 ± 1.13
Preanal Distance (%SL)	22	47.2	51.7	48.8 ± 1.24
Prepelvic Distance (%SL)	22	33.4	36.6	35.3 ± 0.89
Pelvic Fin Length (%SL)	22	10.3	12.1	11.2 ± 0.52
Caudal Peduncle Length (%SL)	22	21.4	25.2	22.6 ± 0.91
Caudal Peduncle Height (%CPL)	22	41.0	52.7	48.2 ± 2.70
Caudal Peduncle Lobe Length (%SL)	22	18.7	24.8	21.5 ± 1.61
Pectoral Fin Base Length(%SL)	22	5.8	7.8	6.7 ± 0.51
Prepectoral Distance (%SL)	22	21.3	23.6	22.6 ± 0.67

Table 1C. Measurements expressed as a percentage of *Lamprichthys tanganicanus* males from Lake Kivu (SD = Standard Deviation; Min = Minimum; Max. = Maximum; Mn. = Mean; N = Number of samples examined; SL = Standard Length; TL = Total Length).

N		Min	Max	Mn ± SD
Standard Length (SL mm)	30	63.1	107.8	82.0 ± 12.36
Body Depth (%SL)	30	16.3	26.3	24.1 ± 1.82
Head Length (%SL)	30	19.0	22.4	20.4 ± 0.77
Head Width (%HL)	30	44.4	57.5	50.6 ± 2.53
Snout Length (%HL)	30	32.0	41.6	36.1 ± 2.35
Cheek depth (%HL)	30	13.1	20.0	16.4 ± 1.63
Eye Diameter (%HL)	30	31.4	45.4	39.4 ± 3.25
Interorbital Width (%HL)	30	37.0	51.5	41.8 ± 2.75
Dorsal Fin Base Length (%SL)	30	14.2	18.9	16.2 ± 1.25
Anal Fin Base Length (%SL)	30	33.9	40.4	36.0 ± 1.34
Preanal Distance (%SL)	30	41.3	47.6	44.3 ± 1.52
Prepelvic Distance (%SL)	30	29.5	34.2	31.6 ± 1.29
Pelvic Fin Length (%SL)	30	10.9	14.2	12.3 ± 0.68
Caudal Peduncle Length (%SL)	30	13.4	22.8	20.4 ± 1.79
Caudal Peduncle Height (%CPL)	30	44.0	59.6	51.0 ± 4.26
Caudal Peduncle Lobe Length (%SL)	30	18.8	24.5	22.1 ± 1.39
Pectoral Fin Base Length (%SL)	30	6.4	8.6	7.3 ± 0.61
Prepectoral Distance (%SL)	30	20.1	23.1	21.9 ± 0.77

Table 1D. Measurements expressed as a percentage in *Lamprichthys tanganicanus* females from Lake Kivu (SD = Standard Deviation; Min = Minimum; Max. = Maximum; Mn. = Mean; N = Number of samples examined; SL = Standard Length; TL = Total Length).

N		Min	Max	Mn ± SD
Standard Length (SL mm)	20	54.5	75.5	67.0 ± 4.33
Body Depth (%SL)	20	21.4	23.9	22.8 ± 0.67
Head Length (%SL)	20	18.8	20.0	20.1± 0.66
Head Width (%HL)	20	49.6	57.7	54.2 ± 2.17
Snout Length (%HL)	20	28.6	37.0	33.1 ± 1.71
Cheek depth (%HL)	20	13.4	20.4	16.9 ± 1.84
Eye Diameter (%HL)	20	39.3	47.2	43.3 ± 2.18
Interorbital Width (%HL)	20	37.8	53.5	46.3 ± 3.54
Dorsal Fin Base Length (%SL)	20	12.1	17.7	13.5 ± 0.84
Anal Fin Base Length (%SL)	20	25.7	29.5	27.4 ± 1.04
Preanal Distance (%SL)	20	48.8	53.1	50.3 ± 1.18
Prepelvic Distance (%SL)	20	33.7	36.9	35.3 ± 0.97
Pelvic Fin Length (%SL)	20	10.7	14.1	12.0 ± 0.95
Caudal Peduncle Length (%SL)	20	20.7	24.3	22.7 ± 0.97
Caudal Peduncle Height (%CPL)	20	43.8	53.5	49.0 ± 2.90
Caudal Peduncle Lobe Length (%SL)	20	17.6	23.6	20.8 ± 1.51
Pectoral Fin Base Length (%SL)	20	5.9	8.3	7.1 ± 0.68
Prepectoral Distance (%SL)	20	20.8	23.7	22.2 ± 0.75

