Length at maturity and gillnet selectivity of Lake Tana's *Barbus* species (Ethiopia): Implications for management and conservation

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Lake Tana's 15 large Barbus *species form the only known intact endemic cyprinid species flock left in the world. The barbs contribute around one third of the total annual catch of the motorised commercial gillnet fishery which was introduced in 1986. A dramatic reduction of the adult* Barbus *stocks and the even lower proportion of recruits at the end of the 1990s, show the necessity for the development, implementation and control of fisheries legislation in Lake Tana. The reproductive biology of the* Barbus *species, essential for fishery management, is poorly known. This paper presents results on size at maturity, size at harvest and gillnet selectivity curves, which can be used to provide a scientific base for management proposals. Size at maturity varied widely among the* Barbus *species, ranging from 18.8 cm in* Barbus brevicephalus *to 44.3 cm in* Barbus crassibarbis. *Males matured at smaller size and reached smaller maximum length than females. Estimated selectivity curves fitted closely or were slightly larger than the observed length-frequency distribution of the commercial catch. The vast majority (85%) of barbs landed by the commercial gillnet fishery were mature. Fishing pressure on juvenile, immature fish is unlikely to be the cause of the observed decrease in* Barbus *stocks. Size control regulations like mesh size restrictions, intended to protect the immature part of fish populations are expected to have little positive effects on the* Barbus *stocks and are therefore not recommended. The drastic reduction in barbs during the 1990s is most like due to recruitment overfishing, that is, poorly regulated high fishing effort by the commercial gillnet fishery on the spawning aggregations of adult barbs during their annual breeding migration in river mouths and surrounding floodplains. Only effort control regulations limiting the gillnet fishery in the spawning season and/or areas will prevent a total collapse of the* Barbus *stocks as has happened to other cyprinids in African lakes. Such measures have to be implemented urgently to guarantee the conservation of Lake Tana's unique biodiversity as a sustainable source of cheap protein and as a natural laboratory to study the evolutionary processes underlying speciation in freshwater fish.*

Keywords: Africa, Cyprinidae, recruitment overfishing, reproductive segregation, species flock, sustainable fisheries

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Introduction

Experimental trawling conducted at 12 stations both in 1991 to 1993 and 1999 to 2001 showed a sharp decrease (up to 70%) in abundance of the endemic *Barbus* species (Cyprinidae) in the Bahar Dar Gulf of Lake Tana over this decade (de Graaf et al., in press). This severe reduction of the *Barbus* stock and the concerns of local fishermen claiming decreased catches in the Bahar Dar Gulf, emphasize the necessity of the development, implementation and control of fisheries legislation in Lake Tana.

Lake Tana, the source of the Blue Nile, is situated at an altitude of 1830 m, in the north-western highlands of Ethiopia. The oligotrophic, shallow lake (average depth 8 m, maximum depth 14 m) covers an area of c. 3050 km^2 and is by far Ethiopia's largest lake, containing half of the country's fresh water supply. The lake's ichtyofauna is effectively isolated from the lower Nile basin by 40 m high waterfalls, at Tissisat ('smoking waters'), 30 km downstream from the Blue Nile outflow.

Traditionally, the fisheries in Lake Tana consisted of a low impact subsistence fishery, operated from reed boats by the Woito people (an ethnic minority) and is limited to the shore areas, using locally made fish traps, hooks, fishing spears and small gillnets (length 15–20 m). The introduction of motorised boats and longer, more efficient, nylon gillnets in 1986 offered new opportunities for fishermen. Most interestingly, the Woito people did not benefit from this development but a new group of Amharic (the ethnic majority) fishermen started operating. Their fishing area was extended to deeper, offshore waters and to distant river mouths (Wudneh, 1998; de Graaf, in prep). Total catches of the commercial gilllnet fishery increased rapidly from 39 metric tonnes (MT) in 1987 to 360 MT in 1997 (LFDP, 1997; Wudneh, 1998). *Barbus* species, *Oreochromis niloticus* (Cichlidae) and *Clarias gariepinus* (Clariidae) each form around a third of the catch.

The large, hexaploid barbs of Lake Tana form, as far as we know, the only remaining intact species flock of large cyprinid fishes in the world. The latest revision of these unique fish, recently completed, resulted in the distinction of 15 *Barbus* species, eight of which were new to science (Nagelkerke and Sibbing, 1997, 2000). Although the taxonomy of the large barbs of Lake Tana has received attention of ichthyologists for the last century (Boulenger, 1911; Bini, 1940; Banister, 1973; Nagelkerke et al., 1994; Mina et al., 1996; Nagelkerke and Sibbing, 2000; Sibbing and Nagelkerke, 2001), many questions on their reproductive biology are still not answered. Detailed information on gonad development, size at maturity, spawning area, and spawning period of each of the 15 species is scarce, fragmented and sometimes unreliable due to limited sampling, misidentification or lumping of species (Nagelkerke and Sibbing, 1996; Wudneh, 1998; Dgebuadze et al., 1999). Information on the reproductive characteristics of the *Barbus* species is required in order to advise on management measures to protect the reproductively active part of the population. Such measures could involve the introduction of a minimum mesh size and closed seasons and/or areas. Proper fisheries management requires that fishing gear harvest large mature fish while allowing the small juveniles to escape (Armstrong et al., 1990), that is, size at harvest is larger than size at maturity. If the length at first harvest is correctly determined, a stock is more likely to be sustained and the yield optimized.

