Aquatic Assessment in the Lake Tumba Landscape, DRCongo

Fish Diversity and Conservation

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Cover: Four fish species from the Bambou stream in 2007
(photo: A. Mputu)

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Abstract

The 80,000 km² Lake Tumba Landscape (LTL) is the only one of the 12 UN Priority Conservation Areas in Africa with a focus on freshwater ecosystems. Surprisingly little though is known about fish in this area. The objective of this thesis is to increase knowledge of fish occurrence in the LTL.

The first paper uses catch statistics to quantify the fish populations in three LTL streams against the background of their physical and chemical environments (Paper I). All the species caught represented 23% of the known Congo Basin fish species. The Lebomo stream had higher catches during the dry than wet season, but this was not the case for the Bambou and Bongo streams. Significant differences in fish species composition between the streams were found, but this probably related more to pH and nutrient status than land use. These streams yield too little fish to be a regular part of the local diet, but the streams may be important reservoirs of biodiversity in the landscape, and also serve as ”sentinels” of change for larger downstream aquatic ecosystems.

The aim of the second paper was to characterize the breeding sites of *Tilapia congica* in order to guide the zoning process for fishery management in Lake Tumba. For this purpose, the nest depths, distances from the shoreline, exposure to sunlight and habitat types were measured. Four extensive groups of breeding sites were located near where tributary rivers entered the lake. All nest sites were exposed to the sun and 90% of sites were within 51-250m of the shoreline. The breeding substrates for *T. congica* are sandy and under hippo grass (*Vossia cuspidata)* (48%) or water lilies (*Nymphaea stellata)* (39%). *Tilapia congica* shared 42% of its nesting sites with other fish species, so protecting the breeding habitat of *T. congica* would likely help other species.

The major overall findings of this thesis are that there is much diversity in the running waters of the LTL, and that knowledge of the location as well as the seasonality of fish breeding patterns can inform better fish management. At this point, it is not clear what effect land use/land cover has on the fishery, but better monitoring can establish a baseline against which eventual changes can be defined in relation to changes in land use and even climate.

Keywords: streams, breeding sites, *Tilapia congica*, fish community structure, fish community composition, Lake Tumba, Lake Tumba Landscape, DRC.

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Dedication

To my father Dianda Ambe Onso Leonard…

Science leads to knowledge, opinion leads to ignorance.
Hippocrates.

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 Mputu, D.A., Willén, E., Bishop, K., Wilander, A., Inogwabini, B.I. (2013). Fish populations and catch statistics in running waters of the Lake Tumba Landscape, DR Congo 2007–2011 *(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.

The contribution of Adèle Mputu to the papers included in this thesis was as follows:

I The respondent led the team that collected the fish in the three streams, identified the fish, and described the physical-chemical environmental characteristics of streams under different land use. The respondent also analyzed the data and led the writing of the paper.

II The respondent participated in the field work and contributed to the writing of the paper. The respondent also identified the breeding sites of fish for the conservation purpose in the Lake Tumba and wrote an initial French language report of the study.

Abbreviations

AD	pre-Anal Depth
ANOSIM	Analysis of Similarity
CCB	Central Congo Basin
CPUE	Catch Per Unit Effort
DAFECN	Département des Affaires Foncières, Environnement et Conservation de la Nature
DRC	Democratic Republic of Congo
IUCN	International Union for Conservation of Nature
LTL	Lake Tumba Landscape
MDGs	Millennium Development Goals
NMDS	Non-Metric Dimensional Scale
NPUE	Number Per Unit Effort
NPS	National Park of Salonga
PD	Prepelvic Depth
SD	Standard Deviation
SEBO	Société d'Élevage de Bandundu Occidental
TL	Total Length
TOC	Total Organic Carbon
UN	United Nations
UNEP	United Nations Environmental Programme
WCS	World Conservation Society
WWF	World Wide Fund for Nature

1 Introduction

The Democratic Republic of Congo (DRC) is a large country with great aquatic resources. Altogether, 3.2% of its total surface area (2,345,000 km²) is covered by surface water which harbors rich biodiversity and an abundance of species (Shumway *et al.,* 2003; Mputu, 2007).

The 80,000 km² Lake Tumba Landscape (LTL) in the Congo Basin is a complex ecosystem with high biodiversity which supports a human population that now exceeds 2 million people. This is probably twice as many as lived there just 25 years ago. The LTL is also one of twelve UN Priority Conservation Areas in Africa, and the only one where the primary conservation interest is the freshwater ecosystem. There are indications that the sustainability of the fish populations in the landscape is being compromised by changes in the form and intensity of land use in the basin (Brooks *et al.,* 2011; Yanggen *et al.,* 2010). Surface waters cover 60–65% of the LTL, depending on season, but little is known about these aquatic ecosystems. The major surface waters in the southern part of the LTL are: the Congo River from Makanza Territory to where the Kwa River flows into the Congo River at Kwamouth; the Fimi, Kasai and Kwa Rivers; the large lakes of the central basin including Lake Maindombe (2,300 km²); Lake Tumba (750 km²) and small lakes such as Ikenge (27 km²), Nkoloetulu (25 km²), Ndeke Ngelo (8 km²) and Etonga (Inogwabini and Mputu, 2010). There are also smaller tributary streams, such as the Bambou, Lebomo, Bongo, Obalakuma, Lokoso, Yala 1 and Yala 2, as well as extensive wetlands and forests that flood. Biodiversity is linked to the diversity of the habitats and each habitat can have distinctive properties. Increased knowledge of the fish resources within the basin and how to use them sustainably can help alleviate poverty and provide alternative sources of protein.