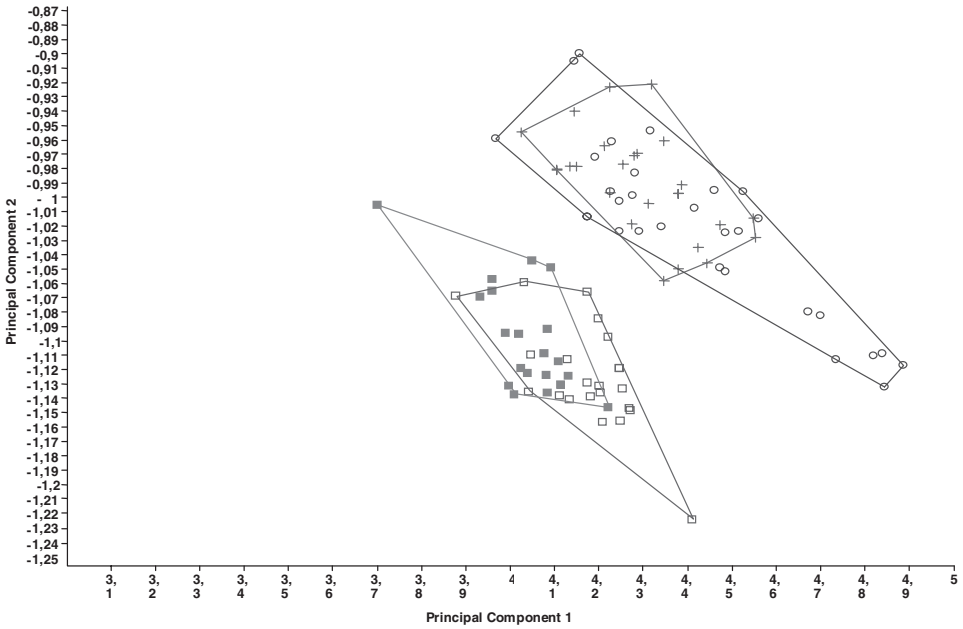

Figure 3. Individual scores on the Principal Component 1 and 2 (measurement in transformed logarithm of all examined samples) for *Lampricthys tanganicanus* males (empty circles, Lake Kivu, n = 26; Cross, Lake Tanganyika, n = 30) and females (empty squares, Lake Kivu, n = 22; full squares, Lake Tanganyika, n = 20).

pectoral fin rays and the numbers of scales along the longitudinal line and around the caudal peduncle. Male and female samples from Lake Kivu were more consistent in their similarity than in Lake Tanganyika (Tables 2A–D).

Appearance of *Lamprichthys tanganicanus* in fishing villages near Lake Kivu

According to fishermen in 9 fishing villages around Lake Kivu, *Lamprichthys tanganicanus* appeared in the fisheries between March and September 2006, mainly 50–200 m from the coast (Table 3). In the 4 Congolese fishing villages, this fish is called "kagame" because fishermen think that the fish was probably introduced in Rwanda. Similarly, fishermen from Rwanda (Gisenyi, Kibuye and Cyangugu) thought that the fish was probably introduced by the Rwandese Ministry of Agriculture (MINAGRI) but here the fish is called "Rwanda rushya", (new Rwanda) and on the Congolese side of the lake, they do not have any idea from where the introduced fish samples could have come (Lushombo, personal communication).

Discussion

The presence of this fish endemic to Lake Tanganyika in Lake Kivu raises many questions. One would be tempted to think that this species probably reached Lake Kivu through the Ruzizi river, which connects the two lakes. The absence of this fish in the important river tributaries of Lake Tanganyika such as the Malagarasi (De Vos and Snoeks, 1994) and the Ruzizi (Marlier, 1953; Nshombo and Kamalebo, personal communication) excludes the

Table 2A. Number and frequency of main meristic characters of *Lamprichthys tanganicanus* males from Lake Tanganyika.