This paper is part of a larger study (de Graaf, 2003) to reconstruct the development of the *Barbus* stocks and related fisheries since the 1980s and to compare the characteristics (selectivity, allocation of effort) of the commercial gillnet fishery with the life history traits of the different *Barbus* species. Here we focus on size at maturity of the barbs and size selectivity of gillnets used by Lake Tana's commercial fishery in order to provide a scientific base for advice on mesh size regulations. The results of this study will also provide essential data for gaining insight in the evolutionary processes underlying speciation within Lake Tana *Barbus*. The actual differences in reproductive characteristics and spawning patterns help to explain if and how mechanisms that prevent interbreeding have evolved within the species flock.

Materials and methods

Length at maturity

Throughout 1999 to 2001, monthly experimental gillnet and trawl programs, using a variety of mesh sizes (3.2, 4.4, 6, 8, 10, 12 cm stretched mesh), were conducted for sampling the southern Bahar Dar Gulf and the mouths of the four permanent contributing rivers (Figure 1). More than 30,000 fish were analysed in the laboratory to determine the reproductive characteristics for each of the 15 *Barbus* species. Fork length (0.1 cm), total weight (0.1 g) and gonad weight (0.01 g) were measured and the gonad developmental stage (1–7 according to De Silva et al. (1985) and Pet et al. (1996)) was determined for each fish. Females and males were considered sexually mature if they had

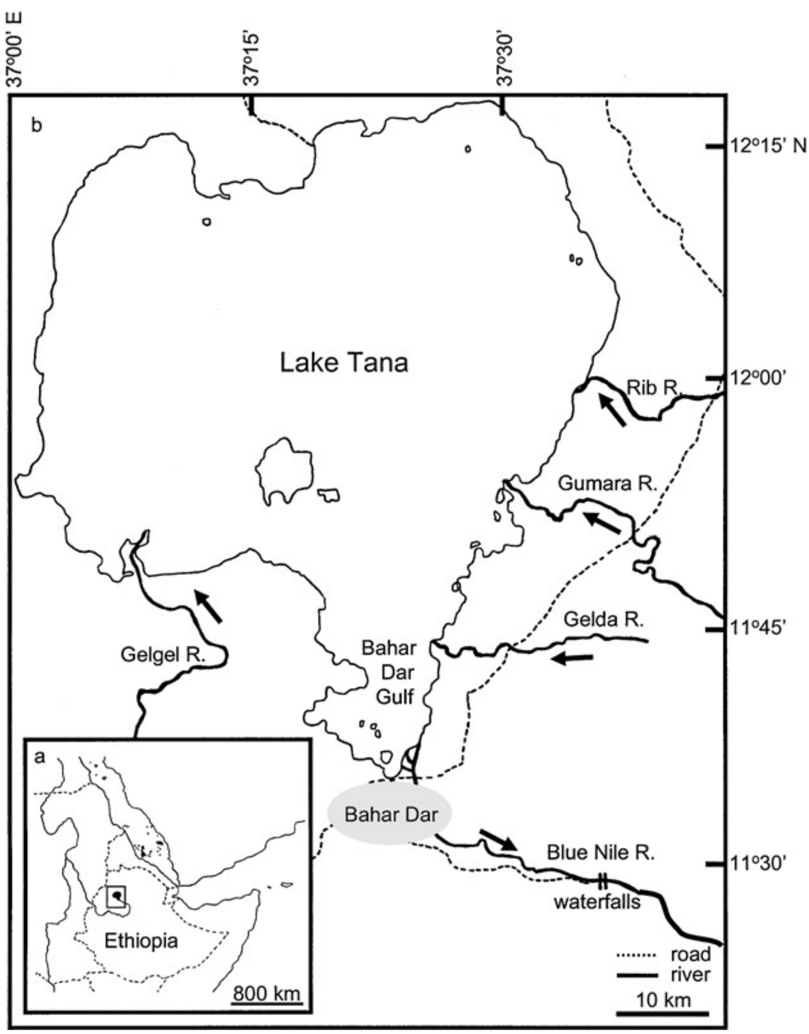

Figure 1. (a) Location of Ethiopia in the Horn of Africa. (b) Lake Tana and its main in- and outflowing rivers.

reached gonad developmental stage 4 or higher. The mean fork length at first maturity ($FL_{50\%}$) was defined as the fork length at which 50% of all the females (or males) were sexually mature. Only fish collected in the 3 peak spawning months of 1999 to 2001 were used for the analysis (July–September, *B. intermedius* "shore-complex" (SC)*, B. dainellii, B. longissimus, B. megastoma, B. truttiformis, B. tsanensis*; August–October, *B. acutirostris, B. brevicephalus, B. crassibarbis, B. gorgorensis, B. gorguari, B. macrophtalmus, B. nedgia, B. platydorsus*; November–January, *B. surkis* (de Graaf et al., unpubl. data)).

