Towards Aquatic Assessment of Lake Tumba, DR Congo

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Cover: Fishermen at Lake Tumba
(photo: Norbert Zanga)

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Abstract

The livelihoods of most communities around the 765 km^2 Lake Tumba are dependent on fish from the lake. Artisanal fishing and other pressures on the aquatic ecosystem are likely to have increased over the last half century. However, few monitoring programs follow these pressures and their influence on the aquatic ecosystem. The main objective of this thesis was to contribute to an improved understanding of the fish population in Lake Tumba to support the development of strategies for improving the fishery as well as assessing changes in the fish population over time.

The fish population was characterized through regular monitoring from 2005 to 2010, with an emphasis on the methodology. This monitoring was complemented by a survey of breeding sites for *Tilapia congica* within Lake Tumba, and an investigation of the relationship between land use and fish catch around islands in the Congo River.

The Catch Per Unit Effort (CPUE) and Number Per Unit Effort (NPUE) differed between sites and seasons, and with water depth and distance from shore. The greatest fish weight was caught between 3.0 and 4.5 m depth, which might explain the larger CPUE during the rainy season, as the water was deeper at the fixed fishing sites. The local population has larger catches during the dry season.

Fewer species (n=42) were found in this study than in the 1959 survey (n=65 species). However, due to the difference in fishing methods, location and effort, it was difficult to draw strong conclusions about how much the fish population had actually changed.

The study of *T. congica* identified four major breeding sites, one of which was about 10 km long, and most nests were found in conjunction with Hippo grass (*Vossia cuspidata)* and Water lily (*Nymphaea stellata)*.

The study of fish near the Congo Islands caught 29 fish species. Cultivation area was related to erosion and the number of species nested offshore from each island.

Due to the growing demand for fish, and the likelihood of more dramatic environmental change in the future, there is a need for developing management and governance strategies, as well as for scientific monitoring of the ecosystem on which to base management. The methodological aspects of this study and the actual findings about current fish status can be of value in this development.

Keywords: Livelihoods, fish community, breeding sites, wet season, CPUE, NPUE, management, artisanal fishing, zoning process, *T. congica*

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Dedication

I dedicate this work to God and my family, especially my wife **Eugenie Mosange** and all our kids, together with both my parents whose moral and mental support has been so important to me. Thank you all for so much.

Contents

List of Publications

This thesis is based on the work contained in the following papers, referred to by Roman numerals in the text:

I Zanga, L. N., Inogwabini, B.I., Wilander, A., Willén, E. and Bishop, K. (2013). The Fish of Lake Tumba: Towards documentation of a resource for livelihoods and biodiversity *(manuscript)*.

II Inogwabini, B.I., Mputu, D.A. and Zanga, L. (2009). The use of breeding sites of Tilapia congica (Yhys & van Audenaerde 1960) to delineate conservation sites in the Lake Tumba, Democratic Republic of Congo: toward the conservation of the lake ecosystem. *African Journal of Ecology* 48(3), 800-806, doi: 10.1111/j.1365-2028.2009.01180.x.

III Inogwabini, B.I. and Zanga, L. (2013). Fish species occurrence, estimates and human activities on the islands of the Congo River, Central Africa. *Environmental Biology of Fishes*, doi: 10.1007/s10641-013-0136-4

Papers II and III are reproduced with the permission of the publishers.

The contribution of Norbert Zanga to the papers included in this thesis was as follows:

I The respondent was responsible for data collection, data analyses, interpretation, and writing of the paper.

II The respondent led the field team that collected the data, and contributed to data collection, data analyses, interpretation of the results, and the writing of the manuscript

III The respondent collected all the fish data, wrote the initial report on the findings in French, and contributed to both the interpretation of the results and the writing of the manuscript.

Abbreviations

A	Auchenoglanis
C	Chrysichthys
M	Mormyrops
T	Tilapia
Abs	Absorbance
CPUE	Catch per unit effort
CREF	Research Center for Ecology and Forestry
DOC	Dissolved organic carbon
DRC	Democratic Republic of Congo
LTL	Lake Tumba Landscape
NPUE	Number of fish Per Unit Effort
SLU	Swedish University of Agricultural Sciences
UN	United Nations
WWF	World Wide Fund for Nature

1 Introduction

The Lake Tumba Landscape (LTL) is one of twelve UN Priority Conservation areas in Africa, and the only one where the primary conservation focus is freshwater ecosystems. The region contains many of the world's largest remaining free-flowing rivers and shallow lakes, and is associated with a rich fish fauna (Kamdem *et al.,* 2006). The LTL encompasses a large and complex network of numerous aquatic habitats that together occupy over 60% of the landscape area (Stiassny and Mamonekene, 2011).

The dominance of swamps and floodable forests around Lake Tumba Landscape means aquatic resource-use, especially fishing, has been the prevailing livelihood in the subsistence economy of rural villages and settlements for decades. In the Eastern segment of this landscape, over 83% of all households currently engage in the fishery, which accounts for ca 80% of the income for the 2 million people in this region (CBFP, 2006). Despite the importance of these waters and the life and livelihoods they support, this freshwater ecosystem is one of the World's least understood.

The rich resources of fish, wildlife, and water have supported the existence of local communities for centuries (Terje and Næsje, 1993). Global forecasts indicate fish constitutes the fastest growing food source in the developing world. Consequently, fish are expected to become a major source of food security, nutrition, diet, and income for poor people in the developing world (Mosepele, 2008).

If the ecosystem is managed sustainably, fish can be a long-term asset to society, while conserving the biodiversity. However, fish fauna are inextricably linked to the biophysical environment in which they exist. Fish are one of the vertebrate groups most threatened by human activity: a threat that is exacerbated by lack of knowledge about appropriate harvesting strategies, the conditions needed to ensure good reproduction, and the physical-chemical requirements of the aquatic community (Lévêque, 2006).

Fish production in Lake Tumba is important because the riparian populations have traditionally used fish as both food and for trade. This exploitation is artisanal, and uses nets, hooks, coracle nets made of mosquito nets, and other methods. At present, the fish resource is primarily exploited by subsistence fishing; commercial fishing has not appeared on a large-scale.

However, fishing is not subject to effective central management, and the exploitation of the aquatic ecosystem poses serious management challenges. The current management of the LTL suffers from shortcomings due to a lack of implementation of government fishery laws, limited scientific understanding of the lake's ecology, and policies flawed by limited scientific understanding. A failure to manage the fishery, and other aspects of the lake's resources, appropriately can have disastrous effects for both the social and economic conditions of the riparian population. This in combination with increased fishing pressure associated with both increasing population and the possibilities of trade, land use/land cover change in association with the exploitation of the terrestrial landscape, and climate change poses a serious future threat to the area. Improving the scientific basis for natural resource management, and the quality of information to managers, users, and the community at large is one solution, especially in combination with traditional knowledge, which is an important source of information that can complement and enrich conventional science.