N°	Meristic characters	Number and frequency
1 2 3 4 5	Dorsal fin formula Anal fin formula Pectoral fin formula Longitudinal line scales Scales around the caudal peduncle	XIV(f 9), XV(f 10), XVI(f 4), XVII(f 3) XXVII(f 2), XXVIII(f 7), XXIX(f 11), XXX(f 4), XXXI(f 2) 13(f 1), 14(f 2), 15(f 22), 16(f 1) 39(f 1), 40(f 2), 41(f 11), 42(f 9), 43(f 3) 10(f 2), 12(f 24)

Table 2B. Number and frequency of main meristic characters of *Lamprichthys tanganicanus* females from Lake Tanganyika.

N°	Meristic characters	Number and frequency
1 2 3 4 5	Dorsal fin formula Anal fin formula Pectoral fin formula Longitudinal line scales Scales around the caudal peduncle	XIII(f 2), XIV(f 13), XV(f 7) XXV(f 1), XXVII(f 2), XXVIII(f 8), XXIX(f 9), XXX(f 2) 14(f 2), 15(f 17), 16(f 3) 40(f 1), 41(f 13), 42(f 4), 43(f 4) 12(f 22)

Table 2C. Number and frequency of main meristic characters of *Lamprichthys tanganicanus* males from Lake Kivu.

N°	Meristic characters	Number and frequency
1 2 3 4 5	Dorsal fin formula Anal fin formula Pectoral fin formula Longitudinal line scales Scales around the caudal peduncle	XIII(f 7), XIV(f 17), XV(f 6) XXV(f 3), XXVI(f 3), XXVII(f 2), XXVIII(f 17), XXIX(f 4), XXX(f 1) 13(f 1), 14(f 4), 15(f 6), 16(f 18), 17(f 1) 40(f 4), 41(f 10), 42(f 4), 43(f 11), 44(f 1) 10(f 10), 12(f 20)

Table 2D. Number and frequency of main meristic characters of *Lamprichthys tanganicanus* females from Lake Kivu.

N°	Meristic characters	Number and frequency
1 2 3 4 5	Dorsal fin formula Anal fin formula Pectoral fin formula Longitudinal line scales around the caudal peduncle	XIII(f 6), XIV(f 12), XV(f 2) XXV(f 1), XXVI(f 2), XXVII(f 2), XXVIII(f 14), XXIX(f 1) 13(f 2), 14(f 6), 15(f 12) 40(f 1), 41(f 11), 42(f 6), 43(f 2) 12(f 20)

assumption of an upward migration from Lake Tanganyika (773 m altitude) to Lake Kivu (1465 m altitude) through the Ruzizi river. The presence of several steep waterfalls in the Ruzizi river further invalidates this assumption.

Like the three cichlid species, *Oreochromis macrochir*, *Tilapia rendalli* and *Oreochromis leucosticus* of Lake Kivu which must have been introduced either directly, or by escaping from fish culture ponds in the Lake Kivu basin in the Democratic Republic of Congo or Rwanda (Snoeks et al., 1997), *Lamprichthys tanganicanus* could have been introduced inadvertently by an aquarist close to the banks of this lake in either one of the bordering countries. This possibility can be rejected, as a survey carried out between January and July 2007 in three towns in Rwanda and four in the Democratic Republic of Congo (Figure 1) showed no past traces of an unspecified aquarist close to the lake dealing in exotic fish from Lake Tanganyika or from elsewhere. The

Table 3. First appearance of *Lamprichthys tanganicanus* in various fishing villages around Lake Kivu.

Site	Town/Village	Month/Year of appearance	Distance from the coastline
1-Bay of Kituku	**Goma (DRC)**	March/2006	50–100 m
2-Bay of Himbi	**Goma (DRC)**	April/2006	100–200 m
4-Bay of Nzulo	**Sake (DRC)**	September/2006	More than 100 m
5-Bay of Kasunyu	**Minova (DRC)**	September/2006	200 m
6-Bay of Bukavu	**Bukavu (DRC)**	September/2006	1000 m
7-Bay of Gisenyi	**Gisenyi (RWANDA)**	February/2006	More than 200 m
8-Bay of Nyabidahe	**Kibuye (RWANDA)**	March/2006	Near the beach
9-Bay of Cyangugu	**Cyangugu (RWANDA)**	May/2006	200 m

Table 4. Mixed broods of *Limnothrissa miodon* and *Lampricthys tanganicanus* at Uvira, Lake Tanganyika collected between February and November 2007.

