

FISH STOCK ASSESSMENT IN THE OKAVANGO DELTA: PRELIMINARY RESULTS FROM A LENGTH BASED ANALYSIS

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Mosepele, K. and Kolding, J. (2003). Fish Stock Assessment in the Okavango delta, Botswana – preliminary results from a length based analysis, pp 363–390. *In* Bernard, T, Mosepele, K and Ramberg, L (Eds). Environmental Monitoring of Tropical and Subtropical Wetlands. *Okavango Report Series No. 1*. University of Botswana, Maun and University of Florida, Gainesville, FLA. ISBN 99912-949-0-2

Abstract

This paper reports on the first length based stock assessment for the Okavango delta fishery. This study was conducted against the background of friction between the different stakeholders of the Okavango Delta fishery, where the main contention was allegations of fish over-exploitation through commercial gill netting. The basic approach involved estimating the vital population parameters (growth and mortality) of selected fish stocks, running a length-based cohort analysis on the selected stocks, and then predicting their long term yield under different fishing scenarios (varying levels of effort) using the Thompson and Bell model. Fishermen were used in this study to collect some of the data, adopting a similar approach to what was done in the assessment of the Bangweulu (Zambia) fishery. The estimated mean exploitation rates from the length cohort analysis (LCA) for all the species is below 0.5, which suggests that the stocks are not biologically over-exploited. The Thompson and Bell yield prediction model indicated that the MSY level for the three-spot and red-breast Tilapia and Nembwe can be reached when the present effort is increased by a factor of 1.8, 2.1 and 3.5 respectively. MSY for the other species could not be identified within the range of possible effort levels. This also suggests that the fish stocks of the Okavango are not over-exploited. The Okavango delta fishery has the lowest yield and effort when compared to other African lakes and river systems using Bayley's logistic equation, which supports the findings that this fishery can be expanded without fear of biological over-exploitation.

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INTRODUCTION

The Okavango Delta is one of the largest inland deltas of the world and the largest freshwater body in Botswana (Merron, 1993). It is found in the northwestern part of the country in the Northwest District, commonly called Ngamiland (Figure 1). The delta is a major tourist attraction in Botswana which receives between 20 000 and 50 000 visitors annually (Merron, 1993; Kolding, 1996; Mandlebe, 1998; Mbaiwa, 2002), and the main water source for north-central Botswana (McCarthy, 1992). It also supports small scale commercial, subsistence, and recreational fisheries (Merron *et al.*, 1995) with 3000 to 5000 resident fishers (Skjønberg and Merafe, 1987; Mosepele, 2001).

Currently, the Okavango fishery is open access. In the past several years this has fuelled friction between the various resource stakeholders. There are over 32 tourist facilities around the delta. The recreational (sport) fishery has alleged that commercial fishing is causing fish stock decline (Bills, 1996; Hagget, 1999). However, other factors such as the drought of the 1980's (Merron, 1993), spraying for tsetse fly (*Glossina morsitans*), and burning riverine vegetation for cattle grazing (Merron and Bruton, 1988) have also been attributed to decreased stock levels.

While friction between competing users is normal in common property resources (Samples, 1989; Welcomme, 1998), it is accentuated by the open access regime in the Okavango delta (Mosepele, 2001). The artisanal fishermen have always argued that fish yields are correlated to the flood regime (Ramberg and van der Waal, 1997) while the recreational fishery has consistently argued that low fish yields are caused by commercialized gill net fishing (Hagget, 1999). A direct relationship between flood levels and flooded areas productivity has been determined in other African water-bodies (Gulland, 1978; Welcomme, 1992; Kolding, 1994; Lae', 1995; Sanyanga, 1996; Jul-Larsen *et al.*, 2003). It is most likely that the Okavango delta fishery also obey this rule. Furthermore, catches from exploited populations have temporal fluctuations due to effort variations (Boerema, 1978; Gulland, 1983; Hillborn and Walters; Welcomme, 1992). In 1999 a fish stock assessment programme was therefore initiated by the Ministry of Agriculture, primarily to provide answers to concerns about fish stock decline, but to also initiate a long-term fishery monitoring program. This paper presents the results from the first data collected between September 1999 and February 2000 (Mosepele 2001).

Scope of Study

The basic idea behind a stock assessment is to determine growth and mortality rates of an exploited stock, which then provides the basis for long-term potential yield prediction under steady-state assumptions with regard to the biological processes. All stock assessment models are based on rates, and the measure of rate is time, which is why the age of the fish caught is needed. Direct extraction of age information from fish in tropical environments is difficult, so stock assessment models for tropical fisheries, especially those in developing countries, are usually implemented in terms of length in which case growth, or the relation between length (size) and time (age) is needed. While length is not a desirable variable from a mathematical/statistical modeling perspective due to its non-linear relationship with time, it is an attractive measurement from a sampling point of view because it is easily taken in the field. Although requiring a substantial amount of data (Kolding *et al.*, 1996), a length based stock assessment is therefore a convenient method to study fish stocks within a narrow temporal scale assuming a constant parameter system to make the approach valid (Sparre and Venema, 1998).

The purpose of this study was to test this approach in the Okavango and to ultimately facilitate the development of a management strategy by assessing the degree of exploitation of the stocks. The large amounts of data needed within a short temporal scale necessitated the use of fishermen in the data collection, which has been tried in a similar African environment (Kolding *et al.*, 1996; Ticheler *et al.*, 1998).

Objectives

1. To estimate preliminary vital population parameters (growth and mortality) of selected fish species,
2. To predict the potential yield of the main stocks based on the derived vital parameters and,
3. To assess the current status of the fishery in view of the present exploitation regime.

MATERIALS AND METHODS

Data Sources

Data from several sampling methods and different gears were used in this study and are summarized in Table 1. For details see Mosepele (2001).