Studies on fish in Lake Tumba have focused on either the biological dimension (Matthes, 1964) or socio-economic aspects (Colom *et al*., 2006). To be sustainable, the management of Lake Tumba and its landscape should be based on an integration of effective social governance institutions with a sound scientific understanding of the ecosystem, supported by ongoing assessment of fish stocks. The 1959 study by Matthes (1964) was a historical benchmark, and in 2005, efforts started to try to establish an ongoing aquatic monitoring program, some of which are reported in this thesis.

That new monitoring program is a part the World Wildlife Fund's (WWF) promotion of natural resource management in the LTL, with an emphasis on the need for developing measures for securing both food and income for the riparian communities and preservation of fish diversity and production. People living around Lake Tumba are culturally and economically water-dependent tribes and most of their living comes from fishery resources (Aveling *et al.*, 2003). Therefore, for these communities, it is essential to identify ways in which fish resources can be managed and exploited sustainably. For local communities and the conservationists working in Lake Tumba, one potential management strategy is to identify fish spawning sites that could be protected in order to reduce the pressure on fish populations.

A strategic vision for the whole lake is needed to guide conservation decisions. This thesis aimed to support this goal through characterizing the status of the fish population in Lake Tumba through regular monitoring over the period 2005-2010, with a particular emphasis on the performance of the techniques used. The study was complemented with a survey of breeding sites for *T. congica* on Lake Tumba, and an investigation of the relationship between land use and fish catch around the islands in the Congo River where it runs through the Lake Tumba Landscape.

2 Objectives

The main objective of this thesis was to contribute to an improved understanding of the fish population in Lake Tumba to support the development of strategies for improving the fishery as well as assessing changes in the fish population over time.

The major questions addressed were:

- How does the fish population change during the year and between years? (Paper I)
- Can fish breeding sites be identified so that they might be protected? (Paper II)
- How does land use on islands influence nearby fish populations? (Paper III)

This thesis is based on three papers, each addressing one of these questions.

3 Materials and Methods

3.1 Study Area

Lake Tumba is located about 0° 50’ S, 18° 0’ E in Equateur province in Democratic Republic of Congo (DRC, Figure 1), and drains north to the Congo River. Lake Tumba is the second largest lake entirely within Congo basin. The largest Lake Mai Ndombe, lies just south of Lake Tumba. Lake Tumba is a shallow lake with a mean depth of about 3 m and an area that varies seasonally from 500 to 765 km^2. The fishing studies for Paper I took place at three sites (Ikoko, Mabali, and Ntondo) along the east coast (Figure 1). About 34 villages surround the Lake, and the main agglomeration is Bikoro. The total population of Bikoro Territory was about 184,123 in 1994 (Anonymous, 1998) and 244,808 in 2004, with an average density of 13 people/km^2 (Anonymous, 2005).

The inventory of the egg nest sites of *T. congica* was undertaken in the northeast of Lake Tumba in February 2006 (Paper II). The study on the islands of the Congo River was located between Irebu (the mouth of Lake Tumba) and Mobeka, both situated in the province of Equateur (Paper III). Islands are a common characteristic of this area of the Congo. The mean altitude of the region is 320 m a.s.l. and the Congo has a mean width ≅ 1800 m, reaching 25 km in some places of the section covered by this study, and the average water flow (3.5 km h^{-1}) is slow due to the flat topography.

Figure 1. Map showing the location of Lake Tumba and the three fishing sites (Paper I).

3.2 Methods Used in Paper I

The fishing equipment selected was nets with two mesh sizes and baited hooks: these were used throughout the entire study period. Baited hooks are advantageous as they can catch species that are not caught with nets.
Fishing was at three sites along the eastern coast of the lake (Figure 1); however, conditions did not allow free, random distribution of the nets. As the fishing effort was different at the three sites, the results were "normalized" with CPUE (Catch per Unit Effort; weight/day) and NPUE (Number of Fish per Unit Effort; number/day). Unless otherwise stated, the strategy was 24 h fishing with both net and hook.

The Simpson diversity index was used to estimate species diversity D. The value of D ranged between 0 and 1, with a larger value representing greater sample diversity.

For statistical calculations, JMP version 10.0 was used. The box plots generated presented a box with 20, 50 and 75 percentiles, whiskers indicating values for 1.5 times the upper or lower interquartile range.

3.3 Methods Used in Paper II

The sampling strategy was guided by local knowledge, which claimed *Tilapia congica* and other species only bred in specific zones. An initial pilot survey, aided by local fishermen, was organized to determine these breeding sites. This was followed by a detailed investigation to collect data on nesting sites (distance from the shore, spread radius), numbers of nest per site, nest substrates ('muddy' or 'sandy'), nest dimensions (length, width and depth), associated habitat (vegetation types), and association with nests of other species and the presence of species other than *T. congica*.

Distance from the shore was measured to the estimated centre of the nest site. Nest numbers per site were simple counts of sighted nests. Nest dimensions were ranked in classes of 20 cm each (1–20, 21–40, 41–60, 61–80, 81–100, and >101 cm). Nests were considered to form an ellipse: therefore, both axes were measured: the length was the large axis and the small axis equaled the nest width. For mapping purposes, waypoints were collected from each breeding site with the Garmin 12xl positioning system (GPS).

3.4 Methods Used in Paper III

The study was conducted over 33 days during the rainy season between 30 October and 03 December 2007. The same team sampled each site and used the same tools over a day. The sampling equipment consisted of 50 m long and 50 cm wide nets of both 2.5 cm and 3.0 cm wide-stretched mesh.

As the objective was to sample 30% of the islands, 33 islands were selected randomly. On these islands, a grid system of 100 m×100 m was laid out in ArcView. On site, the sampling instruments were set up at the pre-selected points. If the sampling point was on solid ground, transects were laid until water was reached. Nets were deployed at 8:00 and revisited twice a day: the nets were left in the water between 18:00–5:00 and 6:00 in the morning (Inogwabini and Zanga, 2013).

At each sampling site, data on the water habitats were collected, this included water depth, samples of the substrates for identification, and water speed. Water depth was measured at 100 m intervals along a transect, running east to west from the central point selected, with a straight stick graduated in cm.

