THE BANGWEULU SWAMPS – A BALANCED SMALL-SCALE MULTISPECIES FISHERY

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This study is dedicated to the memory of Ben Chanda who suddenly passed away while we were working on it. Ben Chanda worked for the African Wildlife Foundation and before that for the Fisheries Department of Zambia.

1. INTRODUCTION

The fishery of the Bangweulu swamps, in Luapula Province, Northern Zambia (Figure 1), is an artisanal small-scale multi-gear, multispecies fishery. Eighty-three species representing 13 taxonomic families have been recorded from the area (Evans, 1978) most of which are caught and utilized. The general impression with the local administration is that the fish stocks are heavily fished. Presently fish stocks are considered threatened by high fishing pressure from both the large numbers of permanent residents in the swamps as well as from the seasonally migrating fishermen coming from surrounding areas. Already for a long time fears have been expressed that the fishery of the Bangweulu system has undergone alarming changes indicated by a decrease in the mean size of fish caught and a general decline in catch per unit effort (Evans, 1978). Total yields however, although fluctuating, show an increasing trend. Fishermen are believed to contribute to these changes by an intensified utilization of small meshed gillnets, seining, weirs, as well as "kutumpula fishing" – a technique which drives the fish into surrounding gillnets by beating into the water (Mortimer, 1965). There is a need for evaluating these changes in the fishery and to establish whether they are indications of possible overfishing, inappropriate (and illegal) fishing practices, or natural factors.

This case study will present and discuss the main results from a length-based stock assessment survey carried out in 1994-1995 (Kolding, Ticheler and Chanda, 1996a, 1996b). The survey was made to establish growth parameters, gear selectivity, individual exploitation rates, and overall exploitation pattern in the multispecies swamp fishery. We conclude that the observed changes are not alarming. On the contrary: we find that the fishery is remarkably adaptable to the natural circumstances; that the exploitation is heavy, but with no evidence of gross overexploitation in general, at the most on some of the larger species; and that the current exploitation pattern is to a large degree unselective and thus in principle ecosystem conserving.

2. BACKGROUND INFORMATION

The Bangweulu perennial swamp (Figure 1) can be characterized as a vast, shallow, oligotrophic, seasonally fluctuating, but predictable aquatic system. The main inflow is via the Chambeshi River that enters the swamps from the east. The surplus water leaves the Bangweulu swamps in its southwestern part through the Luapula River, which later enters the Lake Mweru further north and subsequently connects with the Congo River system. Strong seasonal water level fluctuations with relatively low inter-annual variations (Figure 2) create annual changes in habitat availability (areas of inundation), pathwayas of fish dispersal and pulses of food availability.

The general low level of total dissolved solids in the water, resulting in low conductivity, rank the Bangweulu amongst the most dilute water bodies in Africa (Welcomme, 1972) with very low concentrations of phytoplankton (Table 1). The swamps are dominated by heavy stands of papyrus (*Cyperus papyrus*) along channels and permanent water bodies, fringed by a zone of *Eleocharis* sp. and *Nymphea* sp. *Phragmitus pungens* (reed) and *Eleocharis dulcis* is found on sandy shores of channels. Various sedges, spearworts, wild rice and hippo grass (*Vosia* sp.) are found on firmer ground. The dense emersed vegetation filters nutrients out of the in-flowing Chambeshi waters, especially papyrus, which is able to fix large amounts of nutrients.

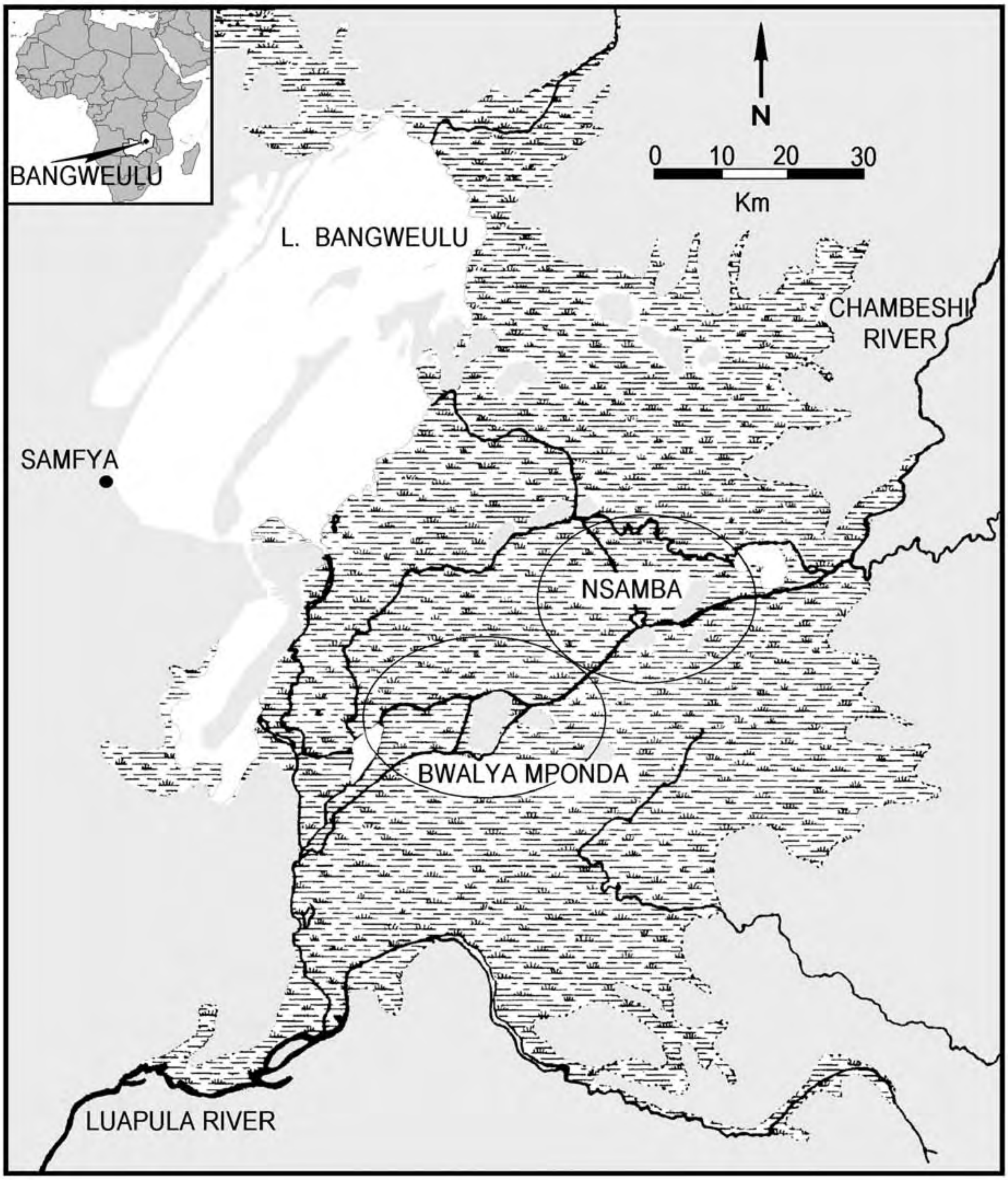


FIGURE 1. *Map of Lake Bangweulu and the perennial swamps with indication of the two sampling areas at Nsamba and Bwalya Mponda. The fisheries research station is located at Samfya. (Map drawn by Elin Holm).*

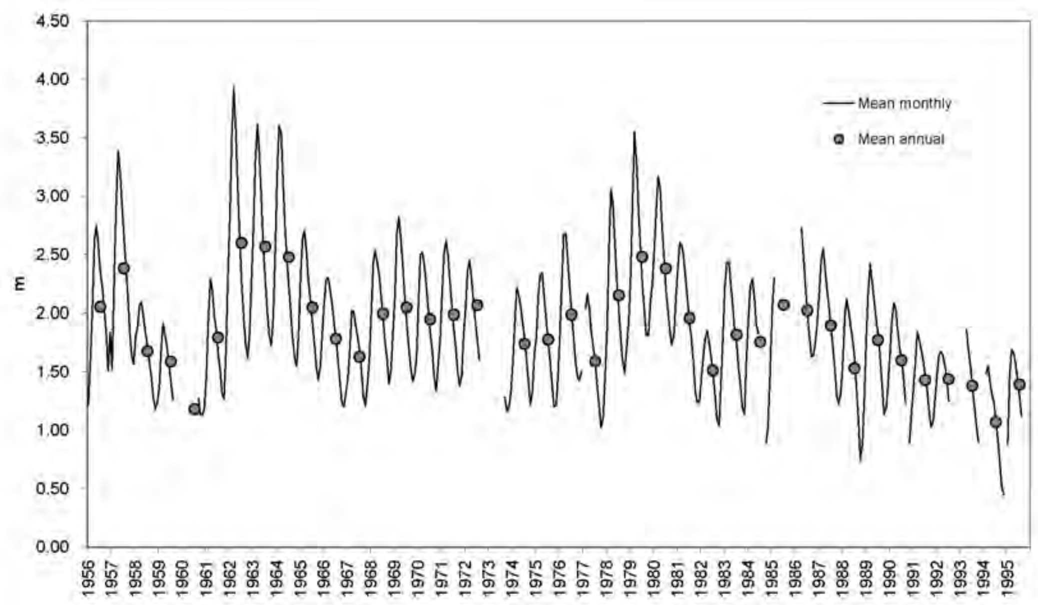


FIGURE 2. *Mean monthly and mean annual water levels of Bangweulu (recorded at Samfya). Mean annual maximum level (March) is 2.46 m (SD 0.60). Mean annual minimum level (October) is1.36 m (SD 0.31).*

TABLE 1. *Selected geographic, limnological and physicochemical data of the Bangweulu system.*

Data	Value	Source
location	10°15' - 12°30' S 29°30' - 30'30°5"E	Bossche and Bernacsek 1990
permanent swamp area (km^2)	5170	Toews 1977
total lake surface area (km^2)	2735	Toews 1977
floodplain area (km^2)	7101	Toews 1977
catchment area (km^2)	109469	Toews 1977
water depth swamps (m)	1 to 2	own data
mean annual water level fluctuation (m)	1.2	Dept. of Water Affairs
minimum water level as percentage of maximum	46 %	
Conductivity (mS m^{-1})	26.5 to 34.3	Bos and Ticheler 1996
pH	6.3 to 6.9	Toews 1977
O_2 %	40-100	Bos and Ticheler 1996
total alkalinity (mg l^{-1})	0.31 to 0.46	Bos and Ticheler 1996
Transparency (m)	0.6 to 1.7	Bos and Ticheler 1996
Total dissolved solids (mg l^{-1})	41.0 to 89.0	own data
Water Temperature (°C)	18.3 to 27.3	Toews 1977
Chlorophyll-*a* (microgram l^{-1})	below detection level of 5 µg l^{-1}	Bos and Ticheler 1996

Fishery research has been carried out intermittently in the Bangweulu lake and swamps since the late 1930s (Ricardo, 1938; Bertram and Trant, 1991), but little has been published in scientific papers or reports (Toews, 1977; Evans, 1978; Toews and Griffith, 1979). Since the late 1970s research has been limited, particularly in the swamp area. In decreasing order of data available the following information on the fisheries existed before the survey:

1) Yield: Fluctuates with a slightly increasing trend. Reported annual yield (mean ±SD) since 1952 is 11, 366 ± 2, 370 tonnes (Figure. 3) (Bazigos, Grant and Williams, 1975; Evans, 1978; Lupikisha, Musuka and Mung'omba, *et al.* 1992, Dept. Fisheries, Zambia).