The Congo River with its length of 4,700 km is the second longest river in the world after the Amazon River, and the third in fish species richness among tropical river basins, following the Amazon and Orinoco basins (Brummett *et* *al*., 2009). The river and its catchment occupy a major part of the inland waters of Central Africa (Brooks *et al.*, 2011). Freshwater of the DRC is of paramount interest because the country's streams, rivers and lakes contain a large botanical and zoological diversity with a high level of endemism, as previous studies have revealed. Also in comparison with lotic systems in other parts of Africa, the systems in DRC appear especially rich. The basin's flow regime (40,000m³/s) remains more or less constant throughout the year (Brummett *et al.*, 2009; Lututala *et al.*, 2007; Banister, 1986). However, there is mounting evidence that freshwater ecosystems across the basin have been disturbed and degraded (WCS, 2003). The Congo Basin also supports some logging, and, like the rest of the world, it is experiencing climate change, though the changes on the regional climate are not well characterized.

The Congo as well as the Amazon basins play important roles in controlling both quantity and quality of water in their watersheds or river basins that can influence climate at the regional (Ellison *et al.,* 2012) and global level (Brummett *et al.,* 2009). They have been said to be two important "lungs of the world" because they regulate the climate of the world (Chapman, 2001).

In the DRC, freshwater provides goods and services to people in many ways. It is used for drinking water, and provides food and building materials. The role of the watershed includes sequestering CO_2, cleansing and recycling the waters, delivering nutrients to floodplains, wetlands and estuaries, and moderating the climate, including floods and droughts. The surface waters of the LTL provide services such as transportation and hydroelectric power, maintain biophysical processes, and support a diversity of habitat types. In rural areas, fish are a staple of the diet for many people; whereas in Kinshasa, the capital of DRC, fish is a very expensive food because of the distance from where the fish are caught. When transporting fish from fishing sites to the commercial market, people also worry about encounters with the police and military. Some fishes have a high commercial value, such as *Parachanna obscurus, Protopterus dolloi, Mormyrops anguilloides,* and *Campylomomyrus sp*.

Freshwater ecosystems constitute the major life-line for most rural people. Approximately 80% of the population relies almost exclusively on natural resources for their livelihoods through gathering, fishing, and hunting (Brooks *et al.,* 2011).

People have always derived direct and indirect benefits from the high biodiversity of the aquatic ecosystems, which is why the conservation of the species found here is important for local people's livelihood and the economy (Brooks *et al.,* 2011). Though there is a high diversity in fish, the exact number of species is not known (Banister, 1986). The knowledge of the fish species and their distribution is very unequal across the country because of the difficulties in travelling from one water body to another. Some regions like Pool Malebo, Yangambi, Lake Tumba, and the Congo River Rapids below Kinshasa (Banister, 1986) have been sampled but not regularly. Streams like the Bongo, Bambou, and Lebomo in the LTL, which have relatively small drainage areas (on the order of 1000 km^2), are almost entirely uninvestigated. Thieme *et al* (2005) estimated that there are more than 700 species in the Congo drainage area, more than 70% of which are endemic; however, discovery of new species is made with every new expedition (Chapman, 2001; Stiassny and Mamonekene (2010).

Some of the major threats facing the Congolese freshwater fish diversity are habitat loss and degradation. The use of destructive fishing methods such as dynamiting, as well as using plant poison, clearing of spawning grounds, and other illegal methods that have their basis in pervasive poverty and ignorance, are some of the reasons; others are sedimentation of reservoirs, lakes, and waterways as a consequence of deforestation, and unplanned urbanization, forest fragmentation, and land degradation due to bad forest management practices (logging) as well as slash and burn agriculture. Further reasons are increasing pollution from domestic and industrial waste, chemical and agro–alimentary factories in Kinshasa, and development and growth of many small towns and villages bordering lakes and rivers. A fundamental reason is lack of education in environmental issues. Furthermore, many waters suffer from increasing abundance of invasive species and the discharge of some rivers is affected by existing hydroelectric dams (Inga I and II) and planned dams (Inga III).

A large part of the aquatic ecosystems of DRC and especially its western regions has naturally very acid waters due to decomposition of organic matter from the forests in the tropical climate. The water pH value usually varies between 4 and 6, and the conductivity between 20 and 30 µS/cm (Brummett and Teugels, 2004; Thieme *et al.,* 2005 and Stiassny and Hopkins, 2007) describe the water color of most rivers in the Congo Province as “black” or tea-colored, which is due to humic substances and inflow of allochthonous organic matter from surrounding forests.