4 Results

4.1 The Fish of Lake Tumba: Towards Documentation of a Resource for Livelihoods and Biodiversity (Paper I)

4.1.1 The Fish Species and catch

Between 2005 and 2010, 164 days of fishing, during both wet and dry seasons at the three sites (Mabali, Ntondo, and Ikoko), yielded a total catch of about 1150 fish comprising 42 species from 12 families. There were differences between the sites. At Mabali, 21 species from 8 families were caught during the dry season of 2005 and 19 species in 7 families were caught during the wet season. At Ikoko, 23 species from 12 families were caught during the dry season of 2006, and at Ntondo, 8 species from 6 families were caught during the dry season of 2010 and 13 species from 7 families were caught during the wet season of the same year. An average of 16 species was found at the three sites; however, the ratio for wet/dry season was 1.1 for species and 1.0 for families (Table 1).

Table 1. *Results from each fishing site and season days.*

	Mabali dry	Mabali wet	Ikoko dry	Ntondo dry	Ntondo wet
Year	2005	2005	2006	2010	2009-10
Fishing days	29	62	12	8	53
Species	21	19	23	8	13
Families	8	7	12	6	7
Diversity Index (D)	0.62	0.71	0.82	0.73	0.73
CPUE (kg⁄day)	0.90	1.02	0.70	0.26	0.43
NPUE (number⁄day)	9.1	8.2	7.8	3.0	4.2
Net/Hook ratio CPUE	0.92	2.00	1.30	0.05	0.18
Net/Hook ratio NPUE	1.0	2.2	2.2	1.0	1.5
Distance shore average (km)	1.43	1.61	2.14	3.61	2.5
Water depth average (m)	2.34	2.75	2.47	3.69	4.5

The comparison of fish species richness among the sites revealed the diversity index for Ikoko during the dry season was larger D=0.82 than for Ntondo D=0.73 and Mabali D=0.71. During the wet season, Ntondo had a higher diversity (D=0.73) than Mabali (D=0.62); however, the seasonal fluctuations were not large.

The catch per unit effort (CPUE) was calculated for all sites in both dry and wet seasons. At Mabali, CPUE was 0.9 kg during the dry season of 2005 and 1.02 kg during the wet season. At Ikoko, CPUE was 0.70 kg during the dry season of 2006, at Ntondo, CPUE was 0.26 kg during the dry season of 2009-2010 and 0.43 kg during the wet season. The median CPUE was 0.33 kg. The median NPUE was 5. At Ikoko, 93 specimens were caught, and at Ntondo, 18 specimens were caught during the dry season and 193 specimens during the wet season.

The influence of distance of fishing from the shoreline on the catch was assessed (Table 1). At Mabali, fishing was at an average distance of 1.43 km from the shore during the dry season and 1.61 km from the shore during the wet season. At Ikoko, the distance to shore was 2.14 km, and at Ntondo, the distance to shore was 3.61 km during the dry season and 2.5 km during the wet season. The average distance to shore for the whole lake was 2.26 km.

The influence of water depth on the catch was investigated. At Mabali, water depth was on average 2.34 m in the dry season and 2.75 m in the wet season. At Ikoko, water depth was 2.47 m in the dry season. At Ntondo, the average water depth was 3.69 m in the dry season and 4.50 m in the wet season. The average depth for all sites was 3.15 m and the ratio of wet to dry season was 1.2 (Table 1).

The CPUE and NPUE were calculated for common species (Table 2). The CPUE/day was low for many species, except *M. anguilloides*, which was 2.2 kg/day (not presented in the table).

Table 2. *Results of NPUE/day and CPUE/day for five common species, Oct. 2005–2010 during 112 fishing days.*

Species	Catch days	NPUE number/day			CPUE g/day		
		Mean	Quantile 75	Maximum	Mean	Quantile 75	Maximum
Alestes liebrechtsii	13	0.15	0	3	4.2	0	155
Chrysichthys ornatus	50	0.82	1	7	63	100	700
Chrysichthys punctatus	22	0.35	0	5	3.8	0	474
Chrysichthys wagenaari	80	3.7	6	21	280	323	2450
Tylochromis lateralis	40	0.96	1	9	71	70	580

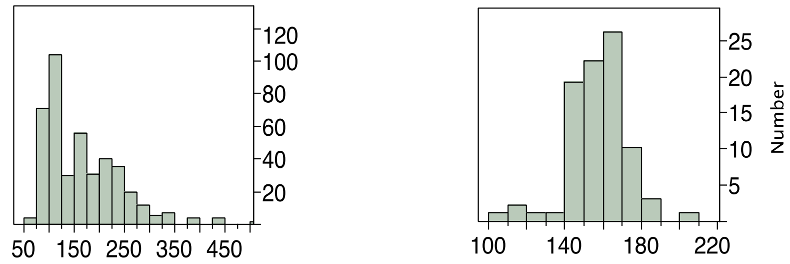
4.1.2 Population Structure

Total length of fish

Total length did not suggest a change in the overall body structure of fish. Some species had longer total length than presented in previous data; except the some commercial species *Hydrocynus goliath,* which had lost 70% of total body length, likely due to heavy fishing pressure. Total body length was reduced in other commercial species, *Parachanna obscura* lost 64% of body length, and *Parachanna insignis* lost 53% of body length.

Total length of two common fish species during 2005-2010

The total length was investigated for two common species, *Chrysichthys wagenaari* and *Tylochromis lateralis*. The total lengths of *C. wagenaari* were clustered around 100 mm to 150 mm, but the mean length was 156 mm. Most *T. lateralis* were between 140 to 170 mm long, with a mean length of 160 mm (Figure 2).



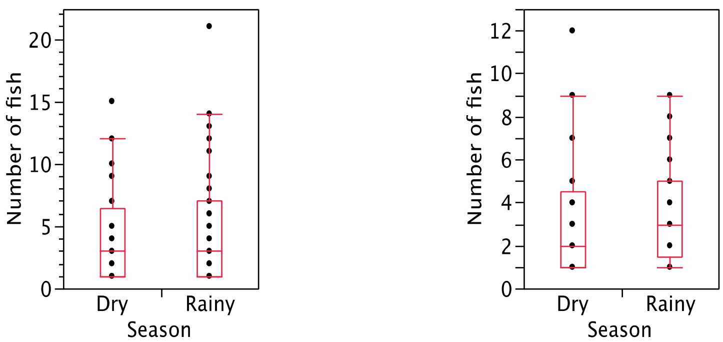
Chrysichthys wagenaari *Tylochromis lateralis*

Figure 2. Distribution of total length (mm) of two common fish species during 2005-2010.

The fishing equipment used limited the size of the fish caught; the smallest *Chrysichthys wagenaari* was 40 mm and the smallest *Tylochromis lateralis* was 105 mm. It is possible larger fish were caught less frequently due to the net mesh size.