2) Effort: Frame surveys from 1965, 1971, 1973, 1975 (additional frame survey) 1992 and 1996 (additional frame survey) indicate no trends in fishing effort (Table 2). This is remarkable as in various African fisheries the numbers of fishermen follow at least the demographic growth in a country (van Zwieten, pers. comm.). The lack of demographic growth probably has to be attributed to the harsh living conditions in the swamps and the limited amount of islands to settle on.

3) Growth: Reported for two species: *Tylochromis bangwelensis* and *Hydrocynus vittatus* (Griffith, 1975, 1977), based on scale readings

4) Mortalities, biomass and production: No reliable information available.

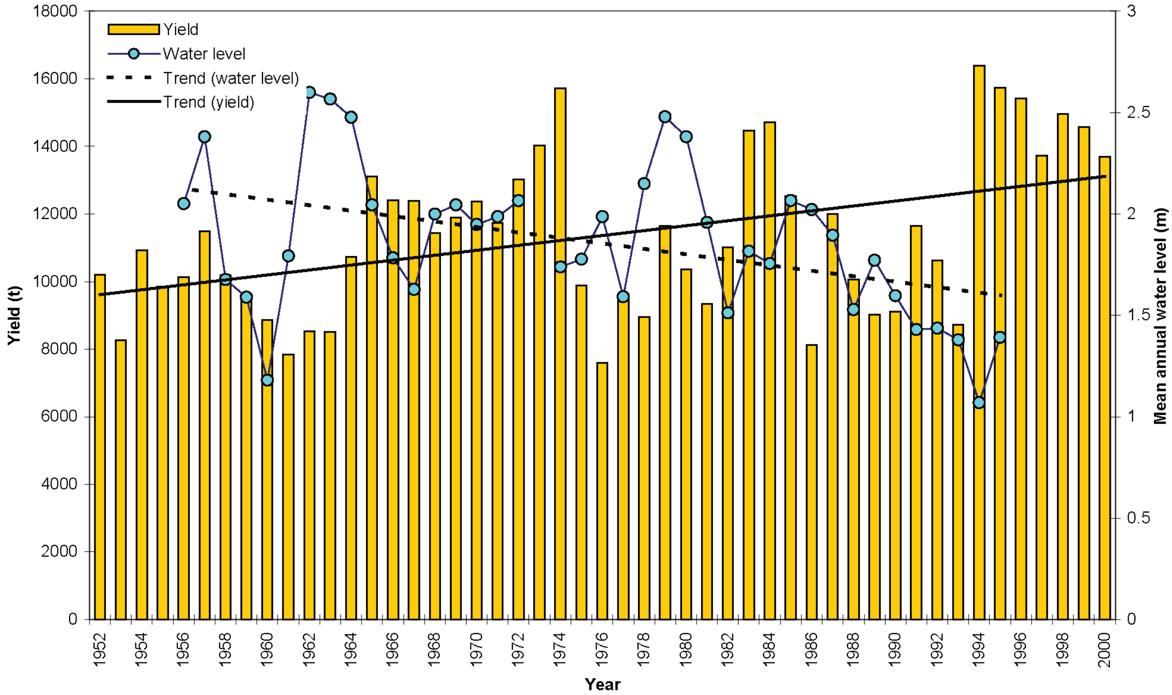


FIGURE 3. *Reported annual yields from the Bangweulu fishery (1952-2000) together with the mean annual water levels (1956-–95). Both trend lines are significantly different from 0 at the 95 percent confidence level. There is no statistical correlation between the annual yield and water level data.*

TABLE 2. *Recorded effort in the Bangweulu fishery*.

Year	No. fishermen	No. actively involved	No. canoes	Source
1965	5 015		6 437	Anon., 1965
1971	5 193	13 878	5 475	Inoue, 1971
1973			8 739	Bazigos, Grant and Williams, 1975
1976		7 696	4 500	Evans, 1978
1992	4 800	10 240	5 900	Ticheler and Chanda, 1993

3. MANAGEMENT REGULATIONS

Fisheries management by the Department of Fisheries in Zambia is primarily focused on effort regulation. A number of nation wide fisheries regulations have been gazetted and one of the duties of the Department is to enforce them.

Regulations currently in place are:
- a closed fishing season from the first of December to the first of March. It is not allowed to fish in this period and transport of fish is prohibited as well.
- mesh size restrictions. In the Bangweulu fishery mesh sizes smaller than 51 mm (2 in”) stretched mesh are prohibited.
- fishing gear and method restrictions. All forms of active fishing are prohibited, this includes the popular kutumpula fishing and seine netting. Although not explicitly mentioned in the fisheries act, fishing weirs are generally regarded as illegal gears as well**.**
- industrial fishing is not allowed in the Bangweulu fishery.

Furthermore Bangweulu is declared an open access fishery. This means that everybody with a fishing licence and legal fishing gear is free to enter the fishery.

In practice however, these regulations are hardly followed by the fishers who disagree with most of them. Fishermen claim that catches of most of the small species as *Tilapia sparmanii*, *Barbus paludinosus*, *Petrocphalus catastoma* and others, are not economically viable if the regulations were to be followed (Chanda, 1998). On the other hand the Department has neither the means nor the manpower to enforce the regulations other than through sporadic patrols. Only during the closed season the transport of fish from the Bangweulu fishery to the outlet markets is controlled to some extent, and with that possibly the levels of fishing effort during that period.

4. METHODS

4.1 Data collection

Fisheries statistics used for estimating annual fish production, species composition, effort, etc., in inland African fisheries are collected by research officers and assistants from governmental research institutes. The methods are usually quite similar and originate from proposals from the FAO in the 1970’s. The techniques used are mainly experimental gillnet surveys (GNS) for biological parameters and fishery independent data, frame surveys (FS) for inventories of all fish production factors, and catch and effort surveys (CAS) for sampled daily catch and effort data. The collection of CAS data typically follows a stratified simple random design, where intensity of sampling depends on available manpower and economical resources. The precision, accuracy, usefulness, and cost-efficiency of these methods have sometimes been questioned (Orach-Meza, 1991) and reliable landing statistics is a notorious problem in many African inland fisheries. However, few other sampling alternatives have been developed or tried out.

In Lake Bangweulu the Department of Fisheries (DoF) has employed for many years the above mentioned data collection methods and sampling design. Multi-mesh experimental gillnet surveys, operated by DoF, were used for biological data collection in the open waters since 1971 and CAS survey rounds were done to collect catch-effort data. However, the sample frequency varied strongly over the years depending on availability of funds. The amount of fish of different species caught in the GNS was inadequate to allow for a realistic assessment of the fish stocks in the swamps. In addition, the structure and composition of the artisanal catches was not reflected in the data collected and the time series of catch and effort data from the CAS surveys was too short and contained too little contrast to allow for meaningful analysis.

It was therefore decided to carry out an independent length-based stock assessment of the most important stocks. To obtain sufficient data within a limited period, a number of full-time professional fishers living in the swamps were selected and engaged to carry out part of the sampling, in parallel with the already established monthly experimental GNS by the DoF. Each fisher would receive a basic fee per month for measuring and recording all his catches by species, length, mesh size and sampling area. Some would utilize their own gear (in order to get a representative picture of the fishing pattern) and some would be issued with experimental gillnets (in order to establish growth and mortality parameters). All the fish caught would belong to the fisher and he would be free to fish where and when he wanted, as long as he recorded the catches. This approach of engaging local fishermen in scientific fisheries data collection is to our knowledge new and had never been tried out before (Ticheler, Kolding and Chanda, 1998).

Two main sampling areas in the central swamps were identified: Bwalya Mponda and Nsamba (Figure 1). In these areas all common swamp habitats were well represented, and it was assumed that the status of the stocks in these areas would represent the situation in most parts of the swamps. In each area five fishermen were engaged in the sampling. Three of these were issued with a standard fleet of experimental gillnets (mesh sizes spanning from 25 mm to 140 mm with 12.5 mm increments, i.e. altogether 10 mesh panels), which they should employ concomitantly with their own nets or methods (e.g. gillnets, seines, or “kutumpula”). They were free to choose when they set the experimental nets as long as they were utilizsed on a frequent regular basis. The two remaining fishermen were chosen among those who used kutumpula or seines. A detailed description and discussion of the “Fishermen Data Collection Method” (FDC) is given in Ticheler, Kolding and Chanda (1998).

Data from the 13 most abundant and commercially important species were selected and analysed with respect to gear selectivity, growth rates, spawning frequency, mortality rates, and present and long-term yield assessment. The yield analysis has concentrated on gillnets, kutumpula nets and seines, which are the most important fishing gear in the perennial swamps. Weirs, in connection with small meshed (3–10 mm) fish traps, are another important fishing method, which are mainly (90 percent) found in the seasonal floodplains. For logistical reasons weirs could therefore not be included in this study (Ticheler, Kolding and Chanda, 1998). A separate detailed analysis of the weir fishery, which catch a broader size range and higher proportion of smaller specimens than all the other gears, is given in Chanda (1998).

The standard experimental gillnets (25 to 140 mm) used by DoF were not representative for length groups smaller than 10–12 cm TL for any of the examined species, and they were also not representative for the artisanal catch composition. In order to estimate growth and mortality parameters for most of the smaller species, which are important in the Bangweulu swamps, the sampling design was extended by supplying five of the fishermen with small-meshed experimental monofilament gillnets (the Swedish Lundgren survey types) alongside the experimental standard gillnets.

4.2 Length-frequency data

Nearly one million single fish measurements from various gears were recorded and computerizsed covering a period of two years from July 1994 to July 1996 (Table 3).

TABLE 3. *The number of individual fish records and fish species collected in different fishing gears between July 1994 and July 1996 (except the Lundgren nets, which covers the period June 1995 to July 1996). Local fishermen collected all data except DoF experimental gillnets.*

Gear/method	No. of records	No. of species
DoF experimental gillnets	16 528	37
Experimental gillnets	264 589	37
Lundgren nets	102 602	36
Artisanal gillnets	233 717	34
Seine fishery	290 736	34
Kutumpula fishery	37 810	21
	945 982	

4.3 Frame survey data

TABLE 4. *Total number of fishing gears by type and mesh size for the Bangweulu swamps and the overall fishing effort used in calculating catch volumes by length group and gear type. Data from frame survey 1992, kutumpula survey 1996. Data from the weir fishery (Chanda, 1998) are included for comparison but not used in this study.*

	Total number by gear type			
Mesh size (mm)	Gillnets	Kutumpula nets	Seines*	Weir traps
3				3 869
4				8 358
6				2 322
8				387
10				
25	534	17	53	
38	6 719	68	178	
50	4 233	135	49	
63	1 260	643		
76	554	74		
89	136	-		
102	-	-		
114	-			
127‡	255			
140	-			
Total	13 691	937	280	15 477
Effort	80	100	160	

*mesh size of the bag.
‡The number of 127 mm gillnets has probably more to do with availability of these nets on the market than with specific preference by fishers for these meshes.
†Effort in number of gear settings per year. For gillnets it is 160*0.5 to adjust for catchability (see methods of analysis).