In DRC, total fish production is difficult to determine. The most extensive fish inventory and investigation of fish production was made in the littoral zones of the large lakes of the Rift Valley in eastern DRC by Corsi *et al* (1980). However, fish production in medium-sized and small streams is unknown although they have high fish diversity. The fish found here belong to the same families but often differ by genus and species name. The mormyrids are the most abundant fish family, both in larger and in smaller water bodies. The

Congolese decree law on fishing stipulates the dates for the open and closed fishing season, but this law is not respected. Fishing has become a daily activity for many people. The behaviors, fishing methods, and tools used do not guarantee the conservation and protection of fish and their habitats in DRC. People believe that there are several layers of fish in water that harbors fishes dying of old age. This belief is based on the black color of the water and the fact that the people cannot see the bottom of the water and check the water depth. Local people do not believe that if they continue their current practices of overfishing and habitat destruction, fishes will disappear from the rivers and lakes. They have other explanations for reduced fish populations, which are connected to old beliefs and habits.

2 Objectives

The overall objective of this thesis is to improve the scientific basis for managing the fish resource in the LTL. In the first study, this was done by defining the spatial and temporal variability of fish communities from systematic catch statistics in three running waters from 2008 to 2011 against the background of their physical and chemical environment (Paper I). In the second study, we focused on locating breeding sites of the species *Tilapia congica* in the vicinity of Lake Tumba as a basis for fishery conservation efforts (Paper II).

The major questions addressed were:

- I What is the fish composition in terms of species richness and abundance in the Bambou, Lebomo and Bongo streams? Can land use close to the streams be reflected in the fish composition?
- II What is the character of the breeding sites of *Tilapia congica* in Lake Tumba? Is there scientific evidence to support identification of areas recommended for conservation of *T. congica* and other associated species?

3 Material and methods

3.1 Paper I

3.1.1 Study area

This study was carried out in streams in DRC, and specifically in Bandundu Province in the southern part of the LTL at Malebo, the field station run by the World Wide Fund for Nature (WWF) with funding support from the Central African Regional Program for the Environment (CARPE). The characteristics of the streams included are presented in Table 1.

The three streams differ in environmental conditions. There is a mature forest around the Bongo, which has logging, located to the north of the Bambou and Lebomo streams. There is a grassland savanna used for ranching around the Lebomo, and a forest savanna around the Bambou, which has fewer human activities. The pH in the Bambou, the stream with the least human influence in the catchment, is lower than in the Bongo and Lebomo streams, possibly because more places around the stream are covered by swamp forest. The Bongo stream, with logging activities, has clearer water compared to the other two and a different nutrient status. Its total nitrogen (Tot_N) (700 µg/l) and phosphorus (Tot_P) concentrations (50 µg/l) are higher. These streams have never been studied except for a 1-day intensive fish capture in 2010, performed as part of the American Museum of Natural History's Congo Project with a purely taxonomic aim (Stiassny and Mamonekene, 2010).

Table 1. *Physical environmental characteristics of the Bambou and Lebomo streams at Malebo in Plateau District and the Bongo Stream in Maindombe District.*

CHARACTER	BAMBOU	LEBOMO	BONGO
Landscape character	forest savanna	grassland savanna	mature forest
Substrate type	sand, pebble	sand, stone	mud, boulder
Land use	natural	ranching	logging
Climate[1]	Aw	Aw	Aw
Latitude/longitude	S02°29'/E016°30'	S02°57'/E016°55'	S01°95'/E017°10'
Elevation (m) of sampling site	440	380	340
Watershed area (km^2)	1,280	1,043	1,802
Water flow(m^3/s) dry/wet season	0.5/1.1	0.7/1.0	0.4/0.9
pH (mean)	4.7	5.5	5.4
Mean water T°C	23	24	24
Tot_P, mean (µg/l)	24	15	50
Tot_N mean (µg/l)	680	490	700
Color Pt (mg/l)*	150	125	60
TOC (µg/l)	17.3	12.3	7.2

[1] Köppen classification system.

*Water color, calculated from absorbance measurements at 420 nm using a factor based on comparison of color (Pt units) and absorbance measurements at the Swedish University of Agriculture (SLU) laboratory. TOC = Total Organic Carbon; Tot_N = total nitrogen concentration; Tot_P = total phosphorus concentration.

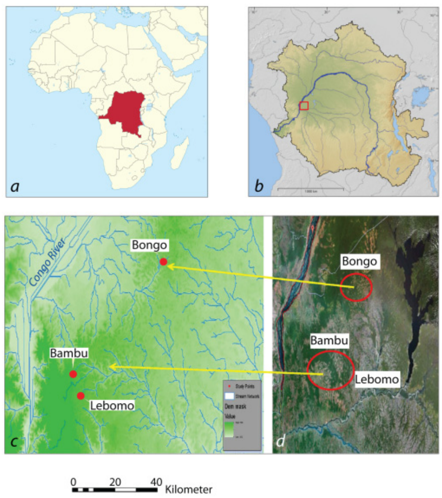

Figure 1. Map of the investigated area in the Lake Tumba Landscape of DRC. a. Congo on the African continent; b. the Congo River drainage area; c. the Bambou and Lebomo streams, which are tributaries of the Leboma river, and the Bongo stream, which is a tributary of the Congo River; and d. satellite image of land covered in the present investigation.

3.1.2 Sampling

The choice of streams was dictated by the land uses (ranching and logging) in the stream catchments. Fishing gear was distributed at ten fishing points on the streams. The distance between fishing points was 200 m. Nets with different mesh sizes, and lines with hooks baited with earthworms were cast in the morning and checked three times a day: at 12:00, 16:00 and 06:00 the following morning. As the width of a stream varied between the fishing points, we moved the nets from one point to the next after each day so that each net was set at each point for 1 day.