4.1.3 Fishing Timing: Rainy/Dry Season and Night/Day

The two species caught most frequently by all types of fishing equipment were *Chrysichthys wagenaari* and *Tylochromis lateralis.* For *C. wagenaari,* there was no difference in the average number of catches per day in both the dry and wet seasons. Conversely, the catches per day of *T. lateralis* differed per season: two specimens per day in the dry seasons and three specimens per day in the wet seasons (Figure 3).



Chrysichthys wagenaari *Tylochromis lateralis*

Figure 3. Catch of two common species during wet and dry seasons.

4.1.4 Fishing Location: Depth and Distance to Shore

Water depth influenced the catch of fish. The CPUE was higher in the depth range 3.0 to 4.5 m, which was where most of the weight (1 to 3600 g/day) was caught (Figure 4).

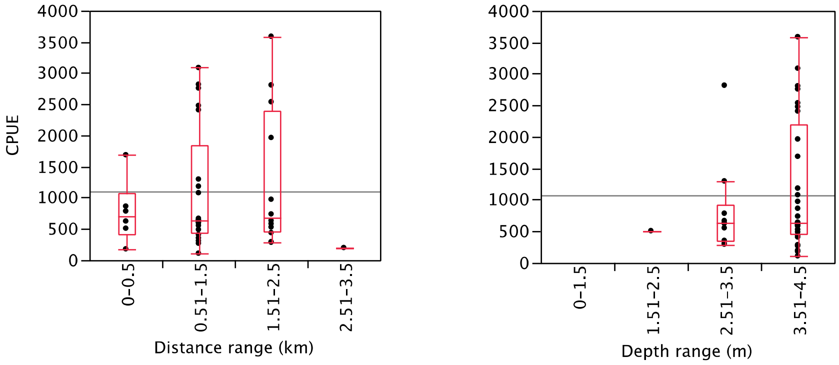


Figure 4. Effect on catch of distance from shore and water depth at the fishing sites. Data for net catches

The distance to shore line also influenced catch, with highest catch weight (CPUE) concentrated at distances from 200 m to 2.5 km from shoreline (Figure 4).

4.1.5 Species and Families 1959 – 2010

The fish species from Matthes survey in 1959 were updated with scientific names based on Froese and Pauly (2013, fishbase.org). In 1959, Matthes (1964) caught 119 species from 25 families from the lake, tributaries, and flooded forest. For the actual lake, there were 65 species in 12 families, another 46 species in 12 families were from the tributaries, a further 8 sporadic species entered from the outlet of the Congo River during high flow. Between 2005 and 2010, 42 species of fish in 12 families were caught in Lake Tumba. There are several possible explanations for this difference. One is of course that the fish fauna has changed. But the present study only covered the eastern part of the lake, and had limited fishing methods compared to those used in 1959 where nets with both smaller and larger mesh size were used, as well as dynamite.

4.1.6 Fishing Method: Hook/Net, Hook Size, and Net Color

The selectivity of two types of fishing equipment were compared. Net (n=17 species) and hook (n=18 species) both caught a similar number of species. *Pterochromis congicus* and a majority of *Tylochromis lateralis* were caught solely by net fishing, whereas, *Chrysichthys wagenaari*, *Clarias angolensis* and *Tilapia congica* were predominantly caught by hook and *Xenomystis nigri* was only caught by hook.

4.2 Breeding Sites (Paper II)

In the investigation on breeding sites, 70 sites and 553 nests were identified, with a mean of 7.9 nests per site (range 1–23 nests per site). Nest depth varied between 0.04 and 2.2 m, with a mean of 0.23 ± 0.08 m. All nest sites (100%) were exposed to the sun. There was a relationship between *T. congica* nesting site and distance to the shore: 90% of nest sites were within the 51 to 250 m from the lakeshore, and 60% were within 51–150 m from the shore (Figure 5).

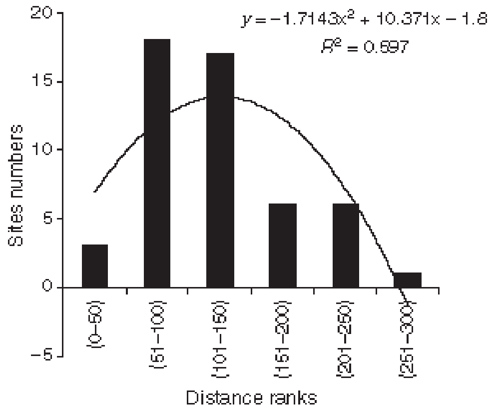


Figure 5. Nesting sites of *T. congica* in relation to distance from shore (m).

The maximum group spread of the nest sites was 300 m, with the single nest site being the minimum spread of a nest. When all contiguous nesting sites were connected, four breeding sites in the Lake Tumba were identified (Figure 6). The core reproduction zone was 100 ha within the largest Bikoro breeding zone.

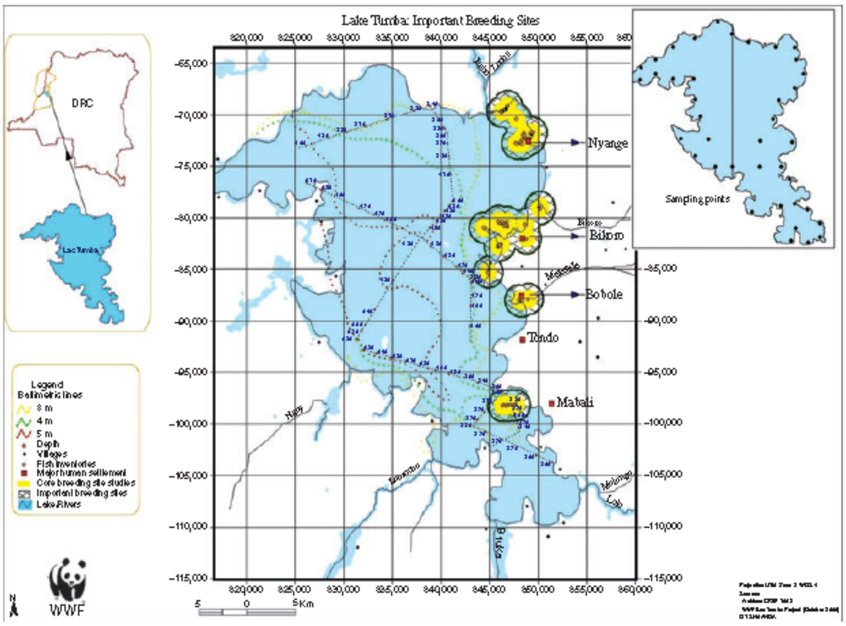


Figure 6. Important *T. congica* breeding sites in Lake Tumba.