Table 1. Summary of data sources used in this study

Data Source	Period	Gear	Mesh Size (mm)	Settings	Data Type
Catch and effort ¹	1999	Gill nets	63 - 125	24977	Catch, effort
Lundgren nets ²	Sep. – Dec., '99	Gill nets	13 - 150	1002	Length, weight
Fisheries Nets ²	Sep '99 - Feb '00	Gill nets	50 - 125	630	Length, weight
Fisheries Nets ² (fishers)	Sep '99 - Feb '00	Gill nets	50 - 125	1588	Length
Commercial nets ²	Sep '99 - Feb '00	Gill nets	63 - 125	5191	Length

¹Collected by fisheries field staff from fishers' records

²Collected by K. Mosepele

Experimental Fishing

Small-meshed Swedish Lundgren Nets (SLN) were used to collect data for analysis of growth of selected fish species, and have been used before successfully in other systems (Kolding et al, 1996). Three sampling stations were chosen at Shakawe, Ngarange and Seronga. Tables 2 and 3 summarize the sampling design for Lundgren nets and Fisheries Research Nets respectively.

Table 2. Sampling design for SLN (number of settings by mesh size by month for each station).

Month	Station	Mesh Size (mm)													Totals	
		13	16	20	25	33	44	50	60	66	76	86	100	125		150
September	Shakawe			12	12	12	12	12	12	12	12	12	12	12	12	144
	Ngarange			10	10	10	10	10	10	10	10	10	10	10	10	120
	Seronga	7	7	8	8	8	8	8	8	8	8	8	8	8	8	110
October	Shakawe			7	7	7	7	7	7	7	7	7	7	7	7	84
	Ngarange			2	2	2	2	2	2	2	2	2	2	2	2	24
	Seronga	3	3	3	3	3	3	3	3	3	3	3	3	3	3	42
November	Shakawe			12	12	12	12	12	12	12	12	12	12	12	12	144
	Ngarange			1	1	1	1	1	1	1	1	1	1	1	1	12
	Seronga	4	4	4	4	4	4	4	4	4	4	4	4	4	4	56
December	Shakawe			8	8	8	8	8	8	8	8	8	8	8	8	96
	Ngarange			13	13	13	13	13	13	13	13	13	13	13	13	156
	Seronga	1	1	1	1	1	1	1	1	1	1	1	1	1	1	14
Totals		15	15	81	81	81	81	81	81	81	81	81	81	81	81	

Table 3. Sampling design for FRN (number settings by mesh size for 1999 and 2000 for each station).

Month	Station	Mesh Sizes (mm)					Totals
		50	80	100	115	125	
September	Shakawe	11	11	11	11	11	55
	Ngarange	8	8	8	8	8	40
	Seronga	10	10	10	10	10	50
October	Shakawe	6	6	6	6	6	30
	Ngarange	2	2	2	2	2	10
	Seronga	2	2	2	2	2	10
November	Shakawe	14	14	14	14	14	70
	Ngarange	6	6	6	6	6	30
	Seronga	7	7	7	7	7	35
December	Shakawe	17	17	17	17	17	85
	Ngarange	12	12	12	12	12	60
	Seronga	9	9	9	9	9	45
January	Shakawe	10	10	10	10	10	50
	Ngarange						
	Seronga	5	5	5	5	5	25
February	Shakawe						
	Ngarange	7	7	7	7	7	35
	Seronga						
Totals		126	126	126	126	126	

Data Collection by Fishermen

Ten commercial and ten subsistence fishermen were involved in data collection following the system described in Ticheler *et al.* (1998). Each fisherman was provided with a 1-m measuring board graduated in centimeters, a pencil and a lined record book, which were swapped monthly for fresh ones. Subsistence fishermen were provided with four fleets of experimental gill nets (FRN) each. Commercial fishermen used their own nets, which were normally only two mesh sizes, 100 mm and 110 mm stretched mesh (and occasionally 125 mm stretched mesh). Subsistence fishers kept their catches as an incentive while the commercial fishers were paid a monthly fee for recording the catches. All fishermen were free to fish when and where they wished according to their traditional behavior.

Fish Species Selected for biological Analysis

1. *Oreochromis andersonii*, Castelnau 1861 (Three-spot Tilapia)
2. *Oreochromis macrochir* Boulenger, 1912 (Green-head Tilapia)
3. *Tilapia rendalli* Boulenger, 1896 (Red-breasted Tilapia)
4. *Serranochromis angusticeps* Boulenger, 1907 (Thin-face large mouth Tilapia)
5. *Hydrocynus vittatus* Castelnau 1861 (Tiger-fish)
6. *Clarias gariepinus*, Buechell, 1822 (Sharp-tooth Catfish)

7. *Serranochromis robustus* Boulenger, 1896(Nembwe)
8. *Schilbe intermedius* Ruppel, 1832 (Silver Catfish)

Data Analysis

Determination of growth

The ELEFAN I module implemented in FiSAT was used to calculate parameters for the generalized von Bertalanffy growth function (VBGF) for length (L) at age (t) (Pauly, 1982).

$$L_t = L_\infty \left(1 - e^{-[K(t-t_0)]} \right) \quad (1)$$

Where; L_∞ is the asymptotic length of fish and K is a curvature parameter.

Determination of ϕ'

ϕ' is a proposed index (Munro and Pauly 1983) used to compare the growth performance of fish in length and is defined as:

$$\phi' = \text{Log}(K) + 2 \text{Log}(L_\infty)$$

Where K and L_∞ are growth parameters from VBGF. (2)

Determination of Total Mortality (Z)

Total mortality (Z) was calculated from a linearized length-converted catch-curve analysis (Gayaniilo and Pauly, 1997) using:

$$\ln \left(\frac{C_i}{\Delta t_i} \right) = a + b \cdot t_i' \quad (3)$$

Where C_i is the number of fish in various length classes i ; Δt_i is the time needed to grow through length class i

$$\Delta t_i = \left(\frac{1}{K} \right) \cdot \ln \left[\frac{L_\infty - L_{i+1}}{L_\infty - L_i} \right] \quad (4)$$

and

$$t_i' = \left(\frac{1}{K} \right) \cdot \ln \left[1 - \left(\frac{L_i}{L_\infty} \right) \right] \quad (5)$$

L_i is the midpoint of length class I ; the value of b with the sign changed provides an estimate of Z .

