Results
Assessment of the Nile Perch Fishery in Lake Victoria

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Abstract

Data from the recorded catch in the fishery, effort estimated from census and other data, and published growth and mortality values are used to assess the Nile perch fishery in Lake Victoria. Surplus production, yield-per-recruit and a range of approximate models are employed. Uncertainties are taken into account by bootstrapping using the error distributions of the input parameters. MSY is estimated at around 270,000 to 320,000 tonnes (around 3.5 to 4.0 tonnes/km^2) with an optimal effort of 16,000 to 20,000 boats.

All the assessment methods indicate that the current Nile perch fishery in Lake Victoria is overexploited. Projections indicate stock collapse within a few years if present expansion of effort continues and immature fish continue to be harvested. It recommended that effort be reduced to around 14000 boats and a minimum size limit of at least 50cm be introduced (pending optimisation of mesh sizes with the Nile tilapia fishery) in order to provide a sustainable Nile perch fishery producing annually around a quarter of a millon tonnes of fish suitable for export markets.

Introduction

The aim of this paper is to assess and provide recommendations for the sustainable exploitation of the Lake Victoria Nile perch fishery, using available data on total commercial catch and fishing effort, incorporating research survey information wherever possible, and acknowledging the considerable uncertainties in the data. Since there are plans for a considerable increase of investment in processing plants and higher value products for Nile Perch fishery exports from the East African region (Bwathondi & Mosille 1988, Reynolds & Ssila 1990, Ogunja *et al.* 1992), it is surprising that a fishery assessment that encompasses the whole lake has not been attempted previously. Moreover, many of those who lay the blame for reduction in Lake Victoria's biodiversity at the door of the Nile perch but have nevertheless acknowledged the fishery benefits (e.g. Witte *et al.* 1992), have often asserted that the present fishery is not sustainable. In no instance has any evidence for this presumed lack of sustainability been put forward and so this paper attempts to fill the gap.

Tagging experiments and commercial catches suggest that individual Nile Perch make extensive movements over the entire surface and depth range of the whole lake (Ligvoet & Mkumbo 1990, Oguto-Ohwayo pers. comm.) and so we feel that an assumption that the fish comprise one stock is reasonable. We have used both constrained optimisation surplus production and yield-per-recruit models, together with a range of approximate assessments, in order to provide as robust an estimate of the relation of the present fisheries catch to MSY as possible. Catch and effort data has been derived from the fisheries records of Uganda, Kenya and Tanzania. In addition, research survey data from the Uganda and Tanzanian Fisheries services has been used to tune the assessment results. Data from 1979 to 1990 was used. This includes the period of rapid growth of the Nile perch population in the early 1980s and the great expansion of the fishery in the late 1980s: unfortunately, it has proved impossible to obtain data from more recent years.

Assembly of data

Commercial Catch and Effort Data

The raw information with which to make an assessment is less than ideal: the fisheries data originates from three different sources with different recording conventions; there are missing blocks of years, the catch data is raised from sub-samples; effort data is sparse and often undifferentiated.

We detail here the methods we have used to turn this information into complete data series for use in the assessment models. In general, we have used linear interpolations and have tuned from research survey data. Where necessary, we have set up alternative scenarios to examine the effects of alternative assumptions. We have used this information to estimate error variance of the catch and effort data set so that this may be used in the assessment.

Fisheries data for Nile perch catches were obtained from the Kenya Fisheries Department Statistical Bulletins, the Tanzanian Fisheries Division Annual Reports and the Ugandan Fisheries Department. There were no Tanzanian 1990 catch data available, so the 1989 figures were used, otherwise the catch data are complete. Total Lake Victoria catch data for 1979-1990 were obtained by summing the catch by species from the three riparian states (Figure 1a).