The identification keys from FishBase (www.fishbase.org) and the American Museum of Natural History (www.amnh.org) were used for identification. The fishes caught were weighed, and their total length (TL), pre-pelvic depth (PD), and pre-anal depth (AD) were measured (Figure 2).

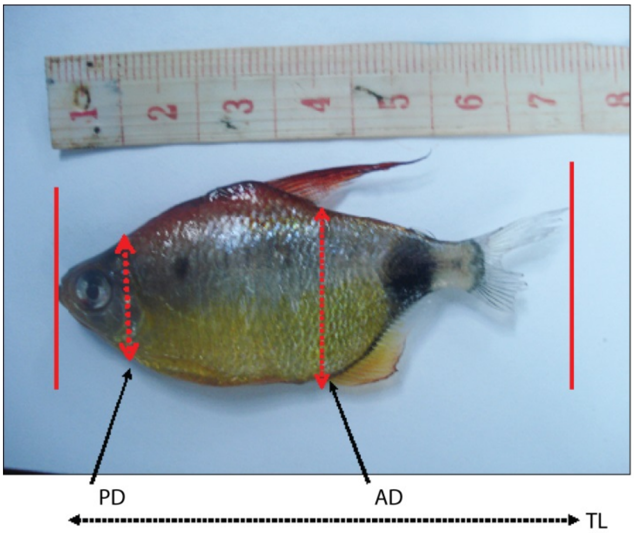

Figure 2. The fish morphologic measurements recorded during the study. The image shows Bathyaethiops greeni.

3.1.3 Environmental variables

A number of environmental variables were recorded for characterization of the streams. These were: water temperature, stream width, water depth, and chemical variables to describe acidity and nutrient status (water color, pH, total organic carbon (TOC), Tot_N, and Tot_P, measured once, in February 2011). The substrate type of the stream and the soil on the stream bank were observed at each fishing point. Also, observations on flooding regime were recorded.

3.1.4 Data analysis

The relative abundance of fish was measured as catch per unit effort (CPUE) and number (of fish) per unit effort (NPUE). This was calculated for the entire set of ten nets and 100 hooks used during 1 day (24 hours). Diversity and similarity calculations were made using the Paleontological Statistics (PAST) software program (Hammer Harper & Ryan, 2001). The flow was calculated based on water velocity (using the floating method), stream width, and water depth (Buchanan & Somers, 1969). Analysis of similarity (ANOSIM) was used for further statistical treatment to study possible differences between sites and seasons (Clarke, 1993). To examine the contribution of separate species, we used the similarity percentages (SIMPER) procedure, which is considered more of an exploratory analysis than a statistical testing. It indicates species that are principally responsible for an observed cluster or for differences between sets of samples. Its discriminating function is the Bray-Curtis Index of Similarity.

3.2 Paper II

3.2.1 Study area

Lake Tumba is a shallow lake (3–6 m depth) in northwestern DRC, in the Bikoro territory of Equateur Province. The lake's surface area is 765 km² but varies with season (Marlier, 1958). Lake Tumba is connected via the Irebu Channel to the Congo River. Water may flow into or out of the lake through this channel depending on whether there is flooding. Lake Tumba is situated in the center of the Tumba–Ngiri–Maindombezone which was designated as a RAMSAR site in 2008. The swamp forest surrounding the lake is inhabited by the Mongo people, who in this area are divided into two castes: the Oto, who farm, and the Twa, Pygmies who fish. The brown and acidic water of Lake Tumba results in low phytoplankton and zooplankton (Corsi, 1984; Bailey, 1986; Mputu, 2007; Inogwabini *et al.*, 2009). The water temperature is about 29–32°C. Matthes (1964) has described the fish community composition in the lake and since 2005–2010, Inogwabini and Lingopa (2006) have performed inventories of fish in the lake. Although tools and methods differed between these two investigations, it was still possible to deduce that the catches of fish had markedly decreased between the 1960s and 2005–2010.

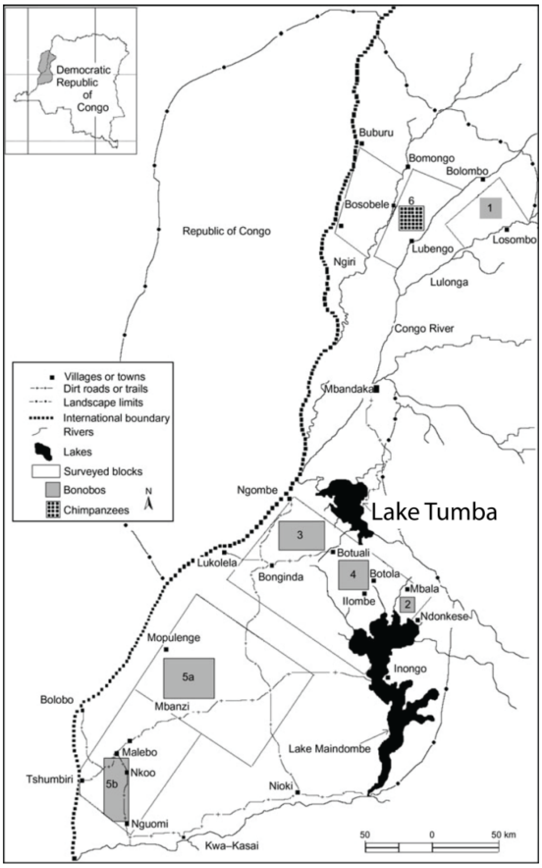

Figure 3. Lake Tumba and its landscape (from Inogwabini *et al.*, 2007).