Determination of natural mortality (M)

Pauly's empirical formula was used to determine natural mortality (Pauly, 1980):

$$\text{Log} (M) = - 0.0066 - 0.279 \log (L_{\infty}) + 0.6543 \log (K) + 0.463 \log(\bar{T}) \quad (6)$$

Where M is natural mortality, K and L_{∞} are growth parameters from VBGF and \bar{T} is the annual mean temperature.

Determination of exploitation rate (E)

The exploitation ratio (E) is computed from:

$$E = F / Z \quad (7)$$

where F is the fishing mortality = Z-M. The optimal value of E (E_{opt}) is about equal to 0.5.

Derivation of Overall Catch Volumes by Length Groups

Assuming steady state, the catch during the life span of a cohort is the same as the total catch of all length groups over one year. Overall annual catches in numbers of fish per length group_j were calculated as:

$$T_j = \sum_{i=1}^{\text{gear}} \frac{F_{ij}}{\text{sample effort}_i} \cdot \# \text{nets}_i \cdot \text{total effort}_i \quad (8)$$

Where, F_{ij} is frequency of length-group_j in gear (net)_i in sample and the number of nets and total effort (total number of settings of mesh_i) were obtained from the 1999 catch and effort data.

Length -based Cohort Analysis (LBCA)

Cohort analysis (CA) assumes that:

$$N_i \approx (N_{i+1} \cdot X_i + C) \cdot X_i \quad (9)$$

Where, N_i and N_{i+1} population size in number between time i and i+1, C is the number of fish caught in the time interval, and the natural decay is expressed by:

$$X_i = \left[\frac{(L_\infty - L_i)}{(L_\infty - L_{i+1})} \right]^{\frac{M}{2K}} \quad (10)$$

Where, L_i and L_{i+1} are length classes, M is natural mortality, K is the curvature parameter, L_∞ is the asymptotic length.

Yield analysis and long-term predictions

The mean annual number in each length class is expressed as (Gayanilo and Pauly, 1997),

$$N_i = \frac{(N_i - N_{i+1})}{Z \cdot \Delta t_i} \quad (11)$$

Where, N_i and N_{i+1} are the number of fish in length classes i and $i+1$, Δt_i is the time interval to grow through length class i , Z is the instantaneous rate of total mortality, Yield in weight is computed from the relationship

$$Y_i = C_i \cdot \bar{w}_i \quad (12)$$

Where, C_i is catch in numbers, \bar{w}_i is the mean weight of the fish of a particular age group, the mean annual biomass in each length group is computed as

$$B_i = N_i \cdot \bar{w}_i \quad (13)$$

and the total annual mean biomass of the stock is expressed as

$$\bar{B} = \sum (B_i) \quad (14)$$

Maximum sustainable yield (MSY) and optimal effort under the present exploitation pattern is calculated by a Thompson and Bell (1934) yield per recruit model where the catches are simulated by varying the fishing effort until the maximum long-term maximum yield, assuming constant recruitment, is found.

Yield Comparisons with other African Systems

Data from 1996 to 1999 were used to calculate yield in $\text{kg} \cdot \text{ha}^{-1} \cdot \text{yr}^{-1}$ from

$$Y = \frac{L_{AV}}{A} \quad (15)$$

Where, L_{AV} is average yield landed, A is area in hectares

The average number of fishermen (131 active fishers identified from Mosepele, 2001) was used to calculate effort, as number of fishermen per km². Bayley (1988) proposed the following empirical relationship to relate yield intensity in a series of African inland fisheries in the form of a logistic curve:

$$\text{Log}_e (y + 1) = ai^{0.5} + bi + c \quad (16)$$

Where, *i* is fishing intensity (effort) in fishermen per km², *a*, *b* and *c* are fitted parameters.

Yield comparisons from Lundgren nets and other areas

Lundgren survey gillnets have been used for experimental fishing in other African freshwater systems (Kolding *et al.*, 1996). As the fish caught are closely related in the various systems, these experimental surveys can be used as rough comparisons for evaluating catch rates in the Okavango using a standard net size of 50 m² (Hay *et al.*, 2000). The same mesh size range was used.

RESULTS

Growth and mortality estimates.

Table 4 summarizes the estimated vital population parameters of the eight selected species. The fishing mortality (*F*) and the exploitation rate (*E*) is here estimated independent of the total catches and are based on the *Z* (total mortality) and *M* (natural mortality) estimates only.

Table 4. A summary of the estimated vital population parameters for the selected species. *F** is estimated from $F=Z-M$, while *E** is estimated from $E=F/Z$. Where *Z* is estimated from length – converted catch curves. *CI_Z* is the confidence interval for *Z*.

Species	<i>L</i> _∞ (cm)	<i>K</i>	φ'	<i>M</i>	<i>Z</i>	<i>CI_Z</i>	<i>F</i> *	<i>E</i> *
<i>H.vittatus</i>	68.00	0.55	3.41	0.88	0.99	1.18 - 0.79	0.11	0.11
<i>S.intermedius</i>	45.50	0.40	2.92	0.80	1.42	1.66 - 1.17	0.62	0.44
<i>C.gariepinus</i>	90.50	0.26	3.33	0.50	1.00	1.16 - 0.83	0.50	0.50
<i>S.angusticeps</i>	44.00	1.00	3.29	1.46	1.95	3.54 - 0.36	0.49	0.25
<i>S.robustus</i>	56.50	0.83	3.42	1.21	2.24	3.48 - 1.00	1.03	0.46
<i>T.rendalli</i>	47.00	0.78	3.24	1.22	3.30	3.72 - 2.91	2.08	0.63
<i>O.andersonii</i>	53.00	1.00	3.45	1.39	3.99	4.46 - 3.52	2.60	0.65
<i>O.macrochir</i>	40.00	1.00	3.20	1.50	2.71	3.54 - 1.88	1.21	0.45
<i>O.andersonii</i> *	26.75	0.25	2.25	0.67	0.50	0.50 - -0.38		
<i>O.macrochir</i> *	27.52	0.42	2.50	0.95	0.24	0.36 - 0.12		

*O.andersonii** and *O.macrochir** were obtained from Booth *et al.*, (1995, 1996), respectively. *E* and *F* could not be calculated because $M > Z$ for both species. *N.B.*: φ is growth performance, *K* is growth curvature, and *E* is exploitation rate.