Data from the Frame Survey of 1992 (Ticheler and Chanda, 1993) and an additional kutumpula survey in 1996 has served as input for the calculation of total annual catch volumes by species, by gear category (artisanal gillnets, kutumpula nets and seines) and by length group (Table 4). During the traditional frame survey no difference was made between stationary gillnets and "kutumpula". However, due to clear difference in the species composition in the kutumpula and stationary gillnet catches (Kolding, 1995; Tables 6 and 7), an additional kutumpula survey was carried out in the swamps where the proportion of all gillnets which is actually being used for kutumpula fishing was obtained (Table 4).

4.4 Methods of analysis

All recorded data were stored in PASGEAR (Kolding, 1996). Most of the calculations, tables and figures were performed using a combination of PASGEAR (ver: 15.10.96) and FiSAT (ver: 1.01, Gayanilo, Sparre and Pauly, 1996; Gayanilo and Pauly 1997). The general approach was based on classical length-structured stock assessment methodology with long-term steady state forecasting (e.g. Sparre and Venema, 1998) using the following steps:

1) Estimation of basic vital parameters (growth and natural mortality) from the experimental gillnet data. For all species the ELEFAN I module implemented in FiSAT was used to calculate parameters for the von Bertalanffy growth function (VBGF) (Gayanilo, Sparre and Pauly, 1988). Total mortality (Z) was calculated from a linearized length-converted catch-curve analysis and natural mortality (M) was calculated from Pauly's (1980) empirical formula with an input Temperature (T) of 23.5 degrees centigrade (estimated mean annual water temperature in the Bangweulu system (Evans, 1978).
2) The growth and natural mortality parameters were used to estimate fishing mortality by length group and overall population sizes from length-based cohort analysis (Jones and van Zalinge, 1981; Jones, 1984; Lassen and Medley, 2001) on the artisanal fishery.
3) Finally a yield analysis and long-term predictions were performed using a length based Thompson and Bell model (Thompson and Bell, 1934). This model combines features of Beverton and Holt's Yield per Recruit model with those of VPA, which it inverts. The basic assumptions are based on a steady state system so that all input parameters, except fishing mortalities, are constants and do not change with fishing effort. Growth parameters, natural mortality, population sizes (recruitment), and fishing mortality by length group estimated in the earlier steps were used as inputs. The Thompson and Bell model was applied for each species in the gillnet, kutumpula, and seine fishery separately (single-species, single gear), as well as on the combined fishery with pooled catches (multi-species and multigear).

The conditions for the validity of this approach are:

1) that the selectivity of the gears used for experimental fishing is such that the derivation of vital parameters is valid, i.e. that the sampled data do represent the population structures, and
2) that it is possible to derive overall catch volumes of the artisanal fishery and that overall length composition data for the artisanal fishery is available.

4.5 Selectivity

The first of these conditions was tested by gillnet selectivity analysis of the experimental catches. Selectivity is a quantitative expression of the probability of capture of a certain size of fish in a certain size of mesh. Indirect methods (i.e. based on catch data alone without *a priori* knowledge on the underlying distribution) for estimating this probability, as in this study, are all based on the assumption that all the fish have the same probability of encountering the gear. This may be a dubious assumption as the smaller fish (specimens or species) normally have a smaller action range than larger fish. This uncertainty, however, is not possible to quantify without independent information on the population sizes and composition. A further assumption of the indirect methods is that all mesh sizes have the same efficiency at their individual "peak length-class", although with the same reasoning as with the previous sassumption, there are indications that the relative fishing efficiency rises with mesh size. Finally, it is a matter of choice which statistical model is used to represent the selection curves for species that also have some degree of entanglement. The statistical models and the method are described in Millar and Holst (1997) and Millar and Fryer (1999) and are implemented in PASGEAR.

4.6 Derivations of overall catch volumes by length groups

The selected fishermen participating in the data collection were encouraged to use their own gillnets. However, it turned out that the participants only used mesh sizes 25, 38, 50 and 102 mm. Therefore their data did not cover the full range of mesh sizes found in the artisanal fishery (Table 4). The overall artisanal catch volume in all gillnets broken down by length groups for Jones' length-based cohort analysis was therefore calculated from the following assumptions: Mean average catch per unit effort ($CPUE_i$) of each mesh $size_i$ per species in the experimental nets were calculated. Overall annual catch per species was calculated from:

$$Total\ catch = \sum (CPUE_i \cdot \#nets\ of\ mesh\ size_i \cdot total\ effort)$$

where total number of $nets_i$ and total effort in days fishing were obtained from the frame survey in 1992 and the additional kutumpula survey in 1996. Overall catches of each species per length $group_j$ were calculated as proportions from total catch (see Kolding,Ticheler and Chanda, 1996b for details). A comparison of CPUE in experimental and artisanal gillnets included in the sampling programme revealed that the artisanal nets were less effective then experimental nets, probably due to the general state of the nets, their smaller size, and their age. Based on the overall average differences an estimated conversion factor of 0.5 for CPUE from the experimental to a "general" artisanal net was therefore applied (Kolding, Ticheler and Chanda, 1996b). No conversion factors were applied for seines or kutumpula nets as the data originated from the gear used in these methods.

4.7 Fishing effort and fishing pattern

The estimated total annual fishing effort in number of days fishing for stationary gillnets and seines was based on data on seasonal and weekly fishing activities from the Frame survey (Ticheler and Chanda, 1993). In Bangweulu catch rates fluctuate seasonally and are inversely correlated with water levels (Figure 4). During the high water period (January to June) the fish will tend to disperse into the floodplains for feeding and breeding, while the densities in the perennial swamp will increase during the low water period (July to December). Such inverse relationship between water levels and catch rates is a general trend found in floodplain fisheries. The peak season (more than 50 percent of fisherman actually fishing) for the whole fishery is from May to November. For the different areas small differences were recorded. On the islands the peak season starts in April and in the swamps it continues up to December. Farming is concentrated (with more than 50 percent of fishermen farming) in the months December to March, except for the swamps where farming is mainly done from January to April. The frame-survey revealed that on average fishermen fish for six months a year (ie. 26 weeks), and during that period for approximately for 6.2 days per week (i.e. 160 days per year per fisher). The effort employed in kutumpula fishing differs from the stationary gillnet fishing. A popular Bemba saying amongst the Unga fishers in the swamps is "*ngawatemwa ukusakila kuti wafilwa ukupela umukashi obe ifumo*", which literally means "a kutumpula fisher will fail to make his wife pregnant". This is because kutumpula fishing is much harder compared to stationary gillnet fishing and this is also the reason why people say kutumpula is done less often as compared to stationary gillnet fishing. Although it is not exactly known, this study estimated kutumpula effort at 4.0 days per week in the fishing season, i.e. 100 days per year.

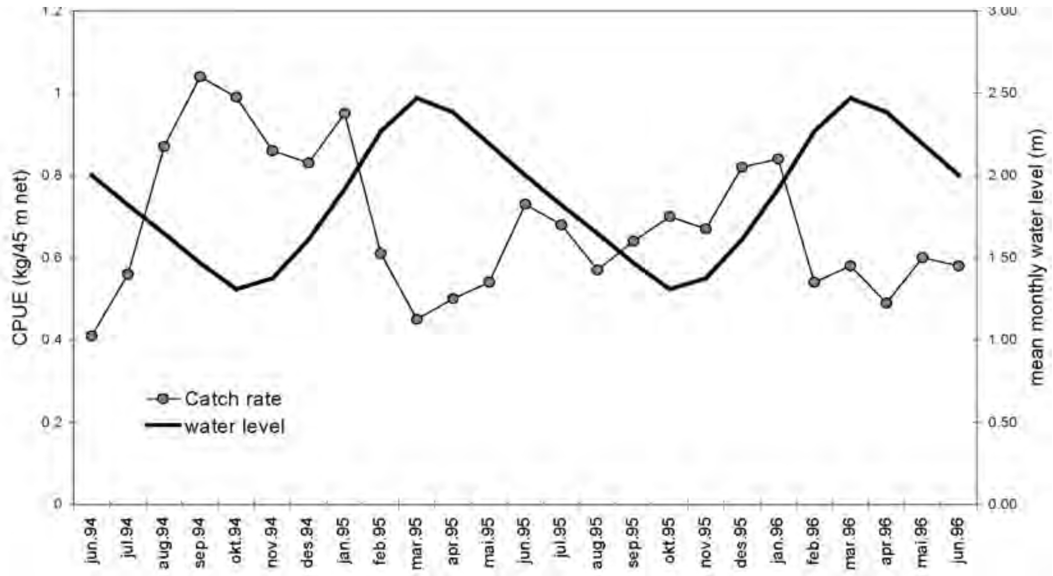


FIGURE 4. *Mean monthly catch rate of all species (kg/45 m net set) in the experimental nets from June 1994 to June 1996 plotted with mean annual water level fluctuations (from the period 1955-1995). The fluctuations are significantly inversely correlated (r = – 0.65).*

The fishery is highly dominated by small meshed nets: all the weir traps and 50 percent of the other gears are less than the legal limit of 51 mm stretched (Table 4, Ticheler and Chanda, 1993; Chanda, 1998). During the 1996 "Kutumpula" survey 809 kutumpula fishers were interviewed and information on the use of 8 105 nets used in the swamps was collected. This is approximately 50 percent of the total number of fishermen covered during the 1992 frame survey. The total number of kutumpula nets is small compared to the total number of stationary gillnets in the swamps (6.8 percent), but for the most commonly used mesh in kutumpula fishing (63 mm), these nets account for one third of all gillnets (Table 4). Kutumpula nets in general have larger mesh sizes than the nets used in stationary gillnet fishing.

4.8 Fish species selection for detailed analysis

Thirteen species were selected for a more detailed analysis of growth, mortality and yield. The first eight were well represented in the experimental gillnets. These were *Marcusenius macrolepidotus*, *Hydrocynus vittatus*, *Clarias gariepinus*, *Oreochromis macrochir*, *Tilapia rendalli*, *Serranochromis angusticeps*, *Serranochromis robustus* and *Serranochromis mellandi*. The last five were small species chosen from the Lundgren nets: *Barbus paludinosis*, *Barbus trimaculatus*, *Petrocephalus catostoma*, *Schilbe mystus* and *Tilapia sparrmanii*. The main criteria for selecting these 13 fish species for a detailed analysis were a) their importance in the artisanal fishery, either by weight or number, and b) the possibility of deriving growth parameters from the data available. The selected species, however, together represent a large variation in biology, distribution and sizes of the species found in the fishery and the first eight alone contribute nearly 75 percent of the total yield (Figure 5 and Table 12).