Mature-immature data were analysed for each *Barbus* species and sex separately using logit regression (Ter Braak and Looman, 1995). In the generalized linear model, the response variable p_i was defined as:

$$p_i = n_i(\text{mature})/(n_i(\text{immature}) + n_i(\text{mature}))$$

where p = response variable (fraction mature fish); n = number of fish; i = fork length. The response variable p_i has a binominal distribution (Sokal and Rolf, 1995). The expected value of the response variable (p) was linked to the linear predictor by a logit function g(M):

$$g(M) = \ln(p_i/1 - p_i)$$

where g(M) = expected value of mature fish and M = overall mean. The linear predictor for the expected fraction of mature fish was defined using the following

Table 1. Sample size (n) and size range (minimum, maximum cm FL) used for girth measurements and calculation of the selectivity curves for each *Barbus* species in 1991–1993 and the sample size (N) of the specimens used to determine the length-frequency distribution of each species in 10 cm stretched mesh gillnets. Note that girth measurements of *B. intermedius* SC and *B. tsanensis* were pooled in 1991–1993 for calculation of the selectivity curves.

	Estimated Selectivity Curves			Observed L-F Distribution
	n	min FL	max FL	N
B. acutirostris	415	10	46	567
B. crassibarbis	—	—	—	97
B. dainellii	—	—	—	43
B. gorguari	131	12	59	79
B. gorgorensis	67	18	59	287
B. longissimus	78	9.7	39	142
B. macrophtalmus	265	8	46	807
B. megastoma	114	8.5	77	912
B. nedgia	104	10	56	163
B. platydorsus	277	9.5	55	750
B. surkis	35	9.6	35.5	450
B. truttiformis	131	10	35.5	797
B. tsanenis	—	—	—	1449
B. intermedius SC	—	—	—	2640
B. intermedius SC/*tsanensis*	1004	5	36	—

model:

$$g(M) = M + fl_i$$

where fl_i = effect of i^{th} fork length. This procedure was implemented using PROC GENMOD of the SAS software package (SAS Institute Inc., 1990). The 95% confidence limits of the fitted value were calculated as described in the GENMOD procedure manual.

Gillnet selectivity

Gillnet selectivity can be predicted from measurements of a species' head girth and maximum girth if gilling and wedging of the fish are the main ways of capture upon swimming into the net. Theoretical selectivity curves were derived by Sechin (1969) and Kawamura (1972) assuming that 1) all fish are captured whose head girth is smaller than, but maximum girth is greater than the mesh perimeter and 2) that girth among any particular size class of fish is distributed normally, with a common variance for all length classes. In this study we used an extended Sechin model as described by Pet et al. (1995). In this model a constant coefficient of variation in body girth was assumed. Optimum fork length (FL_{opt}) was defined as the length of a fish (FL) predicted to be retained most efficiently in a 10 cm stretched mesh gillnet.

In 1991–1993 Wudneh (1998) estimated girth-length relationships for most of the *Barbus* species (Table 1) as well as for *O. niloticus, C. gariepinus* during an experimental trawl program in the southern Bahar Dar Gulf. Fork length and girth circumference (maximum, head) were measured to the nearest mm for the individual fish. Not enough girth data were collected to estimate accurate selectivity curves for *B. crassibarbis* and *B. dainellii*. *Barbus brevicephalus* is a small-sized species (max. 25 cm FL) not retained in the gillnets of the commercial fishermen that use 10 cm stretched mesh. It was therefore not analysed. The girth data of *B. tsanensis* and *B. intermedius* SC were pooled, due to identification problems in 1991 to 1993.

Barbus species composition

Data on species composition and length-frequency distribution of the different *Barbus* species, and of *O. niloticus* and *C. gariepinus* in the catch of the commercial gillnet fishery were collected monthly from June 2001 to December 2001. On three consecutive days per month all *Barbus* and a sample of around 300 *O. niloticus* and 200 *C. gariepinus* landed by the motorised boats in Bahar Dar were identified and measured to the nearest 0.5 cm. Roughly 80% of the total annual *Barbus* catch is landed during these 7 months (Wudneh, 1998; de Graaf, unpubl. data).

Additional data on length-frequency distribution for the *Barbus* species were taken from an experimental gillnet program in the period October 1999 to September 2001 (de Graaf, unpubl. data). Only fish caught in 10 cm stretched mesh gillnets of the experimental gillnet program were used for the assessment of gillnet retention, as this is the same mesh size used by commercial fishermen. Modal fork length (FL_{mode}) was defined as the length of a fish (FL) observed to be retained most efficiently in a 10 cm stretched mesh gillnet.