3.2.2 Sampling

We chose the species *Tilapia congica* because it shares a number of ecological characteristics with other species (feeding ecology, large breeding sites, etc) and the species is easy to identify and follow as an ecological indicator as it lives in association with other species. The species is also used for food.

Once in the field, we asked the local population in which specific part of the lake we could find the spawning sites of *T. congica*, locally named "*Ehete*". A protocol was developed to collect data such as distance from the shore, spread radius, number of nest per site, nest substrate (mud or sand), nest dimensions (length, width, and depth), associated habitat types, and presence of species other than *T. congica*.

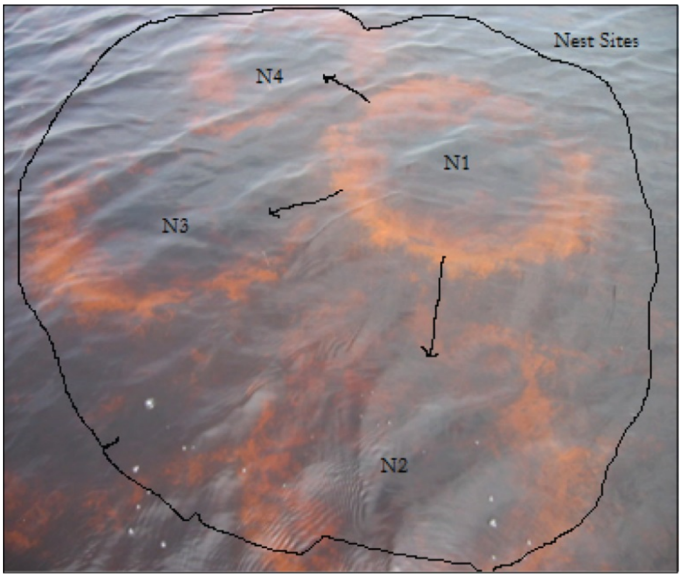

Figure 4. Example of *T. congica* nesting sites under water. N1 to N4 are nests.

3.2.3 Data analysis

To determine if *T. congica* follow a specific trend with regard to distance from the shore, a polynomial regression analysis was carried out. The dimensions of nest were ranked in classes of 20 cm each. The longer axis was the length and the smaller axis was the width. For mapping considerations, geographic coordinates (waypoints) were collected from each breeding site. Coordinates were downloaded onto a computer and recorded on a map.

4 Results

4.1 Fish diversity, community composition and catch statistics with a focus on land-use and other environmental variables (Paper I)

Overall, 2,025 individuals, representing 48 species, 35 genera, 15 families and eight orders, were collected in the three streams, the Bambou, Lebomo, and Bongo, from 2007 to 2011. The Lebomo, which is surrounded by ranching activities, was home to 35 species, seven of which were not found in the other two streams. The Bambou, which is less affected by human activities, hosted 31 species, six of which were only found in its waters. The Bongo had 27 species, six of which were not found in either of the other streams. The diversity indices in all streams were high when based on both types of fishing gear: nets and hooks.

As revealed by Table 2, based on NPUE or CPUE values and expressed as both number and catch per day, the Bambou stream had an NPUE varying between 9 and 24 fishes/day and a CPUE varying between 271 and 555 g/day. The Lebomo stream has between 2 and 10 fishes a day with the catch varying between 98 and 536 g/day. The Bongo stream has between 5 and 30 fishes a day with a catch between 170 and 1116 g/day.

Many fish species reproduce during the wet season when forests are flooded. When the dry season comes and the flood waters recede from these refuges, the fish are flushed from the forest into the streams, rivers and lakes, making them easier for people to catch.

New species were discovered with every new sampling. Figure 5 supports the belief that Central Congo Basin (CCB) waters would prove to be the most biodiverse in the world if they were sampled comprehensively.

Table 2. *Catch as number of fishes per unit effort (NPUE) and as catch (weight in grams per unit effort) for the three streams. The unit of effort was one day.*

Stream	Year	Season	Fishing days	NPUE fish/day	CPUE grams/day
Bambou	2008	Dry	5	14	430
Bambou	2008	Wet	18	24	555
Bambou	2009	Dry	2	11	455
Bambou	2010	Dry	11	10	367
Bambou	2010	Wet	10	9	497
Bambou	2011	Wet	10	9	271
Bongo	2008	Dry	8	29	1094
Bongo	2008	Wet	8	5	170
Bongo	2009	Dry	7	14	451
Bongo	2009	Wet	6	26	765
Bongo	2010	Dry	6	30	1116
Bongo	2010	Wet	8	6	390
Lebomo	2008	Dry	7	10	525
Lebomo	2008	Wet	7	8	270
Lebomo	2009	Dry	13	8	361
Lebomo	2009	Wet	5	7	350
Lebomo	2010	Dry	10	2	116
Lebomo	2010	Wet	15	2	98
Lebomo	2011	Wet	9	10	536