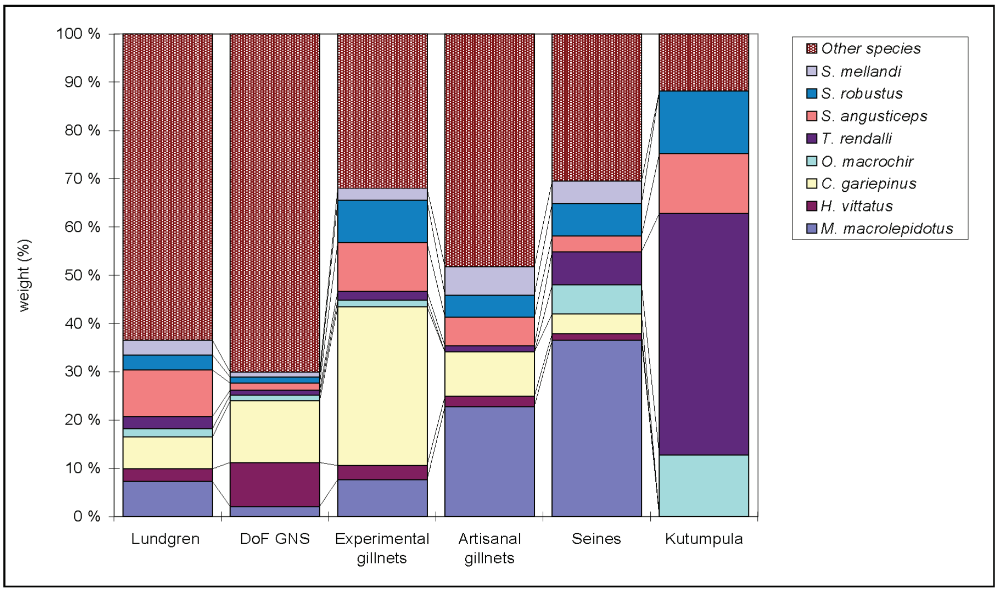
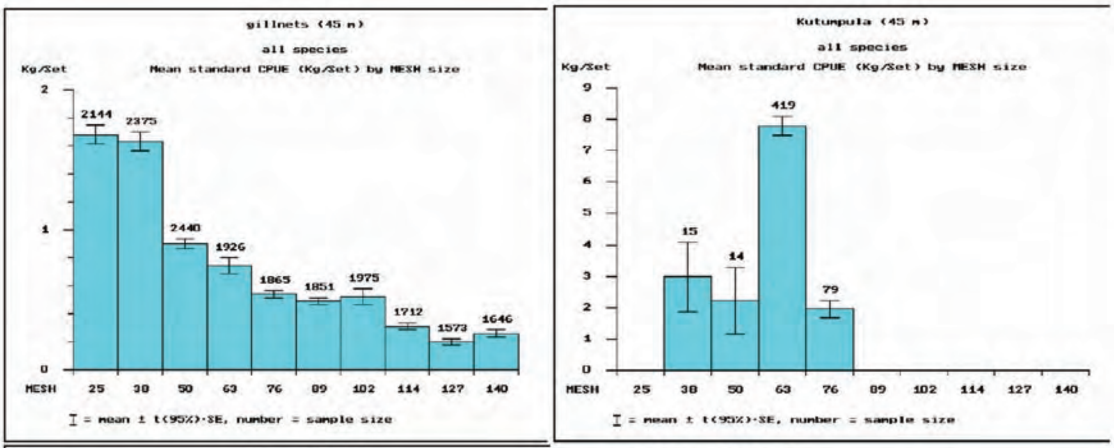


FIGURE 5. *The contribution, weight percentage, of the first eight selected species in the experimental gillnets to the total catch in the different fishing gears.*

RESULTS

Figures 6a to 6c show the mean catch per unit effort in the different mesh sizes by the three gears sampled in this study. Although a few mesh sizes are missing in the kutumpula and seine samples, it is noticeable how close the CPUE pattern by mesh size follows the frequency distributions of the mesh sizes in the fishery (Table 4). Also the relative abundance of the three gear types in the fishery (Table 4) is in close inverse accordance with the overall catch rates of each type (Figure 6 and Table 12).



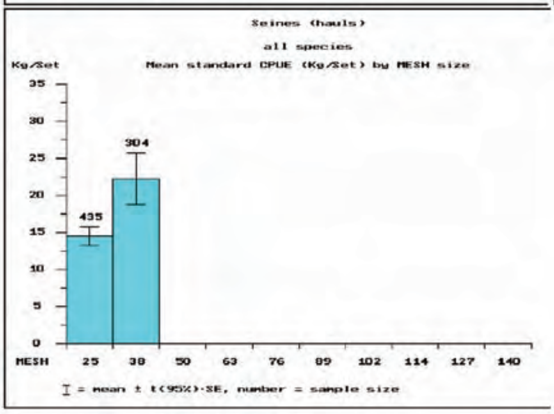


FIGURE 6

A. $Cpue_{(kg)}$ in different mesh sizes for experimental gillnets operated by local fishermen
B. $Cpue_{(kg)}$ in different mesh sizes for kutumpula nets operated by local fishermen
C. $Cpue_{(kg)}$ in different mesh sizes for seine nets operated by local fishermen

5.1 Catch composition in different gears

A distinct difference in catch composition can be observed between the sampling gears (Tables 6 and 7). Furthermore, catches from the GNS by DoF differ to a large extent from the catches realizsed by fishermen using the same gear (experimental gillnets). For example, in the GNS the most important species is *Alestes macrophthalmus,* both by number as well as by weight, while in the fishers experimental nets this species contributes only marginally (<11 percent by number and one percent by weight) to the catch. This can be attributed to different ways of setting the nets. While the DoF surveys primarily set the nets in the open water patches (a.o to reduce the amount of work in cleaning the nets from weeds), fishermen set the nets closer to the banks to target specific species and to improve their catch rates. The results show that the GNS catches in the swamps are not representative for the species composition in the artisanal gears.

TABLE 6. *Relative catch composition, percent number, for the different sampling gears used in this study. Data collected from July 1994 to July 1996, FDC broken down by method. Species contributing with less than 1 percent to the total catch are grouped in "other species".*

Number of settings	GNS		FDC			Lundgren
	Experimental		Artisanal	Kutumpula	Seines	
	1 694	18 037	1 473	527	739	12 076
Alestes macrophthalmus G.	19.7					2.8
Schilbe mystus L.	14.6	12.1	10.9		1.3	21.4
Barbus aff. unitaeniatus G.	10.6	1.9			1.3	5.3
Barbus paludinosis P.	9.3	4.1	10.3			8.0
Petrocephalus catostoma D.	7.9	18.8	24.0		8.2	17.3
Tilapia sparrmanii S.	5.8	19.1	24.1	4.5	5.6	7.1
Marcusenius macrolepidotus P.	4.1	13.8	17.1		48.2	4.1
Hydrocynus vittatus C.	3.5					
Serranochromis mellandi B.	2.3	3.5	4.3	2.4	6.7	1.2
Tylochromis bangwelensis R.	1.9			7.2	1.1	
Hippopotamyrus discorhynchus P.	1.8	1.4	1.8		13.5	1.7
Auchenoglanis occidentalis V.	1.7					
Clarias gariepinus B.	1.2	4.5				
Barbus trimaculatus P.		5.5				12.9
Serranochromis angusticeps B.		4.9	2.3	12.6	1.9	1.4
Synodontis nigromaculatus B.		1.7				1.0
Serranochromis robustus B.		1.6		9.6		
Ctenopoma multispinis P.		1.3				
Tilapia rendalli B.				48.4	3.0	1.0
Oreochromis macrochir B.				10.8	2.1	
Serranochromis macrocephalus B.				3.2		
Marcusenius monteiri G.					2.9	
Other species	15,6	5.8	5.2	1.3	4.2	14.8
Number of species contributing >1%	13	14	8	8	12	13

TABLE 7. *Relative catch composition, percent weight, for the different sampling gears used in this study. Data collected from July 1994 to July 1996, FDC broken down by method. Species contributing with less then one percent to the total catch are grouped in "other species".*

Number of settings	GNS		FDC			Lundgren
	Experimental		Artisanal	Kutumpula	Seines	
	1 694	18 037	1 473	527	739	12 076
Alestes macrophthalmus G.	18.4	1.0				2.6
Auchenoglanis occidentalis V.	14.4	7.5	1.4			3.5
Clarias gariepinus B.	12.8	32.9	9.2		4.1	6.6
Hydrocynus vittatus C.	9.1	3.0	2.1		1.4	2.6
Clarias ngamensis C.	6.5					
Schilbe mystus L.	3.7		3.8	7.1		18.3
Marcusenius macrolepidotus P.	2.1	7.6	22.8		36.5	7.3
Clarias buthopogon S.	2.0	1.9	1.6			1.8
Tylochromis bangwelensis R.	2.0			5.0	1.3	
Chrysichthys sharpii B.	1.9					
Tilapia sparrmanii S.	1.8	6.7	19.4		2.6	7.8
Barbus paludinosis P.	1.7			3.8		3.3
Barbus aff. unitaeniatus G.	1.6					3.3
Serranochromis angusticeps B.	1.5	10.2	5.9	12.4	3.2	9.7
Serranochromis robustus B.	1.2	8.7	4.6	13.0	6.8	3.1
Oreochromis macrochir B.	1.2	1.3		12.8	6.0	1.7
Serranochromis mellandi B.	1.0	2.5	5.9		4.6	3.1
Petrocephalus catostoma D.	1.0	2.4	6.1		1.4	7.0
Tilapia rendalli B.	1.0	1.8	1.3	50.0	6.9	2.5
Mormyrops deliciosus L.		1.1	3.2		10.3	
Synodontis nigromaculatus B.		1.0	2.1			1.7
Serranochromis macrocephalus B.				3.8		
Hippopotamyrus discorhynchus P.					4.5	1.1
Mormyrus longirostris P.					4.0	
Marcusenius monteiri G.					2.2	
Other species	15,1	6.6	3.5	3.0	4.2	13.0
Number of species contributing >1%	19	15	14	8	15	18

The number of species caught also differs by method. GNS and Lundgren nets show the highest species diversity with 19 and 18 different species contributing more than one percent by weight to the total catch. The fishermen using experimental nets, their own nets, and seines have respectively 15, 14 and 15 different species in their catch, and kutumpula target only eight main species. Thus, the three artisanal methods: gillnets, kutumpula and seines, are targeting different parts of the fish community in the swamps. Gillnets are mainly catching smaller species such as *M. macrolepidotus* and *T. sparmanii*, Kutumpula is highly selective on cichlids (96.3 percent by number and 92.0 percent by weight), particularly *T. rendalli* which is well known for its ability of evading stationary gillnets (e.g. Kenmuir, 1984), and the seines are mainly directed at the Mormyridae (59.3 percent by number and 58.9 percent by weight).

5.2 Estimates of vital parameters and long-term yield predictions

Table 8 gives a summary of estimated vital parameters for the selected species. Total mortality Z from the catch curve analysis and natural mortality M from Pauly's formula were used to calculate F and E. The table also includes the length-weight coefficients *a* and *b* used for estimating weights (e.g. weight infinity). For some of the larger species (*H. vittatus*, *C. gariepinus*, *O. macrochir*, *T. rendalli* and *S. robustus*), 2 cm length class intervals were used because FiSAT can only handle up to 50 length groups at a time. A detailed presentation of the derivation of vital parameters and long term yield predictions for the individual selected species in this study are presented in Kolding, Ticheler and Chanda (1996a, 1966b).