Results

Length at maturity

The relation between the proportion of mature fish (≥ stage 4) and the fork length (cm) of the 15 *Barbus* species is given in Figure 2 and Table 2. In general, male *Barbus* mature at a smaller length and attain a smaller maximum length than females. No reliable maturity curves could be estimated for the males of some species. This was probably caused by a lack of small males in the sample (*B. brevicephalus*), a small overall sample size (*B. gorgorensis, B. gorguari, B. longissimus, B. surkis*) and the lack of a short peak spawning season (*B. intermedius* SC). The female maturity data are more complete over the whole size range for each species. The estimated $FL_{50\%}$ differs widely between the females of the different *Barbus* species from as small as 18.2 cm FL in *B. brevicephalus* to as large as 44.1 cm FL in *B. crassibarbis*.

Gillnet selectivity

The results of the gillnet selectivity estimates obtained by applying the Sechin method and the observed length-frequency distribution for the various *Barbus* species are presented in Figure 3. The mode of the actual length-frequency distribution is similar (*B. intermedius* SC, *B. gorgorensis, B. gorguari, B. longissimus, B. megastoma, B. platydorsus,* or (slightly) smaller (*B. acutirostris, B. macrophtalmus, B. nedgia, B. surkis, B. truttiformis* and *B. tsanensis*) than the optimum length predicted by the Sechin method.

Morphological variety is high among the *Barbus* species (Nagelkerke and Sibbing, 2000) which is reflected in the FL_{mode} of the different species ranging from 30 cm FL (*B. tsanensis*) to 37 cm FL (*B. longissimus*). Some species (*B. crassibarbis, B. dainellii, B. gorguari*) displayed more than one mode, most likely due to the relatively low numbers of individuals (n < 100) caught for these species.

The $FL_{50\%}$ is larger than FL_{mode} in *B. crassibarbis, B. gorgorensis, B. gorguari, B. longissimus* and *B. platydorsus*, smaller than the FL_{mode} in B. *dainellii, B. intermedius SC, B. macrophtalmus, B. truttiformis, B. tsanensis* and roughly equal to the FL_{mode} in the remaining species (Figure 3, Table 3).

Barbus species composition

Barbus intermedius SC is in number by far the most dominant species (37.9%) in the catch of the commercial fishery using 10 cm stretched mesh gillnets, followed by *B. tsanensis* (15.4%), *B. platydorsus* (10.3%) and *B. megastoma* (10%) (Table 3). Note that the 5 species (*B. crassibarbis, B. gorgorensis, B. gorguari, B. longissimus, B. platydorsus*) that are predominantly immature fish when harvested ($Fl_{mode} < FL_{50\%}$) contribute only around 15% to the total number of the commercially landed barbs.

Discussion

Life-history traits

Increased mortality due to high fishing pressures can result in maturity at a smaller size (Rochet, 1998; Chen and Mello, 1999; Diamond et al., 1999). An attempt was made during the 1993 to 1994 spawning seasons to determine the $FL_{50\%}$ for *B. acutirostris, B. macrophtalmus,* and *B. tsanensis* (Nagelkerke and Sibbing, 1996). Unfortunately, an incorrect method was used to calculate the maturity curves and $FL_{50\%}$ values, which made those preliminary results unreliable. Reanalysis of the 1993 to 1994 maturity data revealed, however, no significant relationships between fork length and percentage mature individuals, due to low overall sample size and the lack of small individuals for most species. It was therefore impossible to compare the $FL_{50\%}$ of these barbs between the two periods, 1993 to 1994 and 1999 to 2001. The present data, however, form a solid base in order to reliably monitor future changes in this life-history trait.

Size control regulations: minimum mesh size

Currently, the mesh size used by the commercial fishermen is 10 cm stretched mesh. Use of this mesh size ensures that at least 85% of the barbs harvested by the commercial gillnet fishery are large adults as their size at maturity is much smaller than their size at capture (Figures 3, 4). Size control regulations towards