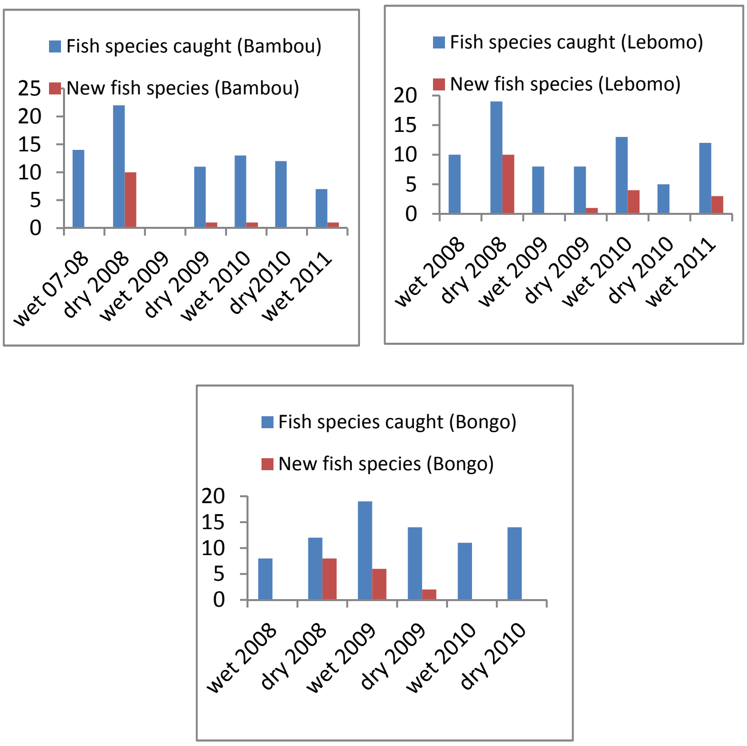

Figure 5. Successive identification of fish species not previously reported for the area, during the years and seasons (wet and dry) indicated in the Bambou, Lebomo and Bongo streams.

The tests done for evaluation of possible differences in abundance of separate net-sampled species, using ANOSIM, between the dry and wet seasons did not show any differences. There was, however, a difference in species occurrence and abundance between the streams. This was most pronounced for the Bongo stream compared to the other two streams (Figure 6). A certain overlap existed between the Bambou and Lebomo, but they also had a significantly different community structure (Global R=0.494, p=0.001).

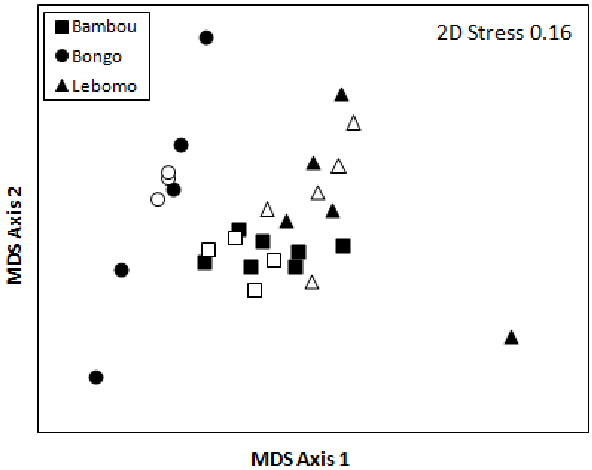

Figure 6. Non-metric multidimensional scaling (NMDS) ordination plot showing the relationship in fish community composition (number of specimens and species) between sites and sampling seasons. The similarities of the fish communities are visualized in a two-dimensional plot, where white symbols represent dry seasons and black symbols represent wet seasons.

There are some differences in water quality between the streams. The pH in the Bambou, the stream least affected by human activity, is lower compared to the others, which have ranching and logging. The Bongo with logging activities has clearer water compared to the other two, but quite a different character as to its nutrient status. Phosphorus is often the most limiting nutrient for primary producers. Its concentration in Bongo was two or three times higher compared to other streams and this may support a higher catch in Bongo than in the other streams (cf. Table 2).

4.2 Characterization of *Tilapia congica* nests and fish associations in nesting sites (Paper II)

A total of 70 spawning sites and 553 nests were identified. The number of nests per site varied between one and 23, with a mean of eight (Table 3). The nesting sites of *T. congica* in 90% of all investigated sites were found to be located between 51 and 250 m from the shoreline. The majority (60%) were located 51–150 m from the shore.

Table 3. *Nest dimension per categories.*

Dimension	Large axis		Small axis	
Range (cm)	N	%	N	%
0-20	7	1.3	3	0.5
21-40	8	1.4	27	4.9
41-60	80	14.5	163	29.5
61-80	276	49.9	290	52.4
81-100	153	27.7	64	11.6
101-140	29	5.2	6	1.1
Total	553	100	553	100

Altogether four extensive breeding sites were identified near the confluences of tributary rivers with the lake (Figure 7). *T. congica* nests in habitats where hippo grass *Vossia cuspidata* (48%) and water lily *Nymphaea stellata* (39%) dominate. *T. congica* shared 42% of its nesting sites with other fish species (Table 4).