Cohort Analysis

The VPA results, giving fishing mortality (F) estimates based on total annual catches and natural mortality (M), are listed in Table 5. Exploitation rates are here estimated from $E=F/F+M$.

Table 5. Mean estimated E, F and initial input for F_t for selected commercial species estimated from cohort analysis.

Species	E	F	F_t
<i>S.intermedius</i>	0.045	0.037	0.100
<i>H.vittatus</i>	0.108	0.107	0.200
<i>O.macrochir</i>	0.162	0.289	0.500
<i>S.angusticeps</i>	0.169	0.296	0.200
<i>C.gariepinus</i>	0.208	0.131	0.200
<i>T.rendalli</i>	0.300	0.523	0.200
<i>O.andersoni</i>	0.317	0.645	0.600
<i>S.robustus</i>	0.330	0.596	0.500

Thompson and Bell Analysis

Table 6. A summary of the present yield (tons) and estimated standing stock biomass (tons) at present effort, and estimated long term MSY (tons) with the multiplication factor (f-factor) of effort needed to reach the MSY for selected species from the Thompson and Bell Yield Prediction model.

Species	Present Yield	Biomass	MSY	f-factor
<i>O.macrochir</i>	4.611	6.711	>6.305	> 4
<i>S.robustus</i>	1.870	2.869	2.479	3.5
<i>T.rendalli</i>	5.427	5.337	5.872	2.1
<i>S.intermedius</i>	2.128	4.702	>4.017	>4
<i>C.gariepinus</i>	6.742	27.426	>8.863	>4
<i>H.vittatus</i>	2.952	12.315	>4.705	>4
<i>S.angusticeps</i>	2.590	5.100	>3.789	>4
<i>O.andersonii</i>	20.065	17.192	21.562	1.8
Sum	46.385	81.652	>57.592	

The yield and biomass at the present effort and the estimated MSY with the corresponding multiplication factor of effort are summarized in Table 6. *O.andersonni* has the highest yield (20 tons) while *S.intermedius* has the lowest yield (0.2 tons) at the present effort. The MSY for most of the species could not be reached at the maximum simulated f-factor of 4 times the present effort. MSY for *T.rendalli* is reached at 2.1x present effort, 1.8x for *O.andersonni* and 3.5x for *S.robustus*.

DISCUSSION

Growth

The VBGF has been discussed and used extensively to model fish growth from length frequency data (Pauly, 1982, 1983, 1987; Sparre and Venema, 1998; Galucci *et al.*, 1996; Lai *et al.*, 1996). This study

used the VBGF implemented in ELEFAN I in Fisat (Gayanilo and Pauly, 1997). Galucci *et al.* (1996) highlighted the weakness of this method by arguing that ELEFAN methods do not have an underlying mathematical or statistical model, which means that the accuracy of the estimated growth parameters cannot be determined.

Concerns about the robustness and validity of this method have been raised in favor of age-based methods from hard body parts (Ebert, 1987; Wetherall *et al.*, 1987; Matsuishi, 1998; Pauly, 1982; Thiam, 1988). However, budget constraints, lack of trained manpower and low access to technology have necessitated the use of length-based methods in tropical fisheries, in lieu of age-based methods (Galucci *et al.*, 1996).

Brander (1975) suggests that length frequency distributions are normally the first step in looking at the detailed structure of the fish population, and in particular for establishing its age composition and growth and mortality rates. Length frequencies, however, are subject to bias from gear selectivity or size specific behavioral differences. Theoretically, a good sample is a random sample, which ensures that all members of a population have an equal probability to be caught (Gulland, 1965). The Lundgren nets used in this study are designed to have little selectivity and it was therefore assumed that representative samples of the populations under study were caught. These were used in the Bangweulu swamps, Zambia, where they facilitated the study of vital population statistics of both smaller sized and larger sized species (Kolding *et al.*, 1996).

Govender, (1994) discusses that length frequencies from young fish are best to determine growth rates because of greater separation of modes. Moreover, growth of younger fish is fastest which makes the identification of moving modes over time easier. Lastly, the determination of K in relation to L_{∞} is more robust when the length frequencies contain younger fish.

It is also possible that the sampling stations in this study could have been a major habitat type for certain size classes. Cannibalistic predators like tiger-fish (Merron and Bruton, 1988) ensure strict size class segregation by habitat, while juvenile Tilapias prefer littoral areas and adults prefer deeper waters Skelton (1993). These spatio-temporal variations in fish availability were not considered in the sampling design and could have therefore biased the results.

Sexual dimorphism was not considered in this study since data for both sexes were pooled for growth estimates, which might have introduced bias in the growth estimates. Skelton (1993) reports that female tiger-fish grow bigger than males, while male sharp-tooth catfish grow bigger than females. Dudley (1972) and Kapetsky (1974) (cited in Welcomme, 1985) indicated differences in growth between sexes for three-spot, green-head and red-breast Tilapia. Salvanes and Ulltang (1992) avoided sources of error in their growth estimates of cod by showing that there were no significant differences between males and females before pooling data from the two sexes.

Tropical floodplain fish growth is characterized as fast and seasonal (Merron and Bruton, 1988; MRAG, 1994) whereupon the seasonalized VBGF has been used to account for these seasonal differences in growth in other studies (Pauly, 1982; Thiam, 1988). However, Sparre (1991) showed that growth seasonality is important for yield calculations only in the case of short-lived species with one or at most two spawning periods during their life (e.g. penaeid shrimp); and that the seasonalized VBGF makes it difficult to estimate Z from length converted catch curves. Therefore, the generalized VBGF was used in this study, instead of the seasonalized model.