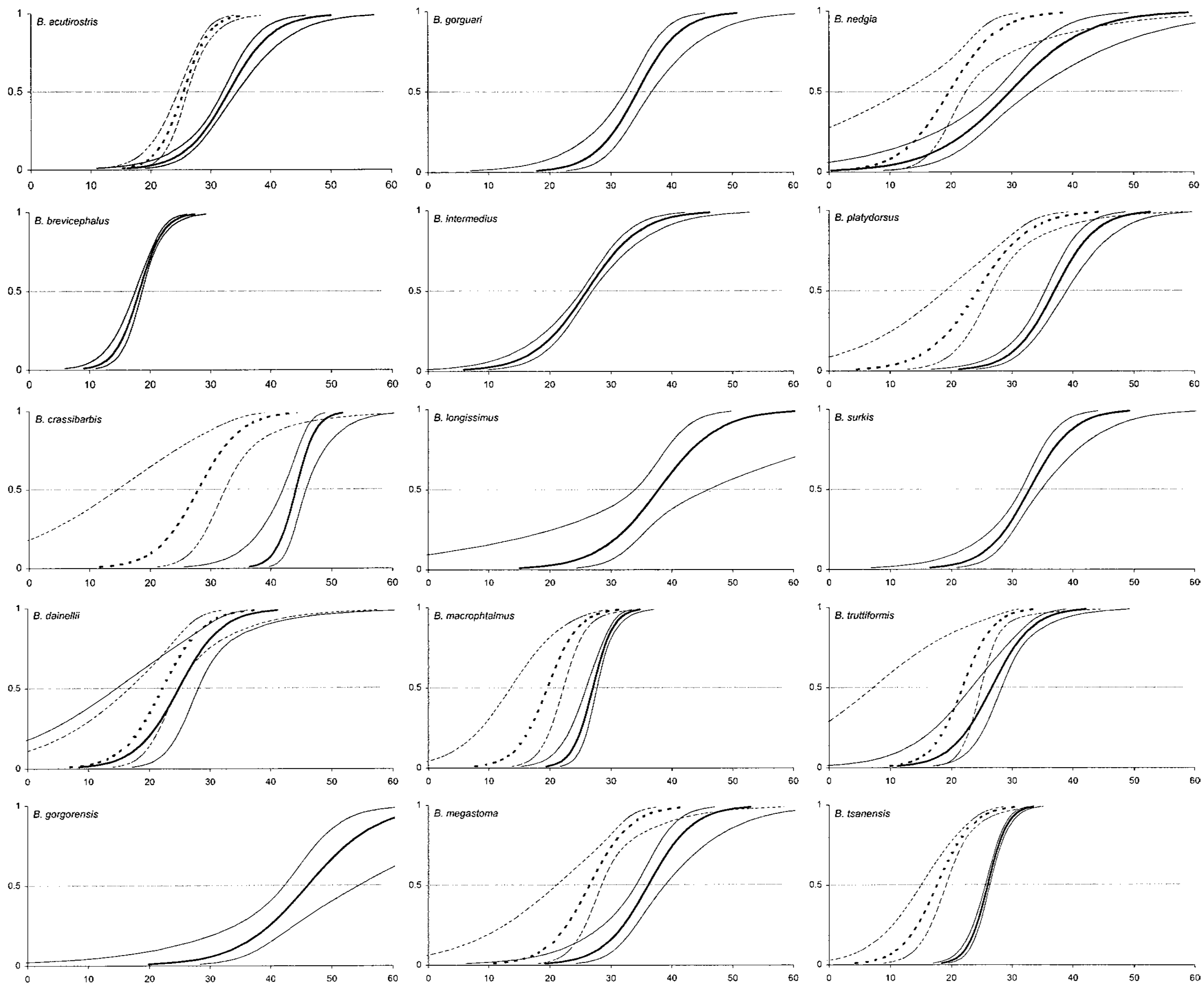

Figure 2. Male (-----) and female (——) sexual maturity curves for each of the 15 *Barbus* species during the spawning months of 1999–2001. Thin lines show lower and upper 95% confidence intervals. Percentage mature on the y-axis, barbs fork length on the x-axis. See Table 2 for values sigmoid curves and number of specimens per species and sex.

Table 2. Estimate of the parameters of the sexual maturity curves (male and female) of the *Barbus* species in Lake Tana in 1999–2001.

Species	Sex	n	a	b	p	FL min	FL 50%	95% CI Lower	95% CI Upper
B. acutirostris	♀	419	0.3	−8.9	***	22.3	33.0	32.0	34.5
	♂	349	0.5	−11.6	***	21.5	25.5	24.6	26.1
B. brevicephalus	♀	954	0.5	−9.1	***	16.4	18.2	17.5	18.7
	♂	324	—	—	ns	13.0	—	—	—
B. crassibarbis	♀	71	0.6	−26.5	***	41.6	44.1	41.9	45.8
	♂	72	0.3	−7.9	*	26.1	28.0	14.5	32.4
B. dainellii	♀	68	0.3	−7.0	*	25.5	24.8	14.5	28.0
	♂	53	0.3	−6.7	**	20.0	22.1	16.6	24.7
B. gorgorensis	♀	61	0.2	−8.1	**	31.0	46.0	42.2	54.2
	♂	34	—	—	ns	27.3	—	—	—
B. gorguari	♀	94	0.3	−9.6	***	26.0	34.3	32.4	36.7
	♂	73	—	—	ns	24.1	—	—	—
B. intermedius SC	♀	1003	0.2	−5.9	***	17.0	26.0	25.2	26.9
	♂	698	—	—	ns	13.2	—	—	—
B. longissimus	♀	77	0.2	−7.6	**	28.5	37.8	33.9	45.9
	♂	34	—	—	ns	26.8	—	—	—
B. macrophtalmus	♀	551	0.6	−16.2	***	26.2	27.0	25.9	27.7
	♂	616	0.4	−7.6	***	21.2	19.6	13.5	22.2
B. megastoma	♀	330	0.3	−9.8	***	27.5	36.1	34.1	38.8
	♂	210	0.3	−7.8	**	27.0	26.5	21.0	28.4
B. nedgia	♀	130	0.2	−4.7	***	19.5	29.7	27.2	33.3
	♂	55	0.2	−4.9	*	17.0	19.8	12.0	22.4
B. platydorsus	♀	257	0.3	−10.8	***	26.3	37.0	35.5	39.0
	♂	162	0.2	−5.7	***	22.5	24.4	19.1	26.7
B. surkis	♀	150	0.3	−9.2	***	25.1	32.9	31.5	34.8
	♂	78	—	—	ns	20.9	—	—	—
B. truttiformis	♀	252	0.3	−7.9	***	25.8	26.6	23.3	28.3
	♂	193	0.4	−8.5	*	23.9	21.8	7.1	24.9
B. tsanensis	♀	812	0.6	−15.8	***	20.6	26.0	25.6	26.3
	♂	486	0.3	−6.1	***	15.7	17.7	15.0	19.1