Table 4. *Habitat types, nest substrates and fish associations in nesting sites.*

Habitat		Substrate		Species association	
Type	%	Type	%	Species	%
Vossia cuspidata	48.2	mud	30.6	*T. congica*	55.36
Nymphaea stellata	39.1	sand	69.4	young *T. congica*	2.64
Melastoma polyanthum	8.3			other fish species	41.8
Irvigna smithii	4.4			other wildlife	0.19
Total	100		100		100

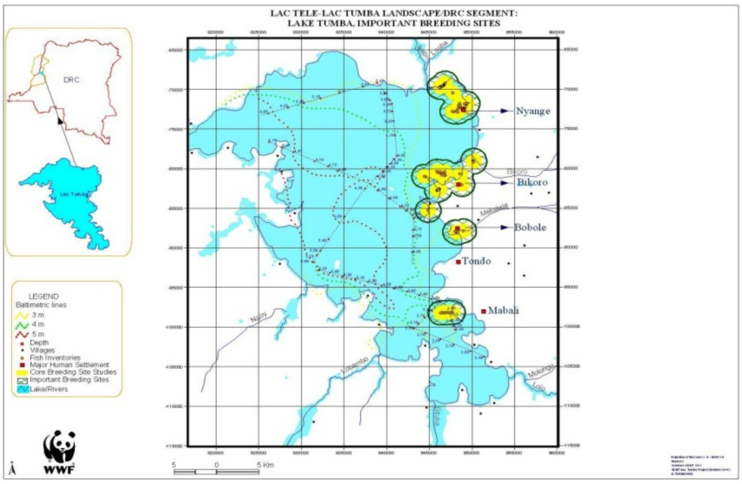

Figure 7. Important breeding sites of *T. congica* in the eastern parts of Lake Tumba. Source Inogwabini *et al.,* 2009.

5 Discussion

5.1 Paper I

The Cuvette Centrale is home to a total of 206 fish species, eleven (5%) of which are endemic to the DRC (WCS, 2003). In this study, 48 species, or 23% of the recorded Central Congo Basin (CCB) fish fauna, were caught. Among the species caught was *Protopterus dolloi*, an endemic species (Banister, 1986; Chapman, 2001). Catfish represent 7% of fish caught in these streams. The percentage of catfish out of the total number of fish in the Cuvette Centrale is higher, 21% (Chapman, 2001). The demand for fish, based on need of fish consumption and commerce, in the Cuvette Central outstripped the supply already in 1983 (DAFECN, 1983), and since then the population has more than doubled (Ministère de Plan, 2005). Today, the production of fish has probably further decreased due to several environmental threats within the CCB, such as urban sewage, dams, erosion, overfishing, logging, cattle farming, industrial pollution, mining, and petroleum exploitation (WCS, 2003).

The Bongo had 27 species altogether, compared to 31 and 35, respectively, for the Bambou and Lebomo. There were 16 species shared by all three streams. Stiassny and Mamonekene (2010) collected ten and 27 species in the Lebomo and Bambou, respectively, with only three species found in both streams. Two species not previously found in the area, *Paramormyrops kingsleyae* and *Raiamas christyi*, were discovered in their investigation.

Staissny and Mamonekene's investigation (2010) was purely taxonomic. Their sampling was based on one single day and involved different sampling tools, whereas during the present study, fish data were collected from 2007 to 2011 and the approach was more ecological. From a diversity point of view, our results can be compared to those from the Luilaka and Salonga Streams in the Salonga National Park (SNP) northeast of our study site, where Inogwabini (2005) captured 30 fish species of fish and identified another 26 based on interviews with fishermen. The Alestidae family was represented by six species in Salonga and five at Malebo, but no species was recorded at both sites.

This study confirms that new samplings still result in new species being found in Cuvette Centrale and particularly in the LTL. This supports the argument that the CCB has a wide variety of fish species (UNEP, 2002). Four species were classified as either vulnerable (VU) (*Clarias submarginatus*, *Chrysichthys dendrophorus*, and *Clupeocharax schoutedeni*) or data deficient (DD) (*Alestes comptus*), according to the International Union for Conservation of Nature (IUCN) red list.

Regarding diversity, this study shows no difference in terms of the Simpson Diversity Index between the dry and the wet seasons when looking at the total of 2,025 fish specimens collected. Headwaters have been considered as having lower diversity compared to bigger rivers and this may generally be true; however, this study reveals a fairly high diversity also in streams. A significant difference in fish community composition was found between the streams, but no significant difference was found between the seasons as there was some overlap (see Figure 6). Lack of fish investigations in many of the intermediate-sized streams and rivers of the Cuvette Central makes any generalizations difficult.

It was difficult to find differences between years, seasons, and streams, according to our results based on either NPUE or CPUE (Table 2). Such small catches make it impossible for people living near these streams to rely on protein from fish to feed their families, which have a mean family size of around eight. Consequently, the people have to rely on protein from other foods rich in protein, like beans and bush meat. One of the questions to be answered in this study was to compare catch by season as local people claim that they catch more during the dry season than the wet season. According to this study, that was confirmed only for the Lebomo stream. The explanation for this might be that the local people use different fishing gear and strategies.

Apart from different phosphorus concentrations, the Bongo is more shaded by the forest canopy, and pH also seems to be a distinguishing environmental variable between the streams (Table 1, Paper I), especially between the Bongo and the Bambou. The lower pH in the Bambou Stream is the result of a high content of organic matter; the water is the color of dark tea because of surrounding swamp forests.