Dates	*Limnothrissa miodon* Number of fry (min-max in total length in mm)	*Lamprichthys tanganicanus* Number of fry (min-max in total length in mm)
16 février 2007	**3.761** (19.1–32.4)	**14** (18.6–26.2)
02 mars 2007	**5.875** (17.3–17.9)	**0** (0–0)
07 mars 2007	**459** (16.4–20.2)	**1** (14.5–14.5)
07 avril 2007	**44** (20.9–21.3)	**3** (14.2–26.1)
27 juin 2007	**2.170** (16.9–35.8)	**32** (12.1–22.6)
25 juillet 2007	**4.834** (18.9–30.7)	**38** (10.2–30.9)
08 novembre 2007	**34** (23.2–33.0)	**8** (25.5–29.3)
TOTAL (%)	**17.177 (99.4%)**	**96 (0.6%)**

scientists attempting to introduce *Stolothrissa* into Lake Kivu in 1959 (Collart, 1960) reported failure using adult individuals. As is widely known nowadays, they were unaware of the fact that they introduced *Limnothrissa miodon* into Lake Kivu, as they were unable to distinguish these species at the larval stage (Collart, 1960, 1989, unpublished; Hauser, 1996). The techniques used at the time of introduction of *L. miodon* do not exclude a simultaneous accidental introduction in 1959 of *L. tanganicanus*. To test the likelihood of this, seven collecting trips were organized in the littoral zone of Lake Tanganyika at Uvira, using a special mosquito net. Fry of *L. miodon* were found to be mixed with those of *L. tanganicanus* although in unequal proportions (respectively 99.4% and 0.6%, see Table 4). In total, 17,231 fry of *Limnothrissa miodon* and *Lamprichthys tanganicanus* were caught between February and July 2007 in inshore of Lake Tanganyika at Uvira. This shows that fry of these two species occur together inshore (at least 10.2–33.0 mm in length) and may have been introduced together into Lake Kivu in 1959.

In general, at the fry stage (no scales) and at more or less equal size, it is difficult to distinguish these two species. However, it is possible to distinguish fry of the two species using a binocular microscope, on the basis of their general body coloration and the shape of the caudal fin (Figure 4).

Supposing that *Lamprichthys* was indeed introduced accidentally in 1959, along with *Limnothrissa*, its relatively late appearance in Lake Kivu may be related to differences in the reproductive biology of these two species. In Lake Tanganyika, *Limnothrissa miodon* lays eggs close to the coast at depths lower than 130 m (Matthes, 1965; Hauser, 1996) where its fry are caught on sandy and

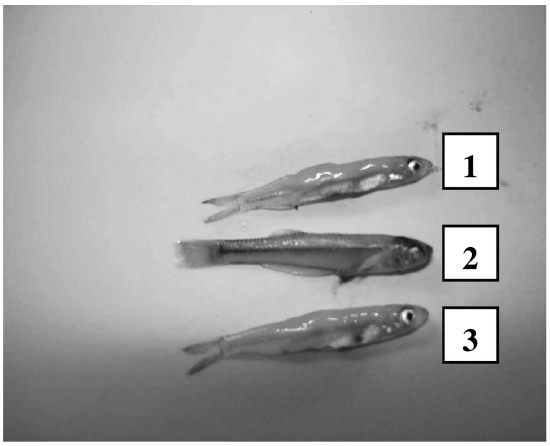

Figure 4. Fry of *Lamprichthys tanganicanus* (N°2 of 23,3 mm in total length) and fry of *Limnothrissa miodon* (N°1 and N°3 of 20,9 mm and 22,2 mm in total length) found in mixed broods at Uvira, Lake Tanganyika (27 June 2007).