n = number of individuals; a and b = coefficients of the sigmoid curves; p = significance levels, ns = not significant, * = $0.05 < p < 0.01$, ** = $0.01 < p < 0.001$, *** = $0.001 < p < 0.0001$; FL_{min} = smallest FL (in cm) at which a mature individual of a *Barbus* species was found; $FL_{50\%}$ = FL (in cm) at which 50% of the males or females are sexually mature; CI = confidence interval.

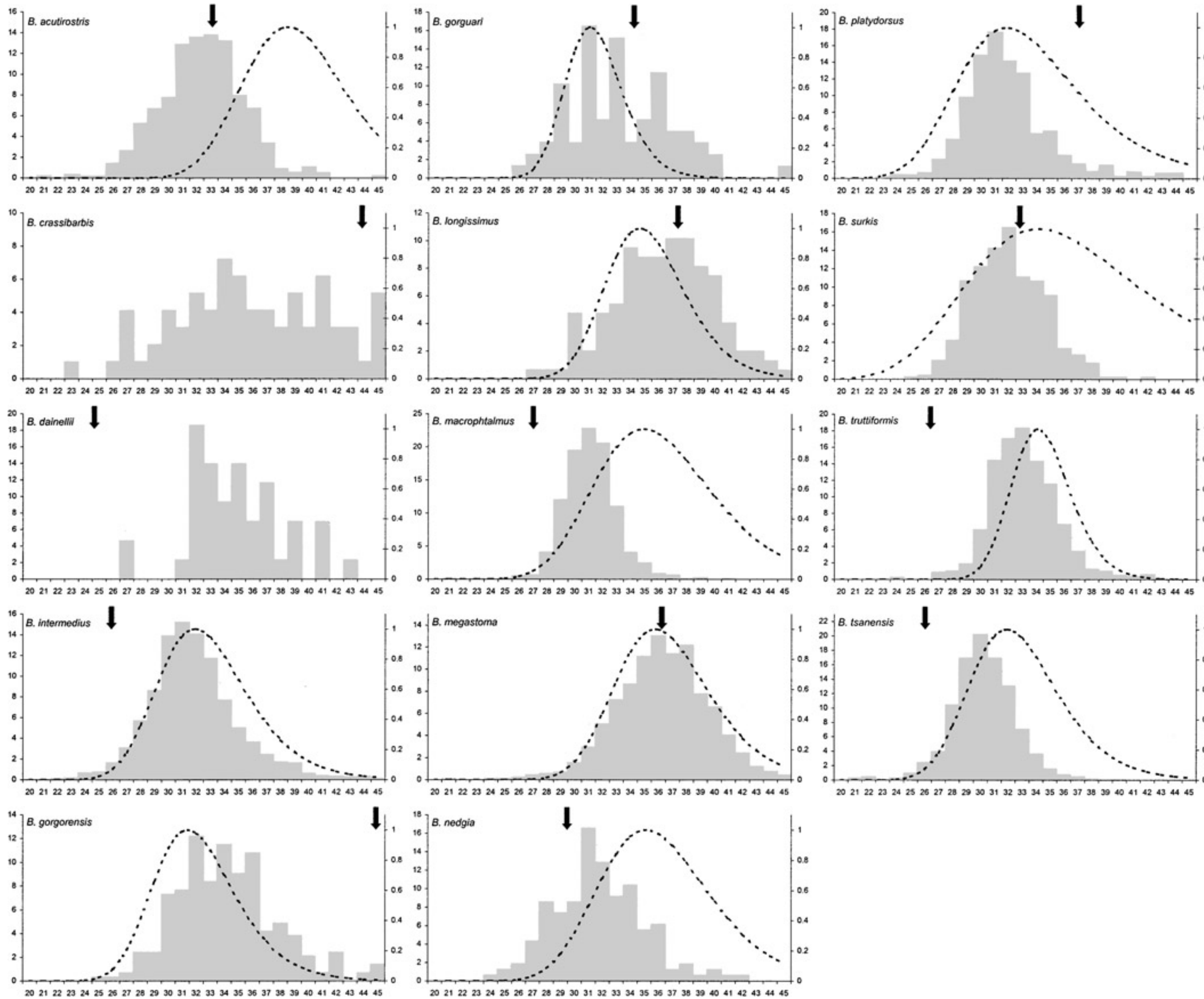

Figure 3. Selectivity curves for 10 cm stretched mesh (dotted line) estimated with the model of Sechin compared with observed length frequency distribution (bars) for the different *Barbus* species. Arrows indicate female $FL_{50\%}$. See Table 1 for n and size range selectivity curves and for n length-frequency distributions.

Table 3. *Barbus* species composition of the commercial catch (in percentage number; n = 5795) during the period June–December 2001 and the comparison of $FL_{50\%}$ (Table 2, Figure 2) with FL_{mode} (Figure 3) for each species.

Species	% Commercial Catch in Numbers		$FL_{50\%}$ Compared with FL_{mode}
B. dainellii	0.5		<
B. intermedius SC	37.9		<
B. macrophtalmus	6.5		<
B. truttiformis	6.3		<
B. tsanensis	15.4		<
Total		66.6	
B. acutirostris	5.2		≈
B. megastoma	10.0		≈
B. nedgia	1.3		≈
B. surkis	0.6		≈
Total		17.1	
B. crassibarbis	0.9		>
B. gorgorensis	3.4		>
B. gorguari	0.6		>
B. longissimus	0.4		>
B. platydorsus	10.3		>
Total		15.6	

the use of increasing mesh size will hardly reduce the fishing pressure on immature fish as the vast majority of the fish landed are mature. A reduction in mesh size used might increase the fishing pressure on juveniles. For example, a reduction in mesh size to 8 cm stretched mesh will have as a result that most *Barbus* harvested will be immature (Figure 4). Again, such a scenario only forms a risk in combination with high fishing pressure. In Lake Tana, the development in the near future of high fishing effort on immature barbs is improbable for two reasons. In the first place, on average only 5 to 7 boats each carrying 2 km of gillnets are operational (Wudneh, 1998; de Graaf, unpubl. data). Secondly, the fishing effort on barbs is concentrated during August and September in the river mouths on the eastern shores, targeting aggregations of large, adult fish. Immature fish do not aggregate in the river mouths during these months.