Booth *et al.*'s. (1995, 1996) estimated growth parameters for three-spot and green-head Tilapia are much lower than from this study as illustrated in Figures 2a and 2b. The estimated VBGF parameters from their study and the ϕ' values (Table 4 and Figures 2 a, 2b) suggest slow growing fish with low growth performance. The results were also considerably lower for both species compared with estimates from van der Waal (1985) (cited in Booth *et al.*, 1995, 1996).

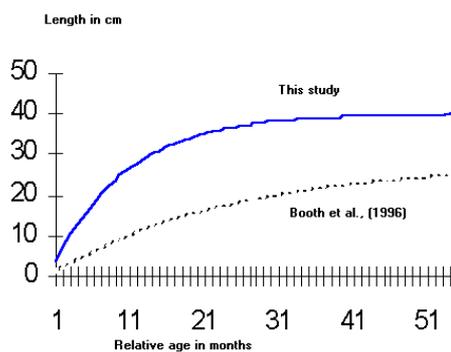


Figure 2a. Comparison of growth parameters between Booth *et al.*, (1996) and this study for green-head Tilapia

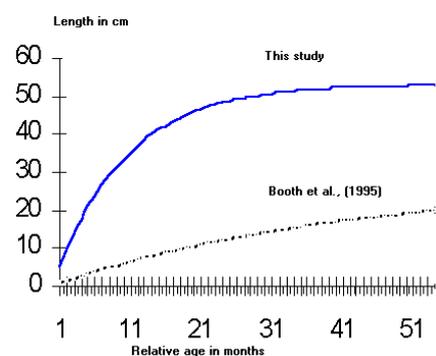


Figure 2 b. Comparison of growth parameters of between Booth *et al.*1995 and this study for three-spot Tilapia

This difference is perhaps a manifestation of the observations that similar species experience different growth rates in different habitats (Lowe-McConnell, 1982; Merron and Bruton, 1988). Booth *et al.*, (1995, 1996) used samples from two lagoons in the seasonal floodplains while this study used samples from the Panhandle area. Merron and Bruton (1988) concluded that the majority of species in the upper Okavango reach a larger size than their counter-parts in the lower seasonal habitats. Moreover, AQUARAP (2000) also observed a high prevalence of smaller sized Cichlids in the lower delta.

Another possibility could be that Booth *et al.*'s. (1995, 1996) growth rates are simply underestimated as suggested by the large differences between their estimated L_{∞} and the observed L_{max} from this study. Furthermore, using the estimated VBGF parameters of Booth *et al.*, (1995, 1996) in Pauly's empirical equation for M and for estimating Z from length-converted catch-curves (Table 4) resulted in $M > Z$. This is clearly unrealistic and suggests that the VBGF parameters used may be unrealistic as well.

The Okavango Delta and the Bangweulu swamps are in many ways comparable in terms of species composition, water chemistry and area (Kolding, 1997). These similarities provide the basis for comparisons with Kolding *et al.*, (1996). Generally, the Okavango Delta species have higher growth performances than their Bangweulu counterparts. This can be attributed to higher food availability in the Okavango Delta than the Bangweulu swamps. The Bangweulu rank amongst the most dilute water bodies in Africa in terms of total dissolved solids in the water (Welcomme, 1972), resulting in low conductivity and low primary production (Bos and Ticheler 1996). The estimated L_{∞} and L_{max} from different studies are summarized in Table 7.

Table 7. Estimated L_{∞} and L_{max} from this study, Skelton (1993) and Kolding *et al.*, (1996). (SL) indicates Standard length and (FL) indicates fork length.

Species	This study (L_{∞})	Skelton (L_{max})	Kolding (L_{∞})
<i>H.vittatus</i>	68	70(FL)	78
<i>S. intermedius</i>	45.5	30(SL)	15
<i>C. gariepinus</i>	90.5	140(SL)	67.5
<i>S. angusticeps</i>	44	41(SL)	36.5
<i>S. robustus</i>	56.5	45(SL)	57
<i>T. rendalli</i>	47	40	35.5
<i>O. anderssoni</i>	53	45	—
<i>O. macrochir</i>	40	40	31.6

Mortalities and Exploitation Rates

Mortality (fishing and natural mortality) rates are important for understanding the rate of population decay (Beverton and Holt, 1957; Ricker, 1975; Pauly, 1983; Gulland, 1965; Sparre and Venema, 1998). Direct estimates of M are often impossible to obtain (Stergiou and Papaconstatinou, 1993), hence methods for measuring M are at best qualified estimates (Sparre and Venema, 1998). Notwithstanding, Pauly's empirical formula has been used extensively in tropical and temperate fisheries to estimate M (Kraljevic' *et al.*, 1996; Gabche and Hockey, 1995; Sparre and Venema, 1998).

Stergiou and Papaconstatinou (1993) found that length-based methods produced low estimates for M , age-based methods produced higher estimates for M , while empirical regressions produced estimates closer to the mean estimates of all the direct methods. While no other methods for estimating M were done in this study, consistency between the estimated M values and the estimated VBGF parameters was tested by applying M on an arbitrary un-fished cohort to determine if it died out at the time where the estimated growth approached L_{∞} (by using Beverton and Holt yield-per-recruit function in a Microsoft excell spreadsheet).

An ambient temperature of 23⁰C was used for both Okavango and Bangweulu to estimate M , which provides a basis for comparison (Table 8). The natural mortality of the Bangweulu catfishes, *O. macrochir* and *T. rendalli* are higher than this study's, whereas natural mortality for *S. angusticeps*, *S. robustus* and *H. vittatus* are lower than this study's. These differences can be attributed to possible differences in predator/prey densities between the two systems, differences in parasites and incidences of diseases, and differences in primary productivity between the two systems.

Table 8. A summary of natural mortality (N) estimates from the Okavango and Bangweulu for selected species. The M for *O. andersonii* was not estimated in the Bangweulu system.