The habitat types in which *T. congica* nested, nest substrates, and fish associations in nesting sites are presented in Table 3. *T. congica* chose most (87%) of its nesting sites within habitat where hippo grass *Vossia cuspidata* (48%) and water lily *Nymphaea stellata* (39%) were the dominant vegetation species (Table 2). *T. congica* shared 42% of its nesting sites with other fish species.

Table 3. *Habitat types, nest substrates, and fish associations in Tilapia congica nesting sites in Lake Tumba.*

Habitat		Substrate		Species association	
Type	%	Type	%	Species	%
Vossia cuspidata	48	Muddy	31	*T. congica*	55
Nymphaea stellata	39	Sandy	69	Young *T. congica*	3
Melastoma polyanthum	8			Other fish species	42
Irvingia smithii	4			Other wildlife	0.2
Total	100		100		100

4.3 Congo Island Fish (Paper III)

The habitats of the Congo islands were mainly mixed mature forest (40%); however, different types of monodominant habitats occupied 60% of the total area. The least represented habitat was *Musanga cecropioides* monodominant forest. Clay and muddy substrates were equally represented and were the predominant soil substrates (>90 %) adjacent to the water. Generally, 48% of all islands were eroded and 76 % had human camps. About 70% of the islands were cultivated, with a mean field size of 1.6 ha (range 0.1–3 ha).

Twenty-nine (n=29) fish morphotypes belonging to 13 families were identified (Table 4). The most cosmopolitan species were Clariidae and Cyprinidae, whereas, species whose habitats were most restricted included Alestidae, Chanidae, Malapteridae and Polypteridae. The number of fish morphotypes decreased with depth of the river and with increasing field size on the nearby island.

Table 4. *Number of species and species associations with substrates*

Fish Family	Morphotypes	Clay	Muddy	Mixed
1. Alestidae	3		+	
2. Characidae	1	+	+	
3. Channidae	1		+	
4. Citharinidae	2			+
5. Claridae	5	+	+	+
6. Cyprinidae	2	+	+	+
7. Distichodontidae	3	+	+	
8. Malapteruridae	1			+
9. Mochokidae	2		+	+
10. Mormyridae	6		+	+
11. Notopteridae	1	+		+
12. Polypteridae	1	+		
13. Schilbeidae	1		+	+

5 Discussion

5.1 Documentation of a Resource for Livelihoods and Biodiversity (Paper I)

Lake Tumba is a large shallow humic lake and the fish live in relatively acid water with a pH ranging from 3.6 to 4.6. The acidity and strong color of these waters result from the high concentrations of dissolved organic carbon (Kalff, 2002). Fish have been important for the local diet since people settled on the banks of Lake Tumba. During the last fifty years, the increase in population, and subsequent increased fishing pressure, in combination with changes in the biological, chemical and physical features of Lake Tumba are hypothesized to have caused degradation of the fishery (Akwah and Yoko, 2004).

Between 2005 and 2010, the most commonly caught fish species were *A. occidentalis, C. wagenaari, C. angolensis, T. congica, T. lateralis, and M. anguilloides* (Figure 7). Among the 65 species found in the lake in 1959, one of these was endemic to Lake Tumba, *Lamprologus tumbanus*.

A. occidentalis *C. wagenaari* *C. angolensis*

T. congica *T. lateralis* *M. anguilloides*

Figure 7. Examples of common fish caught in Lake Tumba during 2005-2010.

The diversity index D of the lake was on average D=0.72, with a range of D=0.62 to D=0.82. Possible explanations for the difference in diversity index are the five different fishing occasions over three sites and a variety of fishing intensities, between 13 and 95 days, spread over two seasons (rainy and dry).The number of fish species currently present in Lake Tumba were compared with the data collected in 1959 by Matthes (1964). In 1959, Matthes found 65 species from 12 families in Lake Tumba, whereas, 42 species from 12 families were caught during 2005 and 2010, which was in agreement with the 2005 study conducted by Inogwabini and Zanga (2013).

One striking difference is the greater number of species recorded in the 1959 survey than were identified in the current study. A decline in fish could be expected from the greater pressures on the fish resource. Since the 1950s, the population has more than doubled from ca. 5 to over 13 inhabitants per km^2, and these people are dependent on fish as their major protein source (Akwah and Yoko, 2004).

However, it is difficult to make a quantitative comparison. The study reported by Matthes (1964) fished a larger number of sites, including tributaries, and used different methods, from finer nets to dynamite. The present study was confined to three locations on the eastern part of the lake. Therefore, it is uncertain how comparable these results are to the results presented by Matthes (1964) from 1959.

There was no major skewing of the distribution of the fish length, indicating the fish populations may not have been changed through fishing pressure. Matthes (1964) presented equations for determining the relationship between weight and total length (Equation 1).

$$K = \frac{\sqrt[3]{10^5 \times W}}{L} \tag{1}$$

We predicted the length of the fish caught 2005-2010 based on measured weight and the equations presented by Matthes (1964), including species-specific K values (Figure 8).