If, however, mesh-size restrictions would be implemented the question remains if all large *Barbus* species can be lumped and treated as 'one'. The variation in the expected (FL_{opt}) and observed (FL_{mode}) size at harvest is relatively small (30-37 cm FL) and is the result of differences in head and body morphology among the *Barbus* species (Nagelkerke and Sibbing, 2000). Size at maturity on the other hand shows large between- and within-species variation, ranging from 18 to 44 cm FL. This large variation in size at maturity does not allow lumping of all the *Barbus* species or treating them as "one" when developing mesh size restrictions. Species dependent mesh size restrictions should, ideally, be developed and implemented. However, such species dependent mesh size restrictions will only be possible if fishermen target the different *Barbus* species separately, which is not the case. Furthermore size-selective

		FL_{opt}								
	$FL_{50\%}$	14	13	12	11	10	9	8	7	6
B. acutirostris	33.0						**34.7**			
B. gorgorensis	46.0	**44.0**								
B. gorguari	34.3				**34.2**					
B. intermedius SC	26.0							**25.5**		
B. longissimus	37.8				**38.1**					
B. macrophtalmus	27.0							**28.0**		
B. megastoma	36.1					**35.8**				
B. nedgia	29.7						**31.6**			
B. platydorsus	37.0			**38.2**						
B. surkis	32.9					**34.1**				
B. truttiformis	26.6							**27.3**		
B. tsanenis	26.0						**28.7**			

Figure 4. Predicted relationship between $FL_{50\%}$ and FL_{opt} with decreasing and increasing mesh size (14-6 cm stretched mesh); white, $FL_{50\%} < FL_{opt}$; light grey, $FL_{50\%} \approx FL_{opt}$, bold figures indicate FL_{opt}; dark grey, $FL_{50\%} > FL_{opt}$. Note that the current mesh size used by the commercial gillnet fisheries is 10 cm stretched mesh.

fishing mortality due to strict mesh size regulations might even cause negative genetic changes in population productivity, such as reduced growth (Conover and Munch, 2002).

Mesh size restrictions will be difficult to implement and their potential positive effect on the sustainability of the *Barbus* fisheries and on the recovery of the drastically reduced stocks is dubious as has been argued above. The current mesh size of 10 cm stretched mesh is adequate; reduction of mesh size only gives reason for concern if accompanied by a sharp increase of fishing effort specifically targeting juveniles barbs. Most importantly, the dramatic decline of *Barbus* stocks in the 1990s (de Graaf et al., in press) is not caused by 'unsustainable' harvesting of juveniles by the commercial gillnet fishery.