rocky beaches (Kalala and Izumi, 1995). In Lake Kivu, *Limnothrissa miodon* appears to spawn in the pelagic zone (De Iong et al., 1983; Hauser, 1996) which could have benefitted the survival of fragile young fry in stable pelagic waters deprived of predators (Marshall, 1987) except *Limnothrissa* itself, in contrast to the pelagic zone of Lake Tanganyika where four predatory species of the family of Latidae roam (Poll, 1953; Coulter, 1991; Brichard, 1989). On the contrary, in Lake Kivu fry of *Lamprichthys tanganicanus* must have faced strong predation from *Limnothrissa* and from some native species, especially the bottom dwelling haplochromines (Snoeks, 1994) near the littoral zone and which cannot be indifferent to alien fry without parental care. In addition, the fecundity of *Limnothrissa miodon* is rather high in Lake Tanganyika with approximately 55,000 eggs for a 140 mm

individual (Matthes, 1965–1966) as well as in Lake Kivu: 51,146 eggs for a female individual 121 mm (Kaningini et al., 1999). On the other hand, only 252 eggs were counted as the highest number of eggs present in an adult female (among eleven females) of *Lampricthys tanganicanus* (83 mm SL). This fecundity is by far lower than that of *Limnothrissa miodon* which may indicate the last species had likely more chance to survive in the habitat of Lake Kivu than *Lamprichthys tanganicanus*. The gonads of female *Lamprichthys tanganicanus* contain many eggs at various stages of maturity indicating that spawning is not restricted to a single period of the year (Poll, 1953). This phenomenon was observed in *Limnothrissa miodon* although spawning peaks are observed in this species in Lake Tanganyika (Matthes, 1965–1966; Mulimbwa and Shirakihara, 1994) as well as in Lake Kivu (Mahy, 1981; De Iong et al., 1983; Kaningini, 1995, 1999).

To evaluate the success of the introduction of the ndakala (*Limnothrissa miodon*) to the Lake Kivu an evaluation mission from the Ministry for the Agriculture of Rwanda (MINAGRI) was set up between October and November 1976 in Kibuye, Cyangugu and Gisenyi (Frank, 1989). *Lamprichthys tanganicanus* was not seen in the lake during this evaluation mission. In addition, despite an intensive sampling programme from 1979 to 1988, no sample of this fish was seen during the survey (Snoeks, 1994).

Conclusions

An analysis of the morphological characteristics of *Lamprichthys tanganicanus* (Poeciliidae) from Lake Tanganyika and those which appeared since 2006 in the fisheries in Lake Kivu shows that those samples from both lakes are identical. Genetic studies based on mitochondrial DNA analysis support these conclusions obtained from morphological comparisons. The presence of young fry of *Lamprichthys tanganicanus* mixed with those of *Limnothrissa miodon* (Clupeidae) in the littoral zone of Lake Tanganyika suggests that the former species may have been accidentally introduced in Lake Kivu in 1959 together with the second one. The late appearance of this fish, thirty years after *Limnothrissa miodon*, may somehow relate to the low fecundity of the species. Important changes in the environment of Lake Kivu may also be another reason of this late appearance of this fish in Lake Kivu although further studies on interspecific relationships between both species are still needed. The presence of this tanganyikan fish in this lake brings the number species actually known from Lake Kivu and its affluents to 29.

A striking morphological change occurred in *Limnothrissa* after its introduction into Lake Kivu in 1959. Roest (1999) had noticed the relatively larger eyes of this species in its new environment and by comparing the relationship eye diameter vs body length, calculated that in Lake Kivu, the eye diameter of *Limnothrissa* of 120–140 mm (fork length) is 12–15% greater than in Tanganyika. Although no reasons for this change are suggested in his paper, this adaptation to the new environment evidently reflects differences in the ecological conditions and particularly in the food web. We found no such change in *Lamprichthys* in Lake Kivu. With no detailed information being available on the feeding habits of *Lamprichthys*, neither in its original habitat in Tanganyika nor here in Lake Kivu, a comparison between the two species would be premature. It is therefore too early to tell whether the absence of morphological change in *Lamprichthys* between the two lakes would reflect its recent introduction into Kivu. This challenge can only be answered by further monitoring and research.