For only one of the selected species in the Bangweulu fishery, *Hydrocynus vittatus*, reliable growth parameters have been obtained previously from scale readings (Griffith, 1975). These were used to fit a comparative growth curve on the length-frequencies for *H. vittatus* in this study. The results showed that the two separate estimates produced nearly identical growth curves in the length interval observed, although Griffith had derived an L_∞ that was 20 cm larger. Separate growth parameters for M. macrolepidotus were estimated for experimental gillnet data as well as for data obtained from Lundgren nets. Again the results were comparable over most of the length range, although the Lundgren data yielded a rather low estimate of L_∞.
It was therefore decided to continue with the set of estimates obtained from the experimental gillnet data.

For two species the estimates for M were bigger than for Z. This indicates that fishing mortalities for these species were extremely low and consequently the exploitation rates close to zero. The reason that estimates for M can be bigger than Z estimates (when F is very small) should be attributed to noise in the data and because M and Z are independent estimates (Section 2.2.6) from different methods.

TABLE 8. *Summary of growth, mortality and length-weight parameters for selected species from length frequency analysis.* L_∞, W_∞, and K *are the parameters for the von Bertalanffy growth equation.* φ' *is the growth performance index (Munro and Pauly, 1983),* Z *and* CI_{Z1} *is the estimated total annual mortality and the 95 percent confidence intervals.* M *is the natural annual mortality,* F *is the annual fishing mortality,* E *is the exploitation rate* (F/Z), a *and* b *are the coefficients for the length-weight regressions.*

Species (length interval)	L_∞ (cm)	W_∞(g)	K	φ'	R_n	Z	CI_{Z1}	M	F	E	a	b
M. macrolepidotus	25.5	179.4	1.11	6.58	0.148	3.73	1.95-1.66	1.86	1.87	0.51	0.012	2 968
H. vittatus (2cm)	58.0	3 268.3	0.53	7.49	0.120	2.55	2.76-2.35	0.90	1.65	0.65	0.008	3 182
H. vittatus (2cm)*	78.0	8 389.5	0.34	7.63	0.127	2.76	3.01-2.50	0.62	2.13	0.77	0.008	3 182
C. gariepinus (2cm)	67.5	2 290.4	0.51	7.75	0.089	1.40	1.50-1.30	0.85	0.55	0.40	0.008	2 983
O. macrochir (2cm)	31.6	687.3	1.00	6.90	0.181	2.74	3.65-1.83	1.62	1.12	0.41	0.015	3 108
T. rendalli (2cm)	35.5	760.1	0.85	6.98	0.134	2.72	3.37-2.07	1.41	1.31	0.48	0.033	2 814
S. angusticeps	36.5	661.9	0.65	6.76	0.107	1.81	1.95-1.66	1.18	0.63	0.35	0.009	3 115
S. robustus (2cm)	57.0	2 898.6	0.51	7.41	0.110	1.76	1.99-1.53	0.89	0.87	0.49	0.008	3 166
S. mellandi†	26.0	267.8	0.78	6.27	0.151	2.12‡		1.44	0.68	0.32	0.014	3 026
Parameter values below were estimated data obtained with experimental, monofilament Lundgren nets												
B. paludinosis	11.45	16.8	1.40	5.21	0.218	2.58	3.22-1.93	2.69		M>Z	0.025	2 671
B. trimaculatus	10.53	13.5	1.40	5.04	0.306	2.37	5.89-1.16	2.57		M>Z	0.025♣	2 671♣
M. macrolepidotus	21.9	114.2	0.85	6.01	0.125	2.53	2.86-2.20	1.62	0.91	0.36	0.012	2 968
P. catostoma	9.2	8.9	1.46	4.82	0.745	3.06	4.83-1.28	2.75	0.31	0.01	0.036	2 483
S. mystus	15.0	34.9	1.29	5.67	0.193	2.51	2.79-2.23	2.36	0.15	0.06	0.005	3 268
T. sparrmanii	13.95	47.4	1.35	5.57	0.179	2.97	3.88-2.04	2.48	0.49	0.16	0.027	2 835

*second Z estimate for *H. vittatus* based on growth parameters from Griffith (1975).
†Growth parameters for S. *mellandi* were obtained from Kolding, Ticheler and Chanda (1996a).
‡ Z from the empirical relationship: $Z = 13.49*W_\infty exp(-0.33)$ (Marshall, 1993).
♣values from *B. paludinosis*.

Table 9 (sorted by the size of the species) gives a summary of the long term Thompson and Bell yield predictions for the various species by the three important fishing metods (artisanal stationary gillnets, kutumpula and seines).

TABLE 9. *Summary of Thompson and Bell long term yield predictions by species and catch method (single species- single gear), sorted by descending order of the size of the species (L_∞). LM is the observed modal length of the catch. L50 percent catch is the length at which 50 percent or more of the catch is smaller than or equal to this length. F-mean is the mean fishing mortality and E-mean is the mean exploitation rate (the latter two were obtained from the cohort analysis), values of E-mean higher then 0.5. are indicated in bold. The effort-factor is the fraction at which the current fishing pressure should be altered to achieve the long term theoretical Maximum Sustainable Yield (MSY, whereby 1= present effort; >1 is under - and <1 is overexploitation). The column MSY-Yield gives the absolute changes between Present Yield and long term MSY if the effort factor was applied. The last column ranks the species-gear combinations on present yield contributing more than 10 tonnes per year with the three largest are highlighted.*

Species	Gear type	LM (cm)	L50% Catch	L_∞- L50%	E mean	F mean	effort factor	Present Yield	MSY (tonnes)	MSY-Yield	Rank yield
C. gariepinus	seines	37	37	30.5	0.257	0.295	1.8	26.4	26.6	0.2	16
	gillnets	23	24	43.5	**0.505**	0.869	0.8	134.6	138.9	4.3	5
	kutumpula	27	28	39.5	**0.720**	2.189	0.6	6.9	7.4	0.5	
H. vittatus	gillnets	17	17	41.0	**0.616**	1.442	0.8	17.7	18.4	0.7	22
	seines	15	15	43.0	**0.680**	1.197	0.4	8.6	11.5	2.9	
S. robustus	seines	17	28	29.0	0.278	0.342	1.0	33.3	32.9	-0.4	14
	kutumpula	22	22	35.0	**0.588**	1.270	0.6	112.3	119.4	7.1	8
	gillnets	17	17	40.0	**0.625**	1.481	0.4	30.0	39.5	9.5	15
S. angusticeps	kutumpula	20	21	15.5	0.327	0.573	1.2	112.6	110.9	-1.7	7
	seines	17	17	19.5	0.358	0.659	1.6	23.9	24.7	0.8	19
	gillnets	16	16	20.5	0.364	0.675	1.0	112.7	112.2	-0.5	6
T. rendalli	**kutumpula**	18	19	16.5	0.357	0.784	1.2	423.1	429.2	6.1	**2**
	gillnets	15	15	20.5	0.401	0.942	1.0	8.0	8.0	0.0	
	seines	14	15	20.5	0.428	1.057	0.8	56.3	57.4	1.1	11
O. macrochir	seines	16	16	15.6	0.269	0.269	2.2	49.3	54.2	4.9	13
	gillnets	15	15	16.6	0.336	0.818	1.2	3.5	3.6	0.1	
	kutumpula	20	19	12.6	0.377	0.979	1.8	109.1	110.8	1.7	9
S. mellandi	gillnets	12	13	13.0	0.397	0.949	0.8	77.9	77.4	-0.5	10
	kutumpula	14	14	12.0	0.410	1.000	1.4	18.8	18.5	-0.3	21
	seines	12	12	14.0	0.437	1.117	0.6	26.2	26.6	0.4	17
M. macrolepidotus	kutumpula	18	18	7.5	0.066	0.131	>4	11.0	undef		24
	gillnets	14	14	11.5	0.333	0.931	1.6	259.0	272.1	13.1	4
	seines	14	14	11.5	0.419	1.344	1.0	456.5	450.7	-5.8	**1**
S. mystus	gillnets	14	13	2.0	0.028	0.067	>4	54.7	undef		12
	seines	11	11	4.0	0.076	0.195	>4	3.3	undef		
T. sparrmanii	**gillnets**	10	10	4.0	0.038	0.099	>4	263.1	undef		**3**
	seines	10	10	4.0	0.044	0.114	>4	23.0	undef		20
	kutumpula	10	10	4.0	0.052	0.135	>4	25.6	undef		18
B. paludinosis	seines	10	10	1.5	0.006	0.017	>4	0.8	undef		
	gillnets	9	9	2.5	0.013	0.036	>4	3.2	undef		
B. trimaculatus	seines	10	10	0.5	0.004	0.010	>4	0.9	undef		
	gillnets	9	9	1.5	0.009	0.023	>4	3.5	undef		
P. catastoma	seines	8	8	1.2	0.003	0.010	>4	15.4	undef		23
	gillnets	8	8	1.2	0.004	0.010	>4	9.4	undef		
							Total	2520.6		44.2	

Table 9 shows that in terms of present yield in the Bangweulu swamps, the three dominant species are:

- the small *Marcusenius macrolepidotus* (which is caught in the large quantity of some 700 tonnes per year in both seines and small meshed gillnets),
- the medium sized *Tilapia rendalli* (420 tonnes in kutumpula), and
- the small *Tilapia sparmanii* making up around 260 tonnes in the gillnets.

Each of the three different gears occupies one of the first three ranks according to yield. The next five ranks, yielding between 135 to 100 tonnes per year, consist of the large *Clarias gariepinus* (gillnets) and the three relatively large cichlids *Serranochromis angusticeps, S. robustus* and *Oreochromis macrochir* (gillnets and kutumpula). The seventh and eighth species in terms of yield are the smaller cichlid *Serranochromis mellandi* and the catfish *Schilbe mystus*. These eight species together make up the 22 highest-ranking yields for the three gears. Only after these species-gear combinations other species, such as the Tigerfish *Hydrocynus vittatus* and the small mormyrid *Petrocephalus catostoma*, are listed. The overall picture is a cichlid dominated fishery, with the exception of *C. gariepinus* and *M. macrolepidotus,* where the catches are rather evenly distributed over the three fishing methods.

The largest species in the system (*C. gariepinus, H. vittatus* and *S. robustus*) have the highest exploitation rates. (Table 9). In fact, there is a clear positive trend between the exploitation rate and size. For all the smaller species (*Schilbe mystus, Tilapia sparmanii*, etc.) the exploitation levels are so small and the natural mortality so high that MSY is undefined within the range of the simulated effort-factor: according to this simulation MSY can be estimated within up to four times the present level of fishing effort.

The bigger the fish are the longer they are subject to exploitation. This is illustrated by correlating the size range of exploitation, which is the difference between Length infinity (L_∞) and the length at which more than 50 percent of the catch of a particular species is obtained (Table 9), with the mean exploitation rate (Figure 7).