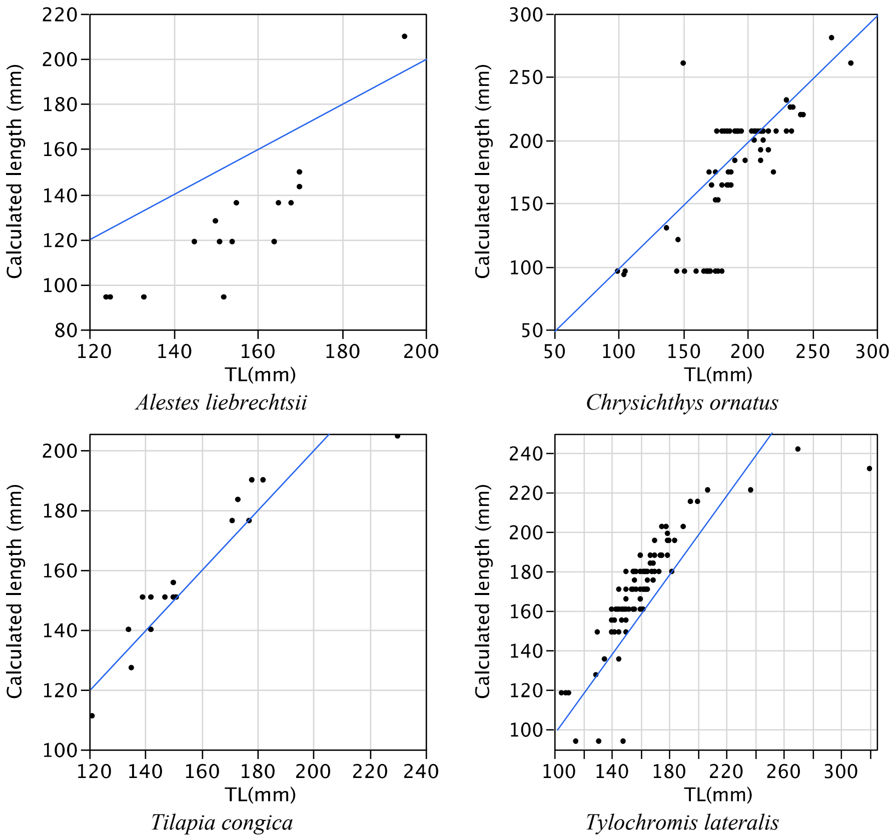


Figure 8. Comparison of measured length (TL, x-axis) with the length calculated (y-axis) from weights measured 2005-2010 using the relationships presented by Matthes (1964). The blue line indicates the 1:1 relationship.

Present fish lengths fitted well with the calculated length and no obvious difference due to change in environmental conditions or fishing was found.

As there was no consistent difference in the length of the longest fish reported for each species from the different studies, this suggested that the changes in the fishery status might not be as dramatic as the smaller number of species caught would suggest. The fish species for which the length ratio has declined are generally species of commercial value, such as *C. gibbosus, D. antroventralis, H. goliath, P. insignis,* and *P. obscura.*

The 42 fish species found during 2005-2010 and the 65 species found in 1959 (Matthes, 1964) can be compared with estimates of fish diversity for African lakes based on lake size, altitude, and mean depth (Amarasinghe and Welcomme, 2002). These estimates vary from 18 to 83 species, with a mean of 40 fish species and are similar to the number of species identified during 2005-2010.

The lake appeared heavily heterotrophic, based on inflow of organic material, both particulate and as dissolved humic substances, low Secchi depth, and high total organic carbon (TOC). The most important paths in the food web are probably allochthonous humic substances that are consumed by heterotrophic bacteria on which both zooplankton, and ultimately the fish population, feed. The lake has a low oxygen concentration (about 5 mg/l), indicating the effect of heterotrophic bacteria.

There is little information on zooplankton in Lake Tumba; however, Kiefer (1957) identified six species of Copepoda and one species of Cladocera (all species found are common in tropical waters), and considers the relatively few species to be caused by the acid water.

Quantitative comparisons of aquatic monitoring need to use consistent and appropriate protocols, and the results from this study identify factors that need to be considered. In order to estimate the fish production/carrying capacity, additional methods have to be used. Standardized gillnets multi-mesh nets, such as EN 14757, of 30 m long and 1.5 m deep and 12 different mesh-sizes ranging from 0.5 to 5.5 cm (maybe 7.0 cm) would improve catches of larger species than in the 2005-2010 catch.

The location of fishing in relation to the distance to the shore will change depending on the season (rainy or dry), as the shoreline retreats/advances 200 m to 3.5 km over the course of the year. Most fish were caught close to the shoreline, which supported findings by Turner (1982) from Lake Malawi (Figure 9) where proximity to the shore was an important factor for the catch. However, for any given location on the lake, the concurrent change of distance to lakeshore and depth between seasons rendered the effect of each single factor difficult to isolate.

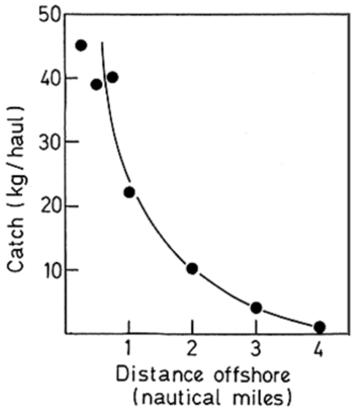


Figure 9. Catch of “Utaka” in Lake Malawi in relation to distance off shore. From Turner (1982).

5.2 The Use of Breeding Sites of Tilapia congica (Thys & van Audenaerde 1960) to Delineate conservation sites in the Lake Tumba, Democratic Republic of Congo: Toward the Conservation of the Lake Ecosystem (Paper II)

The water depths at which *T. congica* nested (mean value 0.23 m, range 0.04–2.2 m) were shallower than described in other African lakes. In Lake Sibaya, South Africa, adult fish of *Tilapia mossambica* (over 8 cm standard length) were usually absent from water deeper than 12 m and shallower than 0–5 m (Bruton and Boltt, 1975). The Lake Tumba nesting depths were also shallower than for *Cyrtocara eucinostomus* (Cichlidae) in Lake Malawi (McKaye, 2004), where breeding site depths ranged between 3 and 9 m.

However, the range of nesting depth in Lake Tumba was similar to that of *Oreochrmomis aureus* in Blue Tilapia (Strong, 2006), and to the exposure of nesting sites in the Sibaya (Bruton and Boltt, 1975). The usage of sandy substrate (70%) for nesting was in agreement with findings on different species in the Cichlidae family across Africa (Bruton and Boltt, 1975).

There is a lack of comparable data on the preferred distance from the shore, however, more than 90% of nest sites were within the range of 51–250 m from the lake shores, with 60% being in the range of 51-150 m. In the interests of conservation, breeding areas should be excluded from fishing activities during the breeding seasons. In addition, *T. congica* shared 42% of its nesting sites with other fish species, suggesting that protection of this particular segment of the breeding site would promote reproduction of other species. It is also advantageous that the likely breeding areas can be identified with the help of map information.

Contiguous nesting sites of *T. congica* occupied a 10 km long breeding band along the lakeshore. Such a large zone (10 km) would provide sufficient habitat for other cohorts of sympatric species. The legal protection of 51–250 m distance from the lakeshores, including 6–10 km long segments of the lakeshore, would protect both species associated with *T. congica* breeding sites and other species and organisms existing in the area.

The largest breeding sites (6–10 km long) were found at the mouths of two major rivers (Ikabu-Looba and Bikoro), and are near or adjacent to major human settlements. The rivers in this region are currently logged and carry tree debris, sand, and soil from forests adjacent to the lake (Inogwabini and Zanga, 2006. Major human settlements in the Congo discharge domestic sewage into the surface water: these discharges contain organic matter that is rich in plant nutrients (nitrogen and phosphorus) that stimulate the production of algae and zooplankton and provide both food resources for fish and microbiological hazards.