Species	Okavango	Bangweulu
<i>H. vittatus</i>	0.88	0.90
<i>S. intermedius</i>	0.80	2.36
<i>C. gariepinus</i>	0.50	0.85
<i>S. angusticeps</i>	1.46	1.18
<i>S. robustus</i>	1.21	0.89
<i>T. rendalli</i>	1.22	1.41
<i>O. andersonii</i>	1.39	—
<i>O. macrochir</i>	1.50	1.62

Z was estimated from the length converted catch curve method (Beverton and Holt, 1957; Gulland, 1969; Ricker, 1975; Pauly 1982, 1983, 1987; Lablance and Carrara, 1988), by assuming that mortality is uniform with age and that the sample is representative of the age groups considered. If these assumptions are satisfied, the right limb of the catch curve is then assumed to be a curve of survivorship, which is both age and time specific (Ricker, 1975).

Z can be split into F and M (Pauly, 1982) so that the exploitation rate (E) can be estimated (Moses, 1988; Gabache and Hockey, 1995; Kraljevic' *et al.*, 1996). The high E for Tilapia is not surprising, considering the targeted fishing that they are subjected to (Mosepele, 2001). However, the E for the silver catfish is surprising since its catches are very low in the fishery (Mmopelwa 2001, 2002). It is possible that the Z for silver catfish might have been underestimated by the length converted catch curve, which would then result in high E estimates. Moreover, several other factors that can affect Z, are variation in lengths of fish of the same cohort, gear selectivity, emigration and immigration of the species when they meet stationary nets (Gabache and Hockey, 1995), which were however not accounted for in this study (for silver catfish).

Cohort analysis (CA) and Yield Prediction (Thompson and Bell)

Cohort analysis (CA), or the length-based cohort analysis (LBCA) has been developed and used extensively (Vaughan *et al.*, 1998; Polacheck *et al.*, 1998; Huiskes, 1998; Gulland, 1965; Pauly, 1984; Gayanilo and Pauly, 1997; Jones, 1984). However, some of the weaknesses of CA rest on its assumptions (Gayanilo and Pauly, 1997; Huiskes, 1998) and Galucci, *et al.*, (1996) conducted some sensitivity analysis to test the robustness of the model. Despite the weakness of this model (LBCA) contrary to the age-based approach, Galucci *et al.* (1996) and Pauly (1984) discuss that the former is best for tropical fisheries. The results from cohort analysis were used as input for yields predictions and the estimation of maximum sustainable yield (MSY) using the Thompson and Bell model (Sparre and Venema, 1998; Gayanilo and Pauly, 1997). The basic assumption behind this model is a steady state system where all the input parameters, except fishing mortalities are constant and do not change with fishing effort. This model can then be used to predict short and long-term yield under different fishing patterns and varying effort, which might be changes in minimum mesh size, decreases or increases of fishing effort, or closed seasons.

Biomass and the value of the catch are incorporated into the model. However, bias from the preceding growth estimates and cohort analysis can affect the subsequent yield predictions and MSY estimations.

Saila *et al.* (1996) argue that there is relatively little theory available currently to predict the impacts of different levels of catch on exploited tropical fish assemblages. The Thompson and Bell model treats predicted yields of the major stocks as independent units (so-called single-species models), which is unrealistic. Multi-species exist in a series of inter and intra specific relationships which regulate population dynamics. Hence, the underlying assumption of steady state is unrealistic considering inter and intra specific interactions that occur within the various stocks in the Okavango and which to a large extent are also governed by climatic variations.

Past populations are reconstructed from LBCA based on estimated values of L_{∞} , M , F_t and K . As already discussed, M is at best a qualified guess, while F_t (terminal F) is always guessed (Pauly, 1984) based on a general knowledge of the fishing mortality on the major stocks, while L_{∞} and K are subject to sampling bias as already discussed. The validity of LBCA is questionable if a systematic bias is introduced into the calculations at any stage. The values are ultimately inter-dependent on each other. Despite these potential drawbacks, Pauly (1984) and Gayanilo and Pauly (1997) argue that the estimates of young fish from LBCA are estimates of absolute recruitment (at the time of sampling), which is normally difficult to estimate.

Another potential setback to the LBCA method rests on the condition that relatively high fishing pressure (high F compared to M) is needed for LBCA to converge rapidly towards the “true” value. Therefore, only fully exploited fisheries would provide reasonable estimates of recruitment (assuming that reasonable estimates of M are used) (Gayanilo and Pauly, 1997). Conversely, given low fishing pressure for a particular stock, LBCA would produce unreliable estimates, which will affect yield prediction. This is possibly the case of all the stocks in the Okavango, given their low exploitation rates (Table 5), but particularly for the silver catfish, which is harvested lightly at present. The mean E and F estimated from LBCA are generally lower than the E and F estimated in Table 4 for all species. The difference in magnitude between E and F from the two methods probably rests on their methodologies. From Table 4, F is estimated from the relationship $F = Z - M$, and E is calculated directly from the F/Z ratio. Therefore, the value of E is variable depending on what portion of the curve is chosen to run the regression for Z .

However, LBCA estimates F and E for each size class in the population based on an iterative process. Therefore LBCA is assumed to provide better estimates based on the directly estimated F by length groups without an overall Z estimate.

As expected, the two main commercial species, three-spot and red-breast Tilapia, are the most exploited in terms of the exploitation rates whereas the silver catfish is the least exploited. The MSY for *O.andersonni* and *T.rendalli* is reached when the present effort is increased approximately by a factor of 2 and about 4 for *S.robustus*. The estimated MSY for all the other species is undefined within the range of f-factors available in the model, which strongly suggests that the stocks are not over-fished.

Varying levels of F_t in the cohort analysis applied to the terminal length groups did not result in any marked change in the mean E for all the species. It can therefore be concluded, with the available data, that the main stocks appear to be underutilized, especially for the silver catfish. Nevertheless, three spot and red breast Tilapia appear to be the relatively highest exploited, and the Thompson and Bell yield prediction suggests that their present yield is approaching the MSY level, faster for the three-spot Tilapia than all the other species.