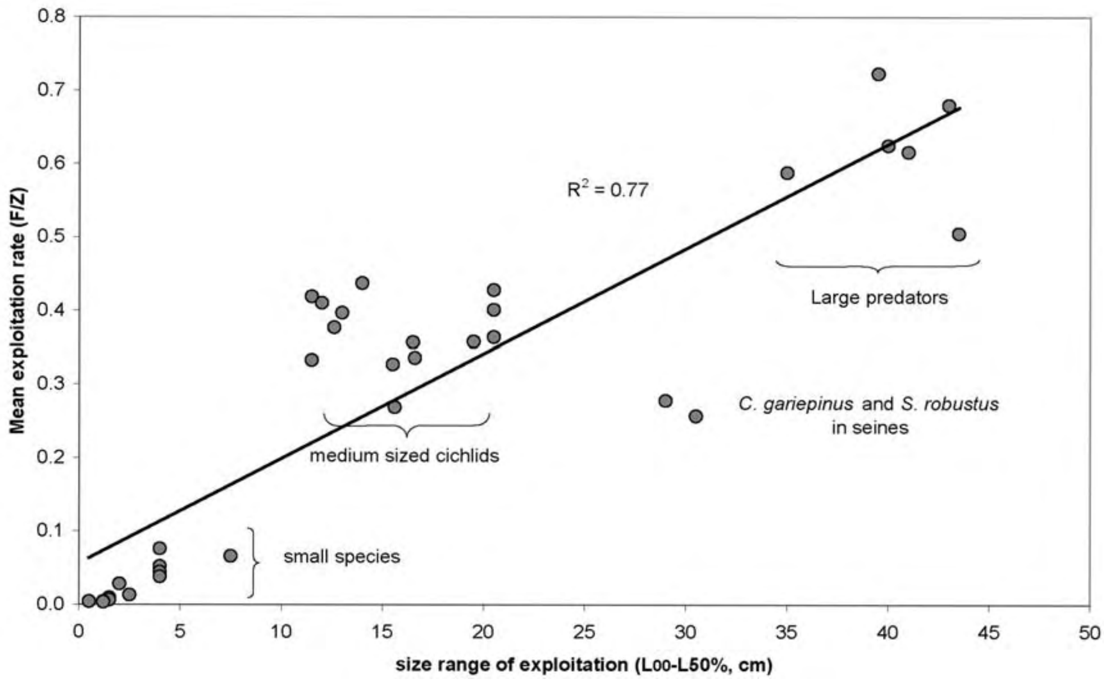


FIGURE 7. *Scatter diagram of E-mean estimates versus "size range of exploitation" (L∞ - L50% catch). Based on data from Table 9.*

Exploitation rates are clearly clustered in three separate groups consisting respectively of large predators, medium sized cichlids and all the small species. The two outliers are *C. gariepinus* and *S. robustus*, caught in the seine nets. All small species are very lightly exploited (E< 0.1), the medium sized species seem fully exploited (0.3<E<0.5), whereas the largest species are over-exploited in terms of the long-term steady-state MSY (E>0.5) (Table 9). This trend is independent of gear category. All three gears are again sharing the three top positions in terms of exploitation levels: kutumpula for *C. gariepinus,* seines for *H. vittatus*, and gillnets for *S. robustus*. Interesting to note, is that even if effort were to be adjusted to the recommended exploitation levels for each gear category (Table 9), the overall long term improvement in yields would only be about 44 tonnes per year, which is less than two percent of the present yield.

TABLE 10. *Summary of Thompson and Bell long term Yield predictions by species (all gears combined), by gear (all species combined) and for all species and all gears combined (multi-species, multigear analysis). To be able to interpret the results of this analysis only the eight species which had defined MSY's within the range of simulated effort levels in the single-species, single-gear analysis were included, that is those with exploitation levels higher than 0.1. The top panel shows the results of each of the eight species based on all three gears combined, i.e. the overall "optimal" exploitation level (effort-factor) of these species compared to the present level with the present combination of gears. Also shown are the cohort analysis results (E-mean and F-mean) on the combined catches of each species in all gears. The middle panel presents the effort-factor estimates of each of the three gears based on all the eight species combined. The bottom panel presents the overall effort-factor, Present Yield and estimated MSY of the all the eight species in all three gears. Z=total mortality. Diff. % = percentage difference between the present estimated yield and the estimated MSY.*

Species/gear Combination	Yield (tonnes)	E-mean	F-mean	Z (F/E)	effort factor	MSY (tonnes)	Diff %
All gears by species							
M. macrolepidotus	726.5	0.355	1.021	2.876	1.6	743.7	2.4
T. rendalli	487.4	0.214	0.383	1.790	2.0	519.3	6.5
S. angusticeps	249.2	0.307	0.522	1.700	1.2	247.1	-0.8
S. robustus	175.6	0.484	0.834	1.723	0.4	198.3	12.0
C. gariepinus	167.9	0.480	0.786	1.638	0.8	171.7	2.3
O. macrochir	161.9	0.228	0.478	2.096	2.0	173.6	7.2
S. mellandi	122.9	0.163	0.483	2.960	>3.0	>165.8	>34.9
H. vittatus	26.3	0.633	1.553	2.453	0.6	30.1	15.3
All species by gear							
Kutumpula	793.8				1.0	796.1	0.3
Seines	680.5				>3.0	>754.8	>10.9
Gillnets	643.4				1.2	661.6	2.8
All species							
All gears	2117.7				1.3	2158.9	1.9

Only the three largest species (*Clarias gariepinus*, *Hydrocynus vittatus* and *Serranochromis robustus*) are biologically "overexploited" in terms of individual maximum yields in the combination of the three gears (Table 10). A reduction in fishing effort could therefore theoretically increase (marginally) the total yield for these species. However, optimizing the yield for *H. vittatus* by 15 percent with a reduction in effort of 40 percent will have no major effect on the total catch since the contribution of this species is limited to 25-30 tonnes per year. *S. robustus* catches could be optimized by 12 percent, but the fishing effort should then be reduced with 60 percent, and this would in turn cause a serious reduction in the catches of smaller species. By contrast, the remaining five species can all be submitted to a higher fishing pressure to increase yields, but again the effect would be rather small: an overall increase of effort of 30 percent, as suggested in the all gears, all species combination, would theoretically only improve the yields with around 2 percent. The overall conclusion from this analysis is that the yield obtained with the present combination of gears and effort is remarkably close to the potential long term MSY under steady state conditions.

5.3 Biomass-size distribution

Based on the cohort analysis of the catches in the experimental gillnets (considered the least selective of the gears studied) a relative biomass-size structure of the main species caught in the Bangweulu swamp can be constructed (Figure 8). The small insectivorous and herbivorous species and individuals with a mode of 9-10 cm dominate the fish community and the biomass is characterized by a steep decline up to a size of around 30 cm. Although the large predators (*C. gariepinus*, *H. vittatus* and *S. robostus*) are the most heavily exploited (Table 10) these species are relatively abundant beyond 30 cm and cause the steep decline to taper off from this size. This could indicate that the larger sized specimen are relatively undisturbed by the present fishery, once grown in size beyond the selectivity range of the present exploitation pattern of the fishery.

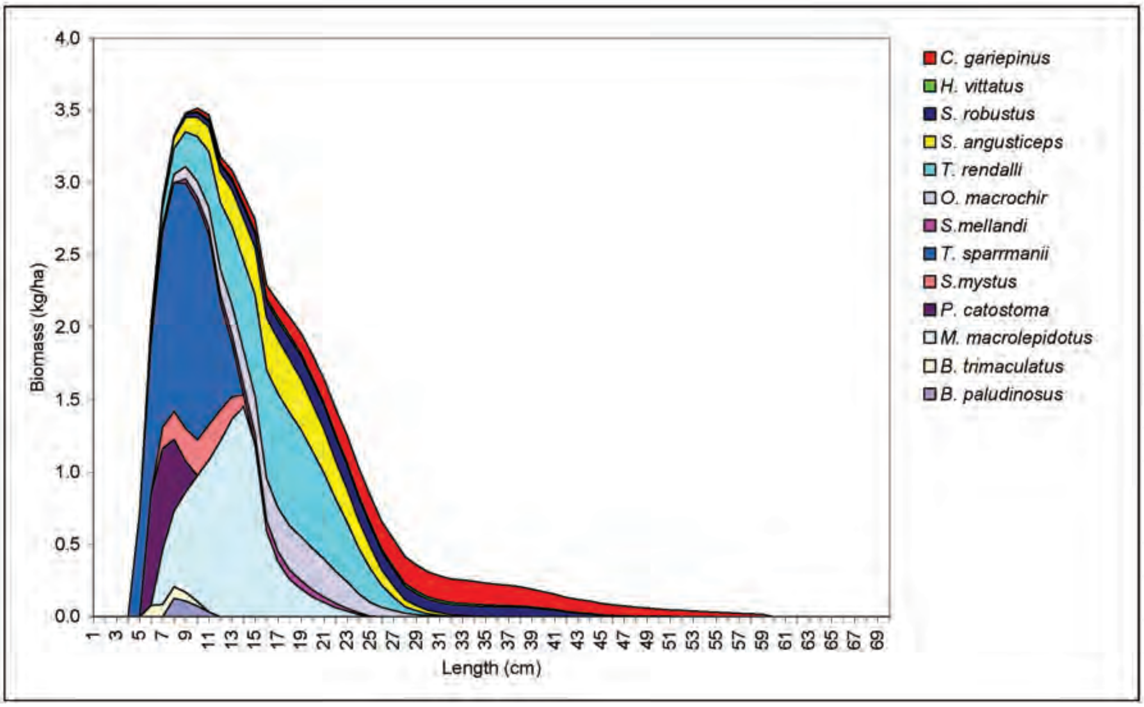


FIGURE 8. *Relative biomass (kg/ha) versus size (cm) of the 13 most common species in the Bangweulu swamps from cohort analysis on the experimental gillnet catches.*

The biomass-size distribution in the Bangweulu swamps would explain the high frequency of small mesh sizes found in the Bangweulu fishery (Table 4). 90 percent of the gillnet catches in numbers are taken in mesh sizes smaller than 50 mm (Figure 9). These catches consist mainly of *T. sparmanni* and *M. macrolepidotus*, which are low to moderately exploited (Table 9).