A socio-economic study (Innovative Resources Management) on the zoning of the Lake Tumba, including the definition of ancestral territory and culturally valued zones (Yoko *et al*., 2005) emphasized that a zoning process of Lake Tumba would combine both socio-economic knowledge and biological information. Therefore, it is proposed that four zones important for breeding should be excluded from fishing activities during the breeding seasons. These zones are Bikoro; the mouth of Ikabu-Looba-Moliba Ehanga at Nyange, the mouth of Meketele at Bobole, Lolo area and Mabali (Figure 6), which covers ~ 480 ha: a small fraction (0.63%) of Lake Tumba that would be protected during breeding seasons. Although the Mabali breeding site is already included in the scientific reserve, protection has never been enforced because local communities claim the fishing right in their ancestral territory. The remaining three areas (Bikoro, Nyange and Bobole-Meketele) need to be delineated.

The process of excluding these zones from fishing activities should be participatory and target the inclusion of all major stakeholders, including local administrative and political authorities, local communities, the fishing industry, and conservation organizations. As with many other issues related to the management of DRC's natural resources, this process will only be successful when government structures, including those at provincial and local levels, are sufficient to enforce regulations and engage local communities in their responsibilities.

5.3 Islands of the Congo River (Paper III)

The study area lies in the mid-Congo and harbors 206 fish species (Aveling *et al.*, 2003). Although only 29 fish morphotypes were identified, this could be explained by three factors: the selectivity of the fishing gear used meant that not all species in the sampled areas could be caught; the 206 species reported by Aveling *et al.*, (2003) were inclusive of flood plain-adapted fish; and most species lists for the Congo suffer from extensive synonymies.

The species association with substrate type confirmed previous findings (Chapman, 2001). Clarideae and Cyprinideae are found in all habitats and substrates and are abundant and widely distributed in the Congo Basin. The species-habitat associations for Alestideae differed from previous studies (Paugey and Schaffer, 2007; Chapman, 2001), but without long-term ecological studies, the explanations will be difficult to elucidate, although adaptation to changing environments due to physically and chemically modified conditions subsequent to increased soil erosion may be one reason.

The richness in fish species decreased with increasing size of agricultural fields. As larger islands are the most eroded of islands, it is logical to infer that island erosion increased sediment load in the water (Shaw and Richardson, 2001). Sediment loads may affect the physical and chemical properties of the water adjacent to the islands and prevent fish species from finding suitable habitats. Although the effects of modified physical and chemical properties of waters are described in other studies, the variation is case specific (De Robertis *et al*., 2003; Rowe and Dean, 1998). As these previous studies are site-specific, these results cannot be compared with the findings of the 2005-2010 study (Paper I), as increased sediment load in water was not documented in that study.

6 Conclusion and Future Perspectives

Lake Tumba and its landscape is a valuable resource. There is concern about the future, especially as relevant data are scarce and understanding is limited. This thesis attempted to establish the present day fish populations, identify breeding sites that could be protected, and explored the possibility that land use change affects nearby fish populations.

The comparison of the current fish population with that identified in the 1959 survey suggested a decline in species numbers; however, it was difficult to quantify the extent of such changes. It is important to look to the future and build a monitoring system that can detect changes, both negative responses to environmental pressures and positive responses to management measures. Both information on the status of the ecosystem and documentation of the performance of specific monitoring methods for use in reproducing and/or improving these methods are presented.

The focus of this thesis was on scientific methods for assessing fish populations; however, effective management requires an understanding of ecosystem function combined with an understanding of the community, both with regard to its visions and governance, as well as an understanding of the ecosystem that is the base of its livelihood.

7 Résumé (French)

Lac Tumba en République démocratique du Congo, Vers l'évaluation aquatique.

Les moyens de subsistance de la plupart des communautés à travers le lac Tumba 765 km^2 sont fortement tributaires des poissons. La pêche artisanale et d'autres pressions sur l'écosystème aquatique sont susceptibles d'avoir augmenté au cours de cinquante dernières années. Il existe moins de programmes de surveillance pour suivre ces pressions ainsi que leur influence sur l'écosystème aquatique, avec quelques exceptions près.

Cette thèse décrit la population de poissons en utilisant le suivi régulier de la période 2005-2010. Ce suivi a été complété par une enquête sur les sites de reproduction de *Tilapia congica* sur le lac Tumba, et une enquête sur la relation entre l'utilisation des terres et les prises de poissons autour des îles du fleuve Congo.

La capture par unité d'effort (CPUE) et nombre par unité d'effort (NPUE) différaient entre les sites et les saisons, mais aussi avec la profondeur et la distance du rivage. La plupart du poids élevé des poissons était pris entre 3,0 et 4,5 m de profondeur. Cela peut expliquer pourquoi les CPUE étaient plus grande pendant la saison des pluies, alors que la population locale avait de plus grandes prises pendant la saison sèche.

Moins d'espèces (42) avaient été trouvées dans cette étude que les 65 trouvées en 1959. En raison de différences dans les méthodes de pêche, la localisation et de l'effort, il est difficile de tirer des conclusions au sujet de combien la population de poissons avait effectivement changée.

Quatre principaux sites de reproduction étaient identifiés à l'étude de *T. congica*, dont l'un était séparé des autres environs 10 km de long, la plupart des nids étaient trouvés en association avec (*Vossia cuspidata*) et (*Nymphaea stellata*).

L'étude des poissons dans les îles du fleuve Congo avait capturée 29 espèces de poissons. La zone de culture était liée à l'érosion et la plupart d'espèces pondaient à coté de chaque île.

En raison de la demande croissante de poisson, et la probabilité de changement environnemental plus dramatique à l'avenir, il est nécessaire d'élaborer des stratégies de gestion et de gouvernance ainsi un suivi scientifique de l'écosystème sur lequel la gestion est basée.

Mots clefs: Bien être, communauté de poisons, sites de pontes, CPUE, NPUE, gestion, processus de zonage, *T. congica*.

References

Akwah, G. & Yoko, A. (2004). Local management forestry resources and halieutic around Lake Ntomba. Exploratory study of dynamics in perspectives for development conservation. IRM DRC, p 46.

Amarasinghe, U. S. & Welcomme, R. L. (2002). An analysis of fish species richness in natural lakes. *Environmental Biology of Fishes* 65, 327-339.

Anonymous (2005). Monographie de l'Equateur. Comité Provincial de la Stratégie de Réduction de la Pauvreté CPSRP/ Équateur Mbandaka, Ministère du Plan, RDC, p 110.

Anonymous (1998). Monographie de l'Equateur. PND/UNOPS Programme National de Relance du Secteur Agricole et Rural (PNSAR) 1997-2001. Ministère de l'agriculture et de l'élevage, du Plan, de l'Education National et de l'Environnement, Conservation de la Nature, Foret et Pêche, p 334.