Status of the Okavango Delta Fishery in view of the present exploitation rate

The concept of the MSY has a long history in fisheries literature, particularly when stock assessment results have been applied to the problems of managing the fisheries (Gulland, 1968). But, the biggest question facing fisheries management is what needs to be optimized? At one time the epitome of fisheries fashion was regulation to achieve maximum sustained yield. Somewhat later, the alternative technology of maximizing economic returns was strongly advocated. More recently, the aim has been to achieve optimum sustained yield (Larkin, 1978). Hilborn and Walters (1992) discuss that MSY should not be the objective of fisheries management, because you literally have to exploit a stock heavily before you can identify its level empirically. Hay *et al.* (2000) reject the concept of MSY because it gives the false impression that a fixed and stable maximum output can be calculated for any fishery, and particularly for an environmentally fluctuating fishery such as found in tropical rivers and floodplains.

The basic problem with the Thompson and Bell yield prediction model is that it is based on a single species model, and is used to treat multi-species stocks. Larkin (1978) suggests that one advantage of

single species models is that they can be readily put together for assessment of how best to harvest when two (or more) species are caught in the same gear, assuming that their biological interactions are trivial. But this assumption is violated considering inter and intra specific competition that exists among multi-species stocks, for spawning, feeding and breeding habitat. The concept of MSY in this regard should then only be taken as one indicator of the state of the stocks. Yield prediction based on the Thompson and Bell model is susceptible to error when the interactions between the various species in the Okavango Delta are not taken into consideration. Therefore, Hay *et al.* (2000) suggest that it is necessary to develop adaptive management systems based on monitoring data with important parameters such as community and stock structures, and life histories of important species.

Preliminary results based on the estimated MSY however, suggest that the main fish stocks of the Okavango Delta fishery are not yet over-exploited. The present effort in the fishery can be at least doubled before the main species of the Okavango commercial fishery (three-spot and red-breast Tilapia) may be subject to biological over-exploitation. Present effort can be quadrupled without danger of biologically over-exploiting the other commercial species in the fishery. However, it should be emphasized that these results are preliminary and should be taken with caution. There are still serious gaps in the information database of the Okavango delta fishery that need to be filled before any conclusive assessments can be made.

Growth estimates from this study compared to Booth *et al.* (1995; 1996) indicate the possibility of at least two populations of three-spot and green-head Tilapia existing in the Okavango. As already discussed, there may be a slow growing, smaller sized population of three-spot and green-head Tilapia in the lower delta and faster growing, larger sized populations in the upper Panhandle. There is need for more studies to validate this observation, because it is possible that the two populations might not respond to the present exploitation in a similar manner.

LBCA and Thompson and Bell analysis estimated a present yield of approximately 46 tons for the Okavango with an estimated MSY greater than 58 tons. This estimated yield is thus lower than the 86 tons recorded in 1999 or the *ca.*200 tons of 1998 (Mosepele, 2000, 2001), which may be due to uncertainties in the total effort used to calculate the total catch by length groups (equation 8). The total effort has been estimated using observations from the 1999 catch and effort data. If a higher estimated effort was used then

the “present” estimated yield would have been larger – whereas the f-factors would not have changed much. The present estimated yield is therefore only an index compared to the “MSY.” What is important is the f-factor. Several reasons might account for these observed discrepancies. Total calculated Tilapia yields from 1999 indicate that 56 tons of Tilapia were harvested (Mosepele, 2000, 2001). CA estimated 35 tons (of the five selected Tilapia species) were harvested which means 21 tons are unaccounted for. Commercial fishers harvest several Tilapia species (Mosepele, 2000) that have not been included in this study due to insufficient data. These might account for 20.3 tons. According to Mosepele (2000), 25 tons of sharp-tooth catfish were harvested in 1999, which contrasts with the 7 tons estimated from this study. Commercial fishermen (such as those used in this study), periodically discard catfish in favor of the highly valued Tilapia species. Furthermore, commercial fishermen have perfected targeted fishing for their preferred species (Mosepele, 2000, 2001, 2002). Bayley (1988) made a similar observation when he pointed out that low yields can be attributed to fishermen restricting their harvest to a few valuable species because of their high value. Moreover, sharp-tooth catfish abundance is highest in the lower delta (Merron and Bruton, 1988; Mosepele, 2000, 2001), which was not covered in this study. It is therefore not possible at this point to determine catfish MSY.

It is interesting to note that the CPUE (kg/set) and the CPUE (no/set) for the Bangweulu Swamps are lower than the Okavango Delta’s (Table 9). Over the same mesh size range, mean weight per fish in the Bangweulu swamps is 13.5 grams while it is 55.5 grams in the Okavango Delta. These differences might depend on the habitat where the nets were set and the time of year, as there are seasonal variations in catch rates (already noted for the Okavango). Nonetheless, this suggests that the mean weight of per fish in the Okavango is higher than the Bangweulu swamps. Everything being equal, this suggests that the fishery in the Okavango is still in the initial phases of exploitation.

Table 9. Comparison of mean CPUE (SE) from Okavango Delta to other water bodies in Africa using similar experimental, standard monofilament (Lundgren) nets (42 x 1.5 m). Data from other systems were taken from Kolding *et al.*, (1996) and Gelchu (1999).