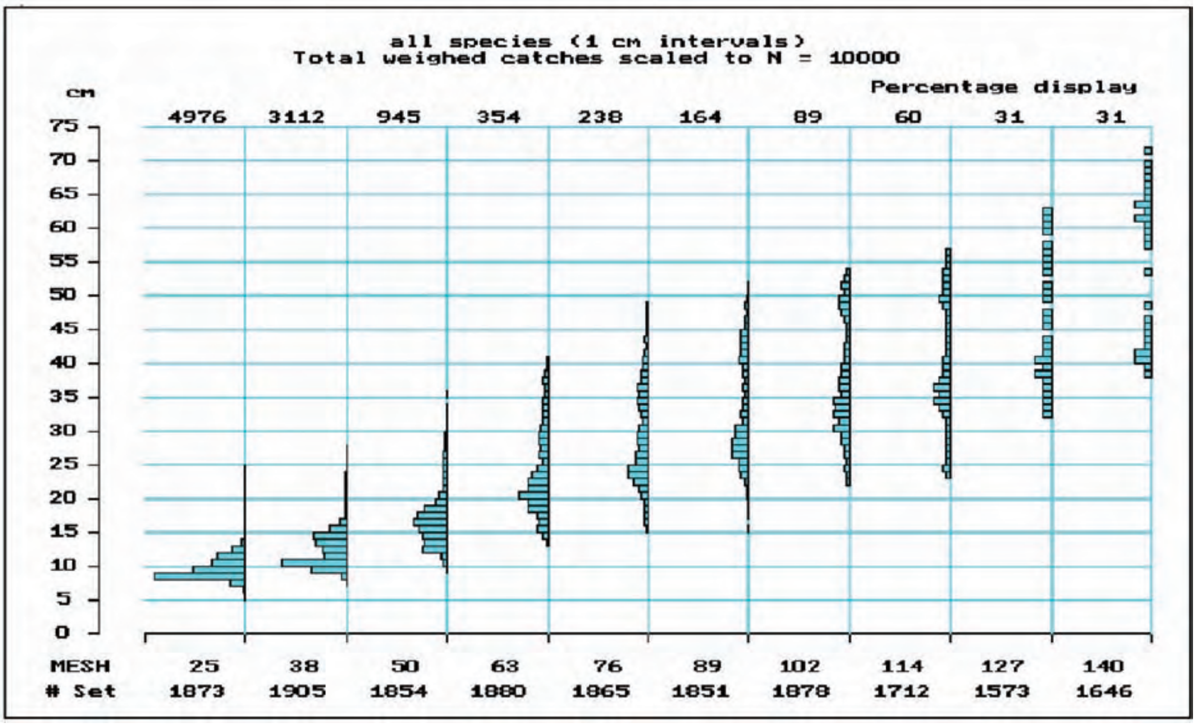


FIGURE 9. *Length frequency distributions and relative number of fish caught (on top, fraction of 10 000) of all species caught in the different mesh sizes of gillnets in Bangweulu swamps.*

5.4 Overall yield estimates

Table 11 gives the contribution to the total yield for the three fishing methods studied. CPUE from data collected by fishermen (by method and mesh size) and Frame Survey figures on total numbers of fishing gear (by type and mesh size) were used to estimate yields. Total annual yield for the swamps in the gillnets, kutumpula and seines is estimated at an average of 2 828 tonnes per year for the period July 1994 to July 1996.

TABLE 11. *Yield estimates (tonnes/year) for the Bangweulu swamps for the period July 1994 to July 1996 in the three gears studied, and the relative contribution of the eight species included in Thompson and Bell long term yield predictions to the total yield.*

Period	Gillnets (tonnes/yr)	Kutumpula (tonnes/yr)	Seines (tonnes/yr)	Total Yield (tonnes/yr)
1-7-94 1-7-95	1 277.0	793.9	1 046.4	3 117.3
1-7-95 1-7-96	984.1	930.1	685.1	2 599.3
Weighted mean Yield$_{yr}$ all species	946.2	902.6	979.1	2 827.9
Weighted mean Yield$_{yr}$ 8 species	643.4	793.8	680.5	2 117.7
Yield of 8 species as % of total yield	68.0	87.9	69.5	74.9
(kg/net/setting)	0.86	9.63	21.85	

In an independent survey on the weirs (Chanda, 1998) this fishery was estimated to produce 6 260 tonnes in 1997, of which *C. gariepinus* alone contributed more than 2 000 tonnes. This means that the weir fishery produced more than twice the amount of the three other main methods combined. The weir fishery, which is the main method in the seasonal floodplains, is catching a broader size range and a larger proportion of small specimens, and is therefore the least selective of the main fishing methods in Bangweulu (Chanda, 1998; Table 4). In terms of species this fishery mainly targets *Clarias gariepinus* (35 percent), *Tilapia rendalli* (12 percent), *Serranochromis angusticeps* (11 percent), *Marcusenius macrolepidotus* (11 percent), and *Serranochromis mellandi* (9 percent) by weight respectively (Chanda, 1998). None of these species are overexploited according to this study (Table 10). For all four gears together, the swamps and floodplains are thus producing around 9 000 tonnes of fish per year, or about 59 percent of the whole Bangweulu fishery (Figure 3). This estimate is in close accordance to Bazigos, Grant and Williams (1975) who estimated that in 1973–1974 an average of 54 percent of the total yield for the Bangweulu fishery is produced by the swamps. Table 11 also indicates that the contribution of the eight selected species used in the Thompson and Bell long-term yield prediction accounted for 75 percent of the total yield of the three gear types studied. Thus the majority of the exploited stocks is taken into consideration. Though catch rates for the three methods in this analysis differ by a factor 10 to 25 (Table 11), the outcome of the daily catch of an individual fisherman appears to be remarkably similar for the three methods when considering the actual daily effort. A gillnet fisher usually owns 8 to 10 gillnets and he operates them on his own. This results in a catch rate between 6.9 and 8.6 kg for a gillnet fisher per day. Kutumpula fishers often team-up with colleagues to be able to enclose a larger area, but each of them uses his own net. This results in a catch rate of 9.6 kg per day for a Kutumpula fisher. Seine fishers have to employ three to four assistants to operate the seine. Usually the catch is shared between the owner and his assistants, resulting in a catch of between 4.4 and 5.5 kg per fisher. These are of course rough estimates and considerable differences will exist between fishers due to differences in quality of the fishing gear (state of maintenance) and the skills of fishermen.

5.5 Catch rates in Bangweulu compared with other African fisheries.

A comparison of catch rates from different other water bodies in Africa (Table 12) shows that in general the catch rates in Bangweulu are low in terms of weight, but high in terms of numbers compared to the other systems. It should be noted that the data from Lake Kariba are from an unfished locality (Zimbabwean side) and from an intensely fished area (Zambian side) (see also Kolding, Musando and Songore this volume, 2003). The CPUE by weight in the experimental multi-filament gillnets in Bangweulu is higher than in Lake Kariba (Zambian side) which is a heavily fished system, but lower than the heavily fished Lake Mweru and the unfished Zimbabwean side of Lake Kariba. The CPUE by number, however, is among the highest of all the other systems and correspondingly the mean weight of the fish, 30 g in the multi-filament nets, is the lowest. This demonstrates the small average size of the fish in Lake Bangweulu as already seen from the biomass-size distribution (Figure 8). Differences in mean size may not be directly comparable between a swamp and an open lake ecosystem. The Okavango Delta, however, should in many ways be an ecosystem comparable with the Bangweulu swamps and here the catch rates in the Lundgren nets are among the highest of the different systems. In contrast to Bangweulu, the Okavango Delta is very lightly exploited (Mosepele, 2000) and this could be a reason for the higher catch rates and higher mean weight. On the other hand, the Okavango River in Namibia is generally highly exploited, and here the catch rates are slightly lower than in the Bangweulu swamps, although the mean weights are higher (Table 12).

TABLE 12. *Comparison of catch rates (mean ±SE) for different water bodies in Africa using similar experimental, monofilament (Lundgren) gillnets (42 x 1.5 m) and standardiszed multi-filament experimental gillnets (45 x 2 m). Sources: Lutembwe, Mukungwa and Kang'ombe (Fjälling and Fürst, 1991). Kariba, Zimbabwian side (=unfished) (Karenge, 1992 and Sanyanga, 1996), Kariba, Zambian side (= fished) (Musando 1996), Lake Ziway (Gelchu 1999), Okavango Delta, Botswana (Mosepele 2000 and Mmopelwa unpublished), Khashm El-Girba (Salih 1994), Mweru-Luapula (van Zwieten and Kapasa, 1996), Okavango River, Namibia (Hay et al., 2000). As the CPUE is obtained with similar standardiszed gillnets (same twine, mesh sizes and gear area), the values are comparable as indices of the fish abundance in the different systems.*

Water body	CPUE (kg/set)	CPUE (no/set)	Mean weight(g)	Mesh sizes (mm)	No. of settings	Net type
Lundgren nets:						
Bangweulu swamps	1.54 ±0.03	118.07 ± 2.27	13.04	13 - 150	869	mono filament
" "	1.36 ±0.08	69.36 ± 5.67	19.60	20 - 150	869	" "
Lutembwe river, Zambia	4.26 ±0.38	-		13 - 150	23	" "
Mukungwa, Zambia	2.35 ±0.44	-		13 - 150	13	" "
Kang'ombe, Zambia	2.02 ±0.38	-		13 - 150	10	" "
Kariba, Zimbabwe	4.20 ±0.30	149.10 ± 7.75	28.17	13 - 150	161	" "
" "	3.72 ±0.29	41.16 ± 2.16	90.38	20 - 150	161	" "
Okavango Delta, Botswana	4.59 ±0.80	82.98 ±10.96	55.31	13 - 150	82	" "
" "	4.36 ±0.78	68.86 ± 8.52	63.32	20 - 150	82	" "
Lake Ziway, Ethiopia	2.47 ±0.22	74.39 ± 4.03	33.20	20 - 160	32	" "
Khashm El Girba, Sudan	2.96 ±0.18	65.48 ± 4.21	45.20	20 - 150	86	" "
Standard experimental gillnets:						
Bangweulu swamps	1.43 ±0.02	48.21 ± 1.03	29.66	25 - 140	18 037	multi filament
Mweru, Zambia	2.94 ±0.12	44.13 ± 2.82	66.62	25 - 140	1 648	" "
Kariba, Zambia	0.57 ±0.03	6.72 ± 0.84	84.82	25 - 140	1 656	" "
Kariba, Zimbabwe	4.60 ±0.11	15.54 ±0.56	296.01	25 - 140	1 169	" "
Okavango Delta, Botswana	7.68 ±0.46	134.30 ±16.4	57.19	22 - 150	406	" "
Okavango River, Namibia	1.44 ±0.08	27.95 ±1.53	51.52	22 - 150	1 076	" "

6. DISCUSSION AND CONCLUSIONS

The underlying assumption in this analysis of a long-term, steady state MSY in the Bangweulu swamps is a strong oversimplification. History shows that all fish populations fluctuate over time, with or without fishing. Nevertheless, almost all fisheries models used for assessing the stocks and evaluation of management options are from necessity built on the simplifying assumption of constant parameters and long-term equilibrium conditions. Only fishing effort and fishing pattern, the parameters we can control, are allowed to vary. The yield analysis presented in this study is only a "snapshot" of the conditions in the Bangweulu swamps during the two years under study. Long time series over decades of reliable catch and effort statistics and environmental parameters are needed to disclose the inherent dynamics of the system. Though not all gears are studied, the coverage of species and methods is assumed to give an impression of the result of the overall exploitation pattern in the fishery. Weirs and traps, the most important other gears in the floodplain fishery exploit the same set of species and sizes as studied here and are the least selective (Chanda, 1998).

As a snapshot, however, this study does provide some insight in the present exploitation pattern of the fish stocks in the swamps. A first conclusion is the seemingly remarkable adaptability of fishermen to fully harvest the various populations in a multi-species fishery. The present fishing in the swamps is dominated by a combination of gillnets, kutumpula and seines. Although fished with unequal intensity and number of units, and mainly targeting different species, each of these fishing methods contribute about the same amount to the total yield (Tables 10 and 11). In addition, the return rate per individual fisher from each method is surprisingly even and the distribution of fishing gears and mesh-sizes in the area seems well balanced to match the catch rates of each gear (Table 4 and Figure 5). The combination and relative proportion of gears, methods, and mesh sizes are on an aggregated level seemingly finely tuned, and result in a maximized yield at a multispecies level.