Aveling, C., Bofaya, B., Hall, J.S., Hart, J.A., Hart, T.B., Inogwabini, B.I., Plumptre, A. & Wilkie, D. (2003). Democratic Republic of Congo – Environmental Analysis. Final Report – Prepared by the Wildlife Conservation Society. Submitted to USAID Washington DC (USA) and Kinshasa (DRC), p 134.

Bruton, M.N. & Boltt, R.E. (1975) Aspects of the biology of Tilapia mossambica Peters (Pisces: Cichlidae) in a natural freshwater lake (Lake Sibaya, South Africa). J. *Fish Biol.* 7, 423–445.

Chapman, L.J. (2001). Fishes of African rain forests – diverse adaptations to environmental challenge. In Weber W, White LJT, Vedder A, Naughton-Treves L. (Editors) African Rain Forest – Ecology and Conservation: An Interdisciplinary Perspective. Yale University Press, New Haven, United States of America, 263-290.

Colom, A., Bakanza, A., Mundeka, J., Hamza, T. & Ntumbandzondo, B. (2006). The socio-economic dimensions of the management of biological resources, in the Lac Télé – Lac Tumba Landscape, DRC Segment: A segment-wide baseline Socio-Economic study's Report. Submitted to the World Wide Fund for Nature DRC, Kinshasa Office, Democratic Republic of Congo, . p 125.

CBFP 2006. The Forests of the Congo Basin. The State of the Forest 2006. T. C. B. F. Partnership, The Congo Basin Forest Partnership, p 244.

De Robertis, A., Ryer, C.H., Veloza, A. & Brodeur. R.D. (2003). Differential effects of turbidity on prey consumption of piscivorous and planktivorous fish. *Canadian Journal of Fisheries and Aquatic Sciences* 60, 1517-1526.

Froese, R. & Pauly, D. Editors (2013). FishBase World Wide Web electronic publication. www.fishbase.org, version (04/2013). Accessed between 1/2009 and 4/2013.

Inogwabini, B.I. & Zanga, L. (2013). Fish species occurrence, estimates and human activities on the islands of the Congo River, Central Africa. *Environmental Biology of Fishes*, doi: 10.1007/s10641-013-0136-4.

Inogwabini, B. & Lingopa, Z. (2006). Les Inventaires des Poissons dans le Lac Tumba, Congo et Ngiri – Paysage Lac Tlélé – Lac Tumba, Segment RDC. Rapport Produit dans le Cadre du Programme CARPE. Type scripted report to the WWF DRC, Kinshasa, Democratic Republic of Congo, p 24.

Kalff, J.F.J. (2002). Limnology. Inland water ecosystems. ISBN 0-13-033775-7

Kamdem, A.T, Amico.J. Olson, D., Blom, A. Trowbridge, L., Bourgess, N., Thieme, M., Abell, R. Carroll, R.W, Gortlan, S. Langrand, O. Mikala, R., O'Hara, D. & Strand, H. (2006). A vision for biodiversity conservation in central Africa: Biological priorities for conservation in the Guinean-Congolian forest and freshwater region. World Wildlife Fund (WWF) Washington, DC 20037-1193 USA, p 96.

Kiefer, F. (1957). Eine kleine Crustaceenausbeute aus dem Tumbasee (Belgisch-Kongo). *Rev. Zool. Bot. Afr.* LVI, 92-100

Lévêque, C. & Paugy, D. (2006). Les poisons des eaux continentals Africaines: Diversité, écologie, utilisation par l'homme. Institut de Recherche pour le Développement, Paris

Matthes, H. (1964). Les poisons du Lac Tumba et de la region d'Ikela, etudes systematique et zoogeographique, Annals du Musee Royale de l'Afrique central, Bruxelles, Belgiques, p 1-198.

McKaye, K.R. (2004). Ecology and breeding behavior of a cichlid fish, Cyrtocara eucinostomus, on a large lake in Lake Malawi, *Africa. Environ. Biol. Fishes* 8, 81–96.

Mosepele. K. (2008). Flood pulse in a subtropical floodplain fishery and the consequences for steady state management. Proceedings of the Second IASTED Africa Conference September 8-10, 2008 Gaborone, Botswana Water Resource Management (AfricaWRM), p 24

Paugey, D & Schaffer, S.A. (2007). Alestidea. In Stiassny, M.L.J., Teugels, G.G. & Hopkins, C.D. (Editors) The fresh and brackish water fishes of the Lower Guinea, West-Central Africa. Institut de Recherche pour le Développement (IRD/France), Muséum National d'Histoire Naturelle (MNHN/France) & Musée Royal de l'Afrique Centrale (Belgique), Volume 1, 347. 2008. University of Botswana, p 56-62.

Rowe, D. K. & Dean, T. (1998). Effects of turbidity on the feeding ability of the juvenile migrant stage of six New Zealand freshwater fish species. *New Zealand Journal of Marine and Freshwater Research* 32, 21-29.

Shaw, E. A. & Richardson, J. S. (2001). Direct and indirect effects of sediment pulse duration on stream invertebrate assemblages and rainbow trout (Oncorhynchus mykiss) growth and survival. *Canadian Journal of Fisheries and Aquatic Sciences* 58, 2213-2221.

Stiassny, M.L.J. & Mamonekene, V. (2011). Fish diversity in the lake Tumba landscape. Department of Ichthyology, AHMN (American Museum of Natural History). USA, p 24 (ms)

Strong, W.A. (2006). A literature review on Blue Tilapia with emphasis on feeding habits. In: http://fishweb.ifas.ufl.edu/CourseMaterials/Cichra%20Class/BlueTilapia.pdf, Accessed 2006-October-23.

Terje, O.S. & Næsje, T.F. (1993). Feasibility study of fish stock assessment programme in Okavango, Botswana. Norsk institutt for naturforskning, p 58.

Turner, J.L. (1982). Analysis of purse seines and gillnets catch data off Nkhata Bay, Lake Malawi: Fishery Expansion Project, Malawi. Biological studies on the pelagic ecosystem of Lake Malawi. Technical Report: FAO, Rome (Italy). Fisheries Department, p 154-163. www.feow.org, Accessed 2012-April-02.

Yoko, A., Tchunza, G. & Mogba, Z. (2005). Synthe`se des Travaux des Ateliers des Commissions Thématiques Locales dans les sites d'intervention IRM – Province Equateur. Type scripted report submitted to CARPE, Kinshasa, Democratic Republic of Congo, p 96.

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