Acknowledgements

We express our thanks to the scientific authorities of the Centre de Recherche en Hydrobiologie, CRH-Uvira, where the senior author is based and particularly to the laboratory staff who collected most of samples from Lake Tanganyika: Mahangaiko K., Matata K., Barasta N., Watuna I., Bahane B. and Mbilize N. We specially thank Professor Erik Verheyen of the Institut Royal des Sciences Naturelles, Brussels, who assisted us in the genetical analysis of samples from both lakes. Finally, we wish to thank the academic authorities of the Université Officielle de Bukavu (UOB), Professors Nyakabwa Mutabana and Muhigwa Bahananga, respectively President of the University and Dean of the Faculty of Science, for their administrative assistance during our research. Finally we are very grateful to two anonymous reviewers for their numerous and helpful comments on the manuscript.

References

Beadle, L. C., 1981. *The inland waters of tropical Africa. An introduction to tropical limnology*. 2nd *ed*. Longman, London.

Bell-Cross, G., Bell-Cross, B., 1971. Introduction of *Limnothrissa miodon* and *Limnocaridina tanganyikae* into Lake Kariba. Fish.Res.Bull. Zamb. 5, 207–214.

Brichard, P., 1989. *Fishes of Lake Tanganyika*. TFH. New York.

Capart, A., 1959. A propos de l'introduction du Ndakala (*Stolothrissa tanganicae*) dans le lac Kivu. (About the introduction of Ndakala (*Stolothrissa tanganicae*) into Lake Kivu. In French.). Bulletin Agricole du Congo Belge et du Ruanda-Urundi 50(4), 1083–1087.

Collart, A., 1960. L'introduction du *Stolothrissa tanganicae* (Ndagala) au lac Kivu. (The introduction of Solthrissa tanganicae to Lake Kivu. In French.). Bulletin Agricole du Congo Belge 51(4), 975–985.

Coulter, G. W., Thiercelin, J.-J., Mondeguer, A., Hecky, R. E., Spigel, R. H., 1991. *Lake Tanganyika and its life*. Oxford University Press, London, and New York.

De Iong, H. H., Spliethoff, P. C., Frank, V. G., 1983. Feeding habits of the clupeid *Limnothrissa miodon* (Boulenger), in Lake Kivu. Hydrobiologia 102, 113–122.

De Vos, L., Snoeks, J., Van den Audenaerde, D. T., 2001. An annotated checklist of the fishes of Rwanda (East Central Africa), with historical data on introductions of commercially important species. Journal of East African Natural History 90, 41–68.

De Vos, L., Snoeks, J., 1994. The non-cichlid fishes of the Lake Tanganyika basin. Arch. Hydrobiol. Beih. Ergebn. Limnol. 44, 391–405.

Frank, V., 1989. Mission d'évaluation de la réussite de l'introduction des isambaza au lac Kivu (Octobre-Novembre 1976). (Evaluation mission of the success of the introduction of Isambaza to Lake Kivu. (October–November, 1976) In French.) Séminaire Trente ans après l'introduction de l'isambaza au lac Kivu. (Seminar: 30 years after the introduction of Isambaza to Lake Kivu. In French.) Projet RWA/87/012, 1–3.

Fryer, G., Iles, T. D., 1972. The Cichlid Fishes of the Great Lakes of Africa: Their Biology and Evolution. Oliver and Boyd. Edinburg, Scotland, UK : 1–641.

Hauser, L., 1996. Genetic and morphological differentiation of native and introduced populations of the Lake Tanganyika sardine, *Limnothrissa miodon*. Doctoral thesis. Department of Biological Sciences, University of Wales, Swansea, U.K., 1–134.

Kalala, K. T., Izumi K., 1995. Early life histories of two clupeids, *Limnothrissa miodon* and *Stolothrissa tanganicae* from Lake Tanganyika. Japanese Journal of Ichthyology 42(1): 81–87.

Kaningini Mwenyimali, 1995. Etude de la croissance, de la reproduction et de l'exploitation de *Limnothrissa miodon* au lac Kivu, bassin de Bukavu (Zaïre). (Study of the growth, reproduction and the exploitation of *Limnothrissa miodon* in Lake Kivu. In French). PhD dissertation. Presses Universitaires de Namur, 1–211.