Water Body	Gear Type	CPUE (kg/set)	CPUE (no/set)	Mesh Size range	No. of settings
Bangweulu Swamps, Zambia	Lundgren	1.5 (0.03)	118.1 (2.27)	13-150	869
Bangweulu, Zambia	“	1.4 (0.87)	36.0 (5.56)	36-150	869
Lutembwe river, Zambia	“	4.3 (0.38)	-	13-150	23
Mukungwa, Zambia	“	2.4 (0.44)	-	13-150	13
Kariba, Zimbabwe	“	4.2 (0.30)	149.1 (7.75)	13-150	161
Kariba, Zimbabwe	“	3.7 (0.29)	16.0 (2.16)	20-150	161
Kang’ombe, Zambia	“	2.0 (0.38)	-	13-150	10
Khashm El Girba, Sudan	“	3.0 (0.19)	48.0 (4.21)	20-150	86
Lake Ziway, Ethiopia	“	2.7 (0.22)	135.0 (6.71)	10-160	32
Lake Ziway, Ethiopia	“	2.5 (0.22)	39.0 (4.03)	20-160	32
Okavango Delta, Botswana	“	4.6 (0.81)	82.7 (11.10)	13-150	81

Table 10. Comparison of mean CPUE (SE) from this study and other studies in the Okavango and from the Namibian portion of the river.

Location	CPUE(kg/set)	CPUE (no/set)	Mesh Size Range
Seronga (this study)	16.08(13.83)	61.42(107.61)	50-125
Seronga (Merron and Bruton, 1988)	11.77(20.82)	38.77(51.68)	50-125
Kwetze	4.31(0.45)	18.14(3.11)	57-118

Standardized catch rates from Seronga (Figure 1), a fished area in lower Okavango, are higher than in Kwetze, an un-fished area in upper Okavango, (Hay *et al.*, 2000) as summarized in Table 10. This study also indicates that present catch rates are higher than during the 1980s (Merron and Bruton 1988). Mean fish size at Seronga was 303 grams (Merron and Bruton, 1988), 262 grams (this study) (a negligible 16% decrease), and 238 grams from Hay *et al.* (2000), which again suggests the Okavango delta fishery is not over-exploited.

The recreational fishery has raised concerns of over-exploitation (Hagget, 1999). The main problem however, might not necessarily be biological over-exploitation of the main stocks *per se*, but rather a decrease in the mean size, because the recreational fishery targets trophy sized-fish. Welcomme (1999) discusses that fish assemblages respond to fishing pressure (and other externally induced stress) by a decline in mean size. Some species, especially the larger, *K*-selected, are unable to accommodate to fishing pressure and disappear from the assemblages. Others, such as the Tilapia, are able to maintain their place in the assemblage by reducing their mean size. He points out that as a correlate of mean length, the mesh size used in the fishery is a rapid indicator of the state of the fishery. The common mesh sizes in the Okavango

gill net fishery for the past several years have been 100, 115 and 125 mm stretched mesh (Mosepele, 2000, 2001, 2002), which suggests that the fish stocks are still healthy.

Bayley (1988) notes a relationship between effort (defined as number of fishermen per km²) and yield in African lakes where yield increases with effort until an optimum level is reached. Compared to other African lakes (Figure 3) and river systems (Figure 4), the Okavango delta has the lowest effort and yield of all the lake systems in the relationship. These observations attest to the conclusion already made that the Okavango Delta fishery is currently underutilized. Assuming that the Okavango is comparable to the other systems, especially the river systems, there is room for expansion of the fishery. However, this observation should be made with caution, taking into consideration the overall productivity of the delta, and also the spatial and seasonal variations in catch rates. Despite the limited amount of data and still preliminary analysis of this work to make any definitive conclusions, it can be fairly strongly suggested that concerns of over-exploitation are invalid. Subject to validation by research, it is possible that the motivating factor contributing towards friction among stakeholders is conflicting resource use.

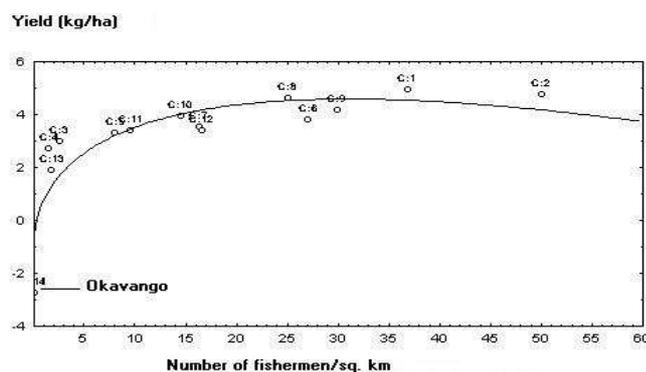


Figure 3. Yield vs. effort for African river systems. This curve explained 68% of the variance. Note that the x-scale was multiplied by 10.

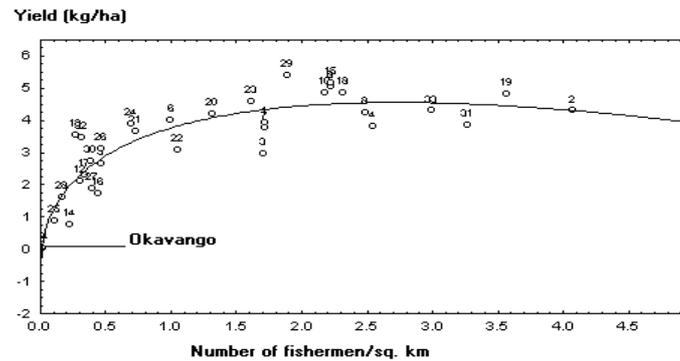


Figure 4. Yield vs. effort for African lakes. This equation explained 77.8% of the variance.

Polacheck *et al.* (1997) argue that the estimations of both current and future stock sizes are based on population models in which biological data from the stock and catch data from the fisheries are used to estimate the parameters of the models. However, large uncertainties exist in the current knowledge and understanding of population dynamics of fish stocks, especially in tropical systems, and more so for the Okavango. Additionally, the sampling error and bias associated with the basic data used for estimating the catch and biological processes are frequently unknown, but potentially large. This observation supports Rothschild's *et al.*, (1996) advice on the need and importance of long time series data as a critical tool towards dynamics systems modeling of mathematical models that determine values of fishing through time. Despite all the limitations and underlying uncertainties, this is the first attempt ever to make a stock assessment in the Okavango. The results show that there is consistency between the estimations and the observations and that the approach used in this study is therefore appears valid. The objectives have been fulfilled.

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