How to balance the appropriate fishing pattern in a complex multispecies fishery is still a hypothetical issue in most of the world's fisheries and, will probably always be. All fishing gears and methods are inherently selective by their design and operation, and different fish species have very different catchabilities due to their habitat preferences and individual behaviour. Therefore, in a mixed multispecies fishery, such as Bangweulu swamps, also a mixture of gears should be utilized to harvest different parts of the community (Misund, Kolding and Fréon, 2002). In this study, long term yields for the artisanal gillnets, kutumpula, and seine fishery were examined under conditions of an unchanged fishing pattern (i.e. proportion of gears and mesh sizes) but with a varying effort. Judging from the perspective of each individual fishing gear (Table 10, middle part) both the gillnet- and the kutumpula fishery seem to be close to the "optimal" level (effort-factor =1), whereas the seine fishery can be increased with a factor of more than three. When analysing each gear in isolation, however, the result for one gear does not account for the effects of the other two and thus simulates a single gear fishery. The general trend when all gears are combined (total fishing mortality) is that the present yield from the combination of fishing gears is very close to the calculated potential yield (MSY) (Table 10). Calculated MSY is reached at a factor 1.3 of the present fishing effort. However, very flat-topped yield curves due to high natural mortalities (Table 8) indicate that increased effort will have little consequences for the overall yield (less than 2 percent gain, Table 10). On the other hand, increased effort will disproportionately decrease the daily return (= catch rates) of the individual fisherman. Judging from the multispecies, multigear analysis of the eight most important species, the present fishing pattern and intensity in the swamps is very close to the calculated biological optimum in terms of maximizing the output. All three main fishing methods examined in this study exploit to a large extent a specific and separate part of the fish community (Table 7). In doing so, these methods complement each other and reflect the diversity in the fish community.

The estimated exploitation rates (E) of the various species examined (Table 10 and Figure 7) fall into three clusters: high, medium and low depending on the size of the species – which again is largely a function of their trophic level. The upper theoretical limit for a sustainable harvest commonly is set at an E=0.5, and for some of the larger predatory species, this value was exceeded in individual gears (Table 9). However, looking at the species in all three gears combined (Table 10), the estimated exploitation rates of the species with a determined MSY within the simulated range of effort range between 0.16 to 0.63 with a mean of 0.36. The upper limit of 0.5 is only surpassed by *Hydrocynus vittatus* with a value of 0.63. This species yields comparatively little (1%) to the total catch in the overall combination of gears (Table 10). The general trend is that fishing mortalities are below or close to the theoretical maximum for large and medium sized fish species, but that they are negligible for most small sized fish species (Table 9, Figure 7). Overall, the larger predatory species seem to be exploited at rates close to

MSY, while the exploitation of the smaller species is decreasing with size. The medium sized fish species – mainly cichlids – contribute the largest proportion to the total yield. Small fish species are mostly under-exploited. Most of the small species contribute relatively little to the total yield (with the exception of *T. sparrmanii* in stationary gillnets), although they are important in terms of the numbers in which they are caught (Table 9).

The fishery is characterized by generally small mesh sizes (mode at 38 mm) (Table 4). This causes the fishing mortality to rise sharply on most species from around 14-16 cm TL (Table 9, Figure 8). The general impression that exists of a decreased mean size in the fishery during the recent years is not therefore surprising considering such a large output of small specimens in the fishery. The question remains, however, if the fishing pattern has changed towards smaller mesh sizes. Unfortunately no historical data on mesh size distribution exist. Still, there is little doubt that the high fishing intensities in Bangweulu has influenced the stock sizes and that the observed decrease in mean size therefore may be true. The market, however, does not seem to differentiate on fish size: almost everything sells at the same price per unit weight. As the small mesh sizes indeed catch significantly "more" fish by numbers (Figures 5 and 9), the incentives of changing the fishing pattern to larger mesh sizes might therefore not exist at present. In addition, a number of important, but small, species (*T. sparrmanii, P. catostoma, S. mystus*, barbus species, etc.) are probably best exploited by the current fishing pattern of small meshed gillnets. In any case, the high number of small fish in the Bangweulu fishery is not an indication of overfishing as the yields have not declined and all the small species are only lightly exploited (Figure 7 and Table 9). The rationale of changing the fishing pattern is therefore also redundant from a biological point of view. On the contrary, increased use of larger meshed nets would only lead to an even higher fishing pressure on the larger species.

The combination of fishing methods and mesh sizes in the Bangweulu swamps harvest all species and all size classes from around 10 cm and upwards, creating an almost unselective fishing pattern. Still, mean exploitation levels increase with fish size due to the increase in exploitation range with size. Theoretically, a non-selective harvesting pattern is ecosystem conserving (Kolding, 1994,: Misund, Kolding and Fréon, 2002;, Jul-Larsen *et al*., 2003). All species are preyed upon at various rates during their lifespan, and for teleosts the highest mortality is usually during the early life history phase (Bailey and Houde, 1989; Caddy, 1991; Hutching, 2002). Thus in principle, the "utopian" but optimal exploitation pattern, by which a community structure – that is the relative abundance proportions of the populations -– could be maintained, is fishing each population in proportion to the rate of the natural mortality (M) it is subjected to (Caddy and Sharp, 1986; Kolding, 1994). If maximum yield is an additional objective, then the exploitation level should increase with trophic level: E = 0.5 for top predators and less for lower trophic levels, where $E=0.5-(M_2/Z)$ depending on the predation mortality (M_2) (Kolding, 1993, 1994). Although predation mortalities are not known, this is actually the fishing pattern that seems to exist in Bangweulu (Figure 7). As all fishing gears are more or less species and/or size selective, such non-selective exploitation patterns can only be achieved by employing a multitude of gears simultaneously. As demonstrated in this case study, multigear, multispecies artisanal floodplain fisheries that employ a very high gear diversity, often seem to be producing an overall species-, abundance-, and size composition that closely matches the ambient ecosystem structure (MRAG, 1994; Claridge, Sorangkhoun and Baird, 1997, Chanda, 1998;, Hoggarth *et al*., 1999a, 1999b). On the ecosystem level such an exploitation pattern could be considered unselective across the species diversity range. Many floodplain fisheries, particularly in Asia, seem to have persisted (albeit with natural fluctuations) with a very high and diverse fishing effort for as long as our observations can tell (Misund, Kolding and Fréon, 2002).

Putting all the above-mentioned aspects together, the impression surfaces that in the Bangweulu swamp fishery a well balanced way to exploit the stocks in all their diversity, using a variety of fishing methods, has evolved. The combination of gears and effort has created an exploitation pattern that appears to have maximized yield from the community without causing deep structural changes. Two of the fishing methods used – seines and kutumpula – are technically illegal but without these methods less than one third of the present and potential yield would be realizsed (Table 10). Actually, without these methods two of the most important species in terms of yields (*M. macrolepidotus* and particularly *T. rendalli*) would hardly be exploited (Table 9). The stocks do not seem to be overfished in a biological sense but there may be little room for expansion under the present overall fishing pattern (Table 10). On the other hand, there is no evidence of any significant changes in fishing effort over the past 30 years (Table 2). Furthermore, from a journey in the late 1930's Bertram and Trant (1991) write "every dry spot in the swamps is inhabited and fishermen crowd together on tiny patches of floating papyrus beds". This descriptive record gives the impression that the fishing effort in the swamps has remained pretty constant for the past 70 years. It is therefore doubtful whether overfishing has ever been a problem in the Bangweulu swamps. The people of the Bangweulu swamps have always been fishing and they have had plenty of time to develop a fishing pattern that would suit the local conditions. From a biological point of view, effort or gear regulations do not seem to be a key issue at present and the catch per unit effort would, in terms of an economic break-even, probably be a regulating factor by itself (Beverton, 1990; Kolding, 1994). From an economic point of view, however, the fishery in the Bangweulu remains a marginal activity in which there is little room for expansion. If the number of fishermen would increase, it will become more and more difficult for individual fishermen to make a living out of it.

This study is a snapshot and should not be seen in isolation, as the Bangweulu swamps are not a more or less independent ecological entity. The swamps are part of a larger complex with a number of major lakes (Lake Bangweulu, Lake Walilupe, Lake Chifunabuli, Lake Kampolombo) and the Chambeshi and Luapula as major rivers. Both on a biological level and on the level of human interventions, many interactions between the different areas take place. There are water and nutrient flows between the swamps and major lakes and rivers, fish migrations take place, fishermen have a pattern of seasonal migrations between the different areas, etc. Therefore this study of the Bangweulu swamps, which can serve as a bench mark in future stock monitoring and assessments, should be followed by a study on the fish stocks in the open waters. As was the case for the swamps, hardly anything is known about the status, the exploitation patterns and the potential of the open water fishery at present. It is recommended that a full stock assessment through a similar set up with involvement of local fishermen in data collection is carried out for the open water fishery.

6.1 Conclusions

Simple data collected by local fishermen in combination with data on the size and structure of the fishery (obtained from Frame Surveys) can be used to estimate total annual yield and assess the fishing pattern. Our results give the impression that the fishers in the Bangweulu swamps have adapted their methods remarkably to fully harvest the various fish stocks and sizes. The combination and relative proportion of gears, methods, and mesh sizes seems to be finely tuned to maximize output without over-exploiting the stocks. In the Bangweulu swamps a well balanced exploitation pattern appears to have evolved in which a variety of fishing methods are being used and the fish resources are exploited in all its diversity. The fishing pattern has most likely evolved over time from trial and error based on individual catch rates. Individual return rates, rather than biological overfishing, might therefore be the most important regulating factor of the future fishery.

With the findings presented here it becomes apparent that the nation wide fisheries regulations, laid down in the Fisheries Act, do not suit the specific conditions prevailing in the Bangweulu swamp fishery. To be able to effectively exploit the diversity of species in the swamps, a variety of fishing gears are required, using small and medium meshed nets. Methods now used to exploit the different species, kutumpula and seines are prohibited and so is the most commonly used mesh size (38 mm stretched mesh). Further analysis is needed to investigate the impact of mesh size regulations, but at the present stage we feel it safe to conclude that kutumpula and seines are not detrimental to the fishery. On the contrary, these methods are harvesting parts of the fish community that otherwise would have remained untapped. The results show the importance to actually investigate the specific selectivity and impact of different fishing methods before making uniform regulations on their use. Many fisheries regulations still in force can be traced back to the colonial administration from the first half of the previous century (Malasha, this volume 2003) and have often proved to be fairly ineffective (Chanda, 1998). Striking a balance between enforcement of management regulations, and leaving room for fishers who are simply trying to survive is not easy. Therefore, the Department of Fisheries should, with the present adoption of the concept of co-management, consider directing all its management efforts towards monitoring and improving the working relation with the fishing community to be able to give advice based on sound scientific investigations.

The Fisheries Act of Zambia should be revised to leave room for differentiation between the various fisheries in the country. In this way specific regulations, adapted to the prevailing conditions in each individual fishery can be designed. For the Bangweulu swamps, kutumpula and seine netting should be legalized and until further analysis is done on the effect of the smallest mesh sizes the Department should tolerate these methods. Instead it should concentrate its efforts on developing and implementing the co-management concept in the fishery acknowledging that the local fishermen in this fishery to a large extent know what they are doing.

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