Effort control regulations: closed areas/season

Characteristic for Africa's large *Barbus* spp., is that they are primarily riverine species, and although some species occur in lakes, all are riverine spawners, undertaking a single annual upstream breeding migration (Tómasson et al., 1984; Skelton et al., 1991). At least half of Lake Tana's *Barbus* species appear to have a similar reproductive strategy. Gonad development of 14 out of the 15 *Barbus* species peaks during August/September (de Graaf et al., unpubl. data) and about half of the 15 *Barbus* species aggregate around river mouths during these 2 months and migrate up the rivers for spawning (Nagelkerke and Sibbing, 1996; Dgebuadze et al., 1999; de Graaf, unpubl. data).

Fishing effort on *Barbus* is not equally distributed in Lake Tana, but is highly variable both in time and in space. Monthly catches of barbs peak at the end of the rainy season in August/September (spawning period; de Graaf, unpubl. data) when fishermen take their highest catches near river mouths (spawning aggregations; de Graaf, unpubl. data). Around 50% of the total annual catch during 1991 to 1993 was landed in just 2 months, August and September and roughly 90% of these barbs were caught near the river mouths and the surrounding flood plains (Wudneh, 1998; de Graaf, in prep).

Recruitment overfishing might occur due to severe and unregulated overfishing of spawning aggregations resulting in a dramatic decrease of recruits (Gabriel et al., 1989; Craig, 1992). In Lake Tana recruitment overfishing potentially threatens the survival of the unique *Barbus* species flock. Recent results show sharp declines in abundance, up to 75% in number and biomass, of different *Barbus* species and more importantly, drastic changes in population structure showing a severe limitation of recruits (de Graaf et al., in press).

If protective measures are not undertaken soon, the future of Lake Tana's barbs and its fisheries might follow the same path as other African cyprinid fisheries. The reproductive strategy of African barbs, that is, as total spawners undertaking single yearly migrations, renders them vulnerable to overexploitation as many cyprinid fisheries are centred on these spawning migrations. The susceptibility of cyprinids for modern fisheries concentrating on spawning runs has been demonstrated repeatedly by the drastic decline of several *Labeo* fisheries (Lake Malawi, Luapula River in Zambia, Lake Victoria) after the introduction of nylon netting and increased fishing pressures in the 1950s and 1960s (Skelton et al., 1991). Lake Victoria's cyprinid fishery deteriorated as a result of intensive gillnetting of gravid female *B. altianalis* and *L. victorianus* near river mouths. Unregulated fisheries after the introduction of the more efficient gillnets compared to traditional fishing gear, had severe impact on the populations of these once abundant species as gillnets were set near river mouths, effectively blocking them off from the lake (Ogutu-Ohwayo, 1990; Ochumba and Manyala, 1992).

Only effort control regulations, limiting the gillnet fishery in spawning seasons and/or areas, will be appropriate to prevent the barbs from undergoing the same fate as the cyprinids in other African lakes. A further advantage of a management plan based on effort control regulations is that the *Barbus* species can be lumped and treated as 'one', as all species more or less spawn in the same restricted period (August–September) and areas (river mouths and surrounding floodplains).

However, for any policy to be effective in the fishing community around Lake Tana it is important that representatives of the stakeholders and the state (different governmental offices of the Amhara National Regional State) are involved in the development, implementation and control of fisheries management. Continuous monitoring of the commercial catches is a first priority to evaluate the condition of the system and follow the effects of implemented management regulations.

Lake Tana; Ethiopia's biodiversity hot spot

Although Ethiopia hosts a number of endemic birds and mammals above the waterline, Lake Tana has remarkable high number of endemic species per km^2. This unique source of biodiversity is worth conserving for future generations as it may be considered to be a natural laboratory of evolution of great scientific potential. More importantly, for the local people, it should be a sustainable source of cheap protein. A species-rich ecosystem may produce a higher biomass than expected from the performance of individual species grown alone, due to a more efficient utilisation of the resources by the members of a highly diverse community (Loreau et al., 2001; Tilman et al., 2001). Furthermore, biodiversity may provide resilience against environmental fluctuations (see Loreau et al., 2001).

In addition to providing a scientific base for implementing fisheries regulation in Lake Tana, the results of the present study also shed some light on the origin of lake Tana's biodiversity, the evolution of the *Barbus* species. Reproductive isolation is a decisive character in the distinction of biological species. Genetically based morphological differences between the evolving populations of *Barbus* could only have become fixed by, at least partially, assortative mating. The assumed reproductive segregation among the *Barbus* species is supported by the large, consistent differences in average size at maturity ($FL_{50\%}$). This variety in reproductive characteristics suggests differentiation in life-history traits among the *Barbus* species, such as life span, growth rate and age at first maturity. Genetic differentiation and reproductive isolation could be inferred from such differences in ecology and life-history and therefore be instrumental in speciation events (Crawford and Balon, 1994; Taylor, 1999).

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