The species recorded in this study mainly have competitive ability in the reported acidity range (pH 6–7), according to FishBase data, although they apparently also survive and are able to reproduce under more acid conditions. Studies from these three streams are valuable in the sense that they increase the knowledge of species tolerance especially to very acid environments (pH <5).

The temperature preferences reported by FishBase for the species coincide with temperatures recorded in this investigation (22–25°C).

Aquatic ecosystems are particularly vulnerable to environmental change, and for this reason, they are considered as sensitive indicators of environmental change both locally and globally (Williamson *et al.*, 2008). In this study, it was difficult to establish the impact of cattle farming and logging around the streams. Further studies should aim to investigate this issue.

It is probable that the CCB is home to fish species not yet described, as has been suggested by this study. To research and record the total species richness, studies on fish identification should be extended to more of the streams in the whole Congo Basin. The physical, chemical, and environmental variables studied in this investigation also give an indication of water quality in this region.

It is recommended to establish a monitoring program in this region of DRC to develop a database not only of fish, but also of other aquatic organisms in the food web. This information might successively lead to recommendations for a more sustainable use of the fish resource.

5.2 Paper II

The study of breading sites of *T. congica* has given an insight into the biophysical and ecological characteristics of this species. The study has allowed us to identify the parameters that could guide development of a good conservation strategy for *T. congica* and sympatric species in the lake, as well as in other, similar aquatic systems. Therefore, this paper presents a model for determination of conservation areas in aquatic environments. The important elements for this model are riparian vegetation, depth, and substrate. Regarding substrate, in the case of *T. congica*, the habitat of choice was characterized by *V. cuspidata* and *N. stellata* on a sandy substrate. These results are consistent with those of previous studies undertaken in other lacustrine environments (Genner, 1999; Inogwabini, 2006). The majority of nests were situated in a band 50 and 150 m from the shoreline. If we want to preserve the species *T. congica* and sympatric species, we will need to protect areas with *V. cuspidata* and *N. stellata* or vegetation of similar structural appearance and with a sandy substrate. This could be accomplished by banning fishing within 300 m of the shore where breeding sites are to be protected. If these breeding sites are not protected, we suspect that this will lead to a depletion of *T. congica* and its co-occurring species. The biggest threat in this lake is that there is no restriction in fishing periods. Fishing is a daily activity of all the villagers around Lake

Tumba. This is justified by the fact that fishing is the only guaranteed source of income and protein for the villagers.

To protect *T. congica* and its co-occurring species, the Congolese State should protect areas from 300 m of lake shores in confluence areas with tributaries. In addition, the State should implement laws on the exploitation of fish resources of Congolese aquatic ecosystems in general and Lake Tumba in particular, by identifying fishing zones based on the nesting areas of *T. congica* defined in this work. This would be one way to reduce the risk of depleting important edible fish stocks in Lake Tumba. Another more advanced strategy would be to restrict fishing by determining maximum sustainable yield and a minimum protection area of spawning grounds. But to do this requires more knowledge of the ecosystem.

6 Conclusions and future perspectives

It is true that the DRC has a high biodiversity because of its variety of habitats and its location in the CCB, which is considered a second pair of “lungs of the world” (WCS, 2003). We have shown that smaller as well as larger watercourses can have high fish diversity. Growing human settlement and increasing populations seem to be an imminent threat to the maintenance of this diversity, through destruction of aquatic habitats. In the CCB, many threats, such as urban sewage, dams, erosion, overfishing, logging, ranching, industrial pollution, as well as mining and petroleum exploitation, can threaten aquatic biodiversity. However, at Malebo, this study could not reveal any impact of logging and ranching, either on fish composition and structure or on water quality.

Small rivers or streams are a very important part of the aquatic system because they act as channels where nutrients from a catchment are carried down to larger rivers and lakes. As the water quality depends on conditions in a catchment, protection is important.

Scientific data at Malebo and generally from the DRC, are scarce. It is a matter of urgency to continue collection of data on fishes and various physical–chemical and other relevant environmental parameters in the region. The knowledge and understanding gained will contribute to a better basis for human welfare in the region.

To determine the aquatic status of the LTL, data on both abiotic and biotic conditions should be combined for a good understanding of the current conditions and prediction of their future state.

It is also important to enhance awareness, in the local population, of the protection, conservation, and sustainable management of the natural resources which they so heavily depend on. Even if small streams cannot meet the needs for fish protein of the local population, the protection of the species could nevertheless improve sustainable fish production downstream.

To prevent overfishing, the people need education on use of other sources of protein in addition to fish, such as beans and soy beans or bush meat.

Even without knowledge about fish population structures in the LTL and how much they may have changed in recent years, it may be possible to improve fish abundance and biodiversity by regulating levels of harvest and fishing techniques, as well as managing land use impacts. There is a need to educate people on environmental issues and thus to improve sustainable management and conservation of aquatic resources.

Based on the foregoing, we rely on the government's desire for implementing legal instruments for regulating an open and a closed fishing period. An integrated conservation management plan is also needed in the LTL to improve population livelihood.

Freshwaters are still largely un-researched in DRC despite the country's extensive surface waters. It is recommended to train personnel in this field and develop infrastructure and equipment (laboratories) for testing water quality and the aquatic biota. Assistance from universities and governmental and nongovernmental institutions in this regard would be welcome.

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