Kaningini, B., Micha, J.-Cl., Vandenaute, J., Platteau, J.-P., Watongoka, H., Mélard, C., Wilondja, M. K., Isumbisho, M., 1999. Pêche du Sambaza au filet maillant dans le lac Kivu. (Fishery of Sambaza with gillnet in Lake Kivu. In French.). Final report of the NGO/219/92/Zaïre Project. University Press of Namur, 1–187. Rapport final du projet ONG/219/92/Zaïre. Presses Universitaires de Namur, 1–187.

Mahy, G., 1981. Synthèses des résultats des recherches effectuées par l'UNR (octobre 1979–mai 1981) et par les experts associés (février-décembre 80), sous la direction du professeur Gérard Mahy, de l'UNR. (Synthesis of the research results carried out by the National University of Rwanda UNR (October 1979–May 1981) and by associate experts (February–December 1980), under the direction of Professor Gérard Mahy, from the UNR. In French.). Project RWA/77/010. Tripartite revue june 1980, 1–10. Projet RWA/77/010. Développement de la pêche au lac Kivu. Revue tripartite-juin 1980, 1–10.

Marlier, G., 1953. Etude biogéographique du bassin de la Ruzizi basée sur la distribution des poissons. (Biogeographic study of the Ruzizi basin based on the distribution of fishes. In French.). King's Society of Belgium, Annals LXXXIV, 175–224.

Marshall, B. E., 1987. Growth and mortality of introduced Lake Tanganyika clupeid, *Limnothrissa miodon*, in Lake Kariba. J. Fish Biol. Volume 31, 603–615.

Mulimbwa, N., Shirakihara, K., 1994. Growth, recruitment and reproduction of sardines (*Stolothrissa tanganicae* and *Limnothrissa miodon*) in Northwestern Lake Tanganyika. Tropics 4(1), 57–67.

Patterson, G., Makin, J. (eds), 1998. The State of Biodiversity in Lake Tanganyika–A Literature Review. Chatham, UK : Natural Resources Institute, 1–143.

Poll, M., 1953. Exploration hydrobiologique du lac Tanganika (1946–1947). (Hydrobiological Exploration of Lake Tanganyika (1946–1947). In French.). Résultats scientifiques. Volume III, Fascicule 5A. Poissons Non Cichlidae, 1–251.

Poll, M., 1956. Exploration hydrobiologique du lac Tanganika (1946–1947). (Hydrobiological Exploration of Lake Tanganyika (1946–1947). In French.). Résultats scientifiques. Volume III, Fascicule 5B. Poissons Cichlidae, 1–619.

Pouclet, A., 1978. Les communications entre les grands lacs de l'Afrique centrale. Implications sur la structure du rift occidental. (Communications between the great lakes of Central Africa. Implications on the structure of the west rift. King's Museum of Central Africa. In French.). Mus. Roy. Afr. Centr. Dépt Géol. Min., Rapp. Ann. 1977, 145–155.

Roest, F. C., 1999. Introduction of a pelagic fish into a large natural lake: Lake Kivu, Central Africa. In: W.L.T. van Densen and M.J. Morris (Eds.), *Fish and fisheries of lakes and reservoirs in Southeast Asia and Africa*, pp. 327–338. Westbury Publising, Otley, UK.

Snoeks, J., 1994. The Haplochromines (Teleostei, Cichlidae) of Lake Kivu (East Africa). In French. Musée Royal de l'Afrique Centrale, Tervuren, Belgique. Annales Sciences Zoologiques. Volume 270, 1–221.

Snoeks, J., De Vos, L., Thys Van den Audenaerde, D., 1997. The ichthyography of Lake Kivu. South African Journal of Science. Vol. 93, pp. 579–584.

Verheyen, Erik, Salzburger, Walter, Snoeks, Jos, Meyer, Axel, 2003. Origin of the superflock of cichlid fishes from Lake Victoria, East Africa. Science 300(5617): 325–329.

Worthington, B. E., Lowe-McConnell, R. H., 1994. African lakes reviewed: creation and destruction of biodiversity. Environmental Conservation. Volume 21, N°3, 199–213.