Fishing effort targeted on Nile perch was not differentiated in the catch statistics. Total effort, measured as "number of canoes", was available from Tanzania until 1989. However, there were only 11 effort data points from Kenya (Kenya Fisheries Department Statistical Bulletins, Reynolds *et al.*, this volume) and 6 effort figures from Uganda in the period 1963-1991 (Kudhongania & Coenen 1992, Orach-Meza 1992). The later figures, conducted under an improved frame survey, are considered to be reasonably accurate (Nyeko & Acere 1990). In order to estimate the total effort in Lake Victoria, the number of canoes per kilometre of shoreline in Tanzania was used to make a first estimate of the effort for the other two countries (it was assumed that the number of canoes in 1990 was the same as in 1989). This estimate was then tuned, as explained below, to real data for Uganda and Kenya to provide interpolations for years with no effort data. Shorelines were measured from a large-scale map.

To illustrate the method, Figure 1a shows the estimated number of canoes in Kenya calculated from the Tanzanian canoe density together with the known number of Kenyan canoes for the years available. Both sets of figures follow a similar upward trend but the real data points lie above the estimated points. This may be expected because fishing intensity in Kenya is higher than in Tanzania. Since the trend in the Kenyan data mirrored that in the estimated data a regression line was fitted, providing an interpolated estimate for the years with no data.

As in the Kenyan data, the estimated data for Uganda followed the same trend as the three real data points, but had higher absolute values. The estimated data line was hence lowered by a factor of 0.75, which is the ratio of estimated to actual canoes in 1990, considered the most accurate data point. The number of canoes per country were then summed to give the total canoe effort in Lake Victoria (Figure 1b).

There was no direct data available on the number of canoes fishing for Nile Perch. However, Ligvoet *et al.* (1988), give the percentage of fishers targeting Nile Perch from 1979 to 1986 in Tanzania. In the absence of other information, this figure was used to represent the percentage of total effort directed at Nile Perch. The graph was extrapolated from 1986 to 1990 under 2 scenarios, one with increasing Nile perch effort (*standard effort scenario*) and one where effort levelled off (*lower effort scenario*). The proportion of canoes targeting Nile Perch was then multiplied by the total number of canoes for the years 1979 to 1990 to give the total effort directed at Nile Perch (Figure 1b).

There are clearly considerable uncertainties in the catch and effort data thus assembled. Total catch data for the three countries showed fluctuations between 9 and 14% around smooth linear trends. Effort data showed fluctuations of around 5%. We chose an error value of 20% independently on each catch and effort data point to express likely errors. Uncertainty in the trend of fishing boats targeting Nile perch is reflected in our choice of two alternative effort scenarios from 1986 to 1990.

Research Survey Data

Research survey data has been used to constrain the fit of the surplus production assessment in two ways. First, to provide an absolute estimate of total Nile Perch stock biomass in one particular year after the main population explosion in the lake (1987), and secondly, to provide an index of relative biomass abundance during the rapid population explosion period from 1979 to 1985.

First, trawl surveys in Tanzania during 1987 estimated Nile Perch biomass at 321,540 tonnes in waters shallower than 40 m (Ligvoet & Mkumbo 1990), using the swept area method with an escapement factor of 0.5 (Pauly 1984, Sparre *et al.* 1989). About half the lake is deeper than 40 m, but Nile perch rarely inhabits water deeper than 60m because of de-oxygenation (Hecky 1993). Water shallower than the 60m depth contour is equivalent to about 80% of the lake's surface area. This raises the trawl survey biomass estimate to around 578,000 tonnes. Assuming about 20% error in these figures, we estimate that the total Nile Perch biomass in 1987 was likely to have been between 500,000 and 700,000 tonnes and this range was used to constrain the surplus production fit.

Secondly, we used research trawl data from each of the three riparian countries. In Uganda, a Fisheries Department research trawl with 20 mm mesh operated from Jinja from 1980 to 1985. During this period 761 standard trawls were made totalling over 800 hours (Acere 1988). In the Mwanza Gulf of Tanzania, published data cover standard trawls with 20 mm and 70 mm trawls (Witte *et al.*, 1992) from 1979 to 1988. In the Nyanza Gulf, Kenya, 38mm mesh trawls were made between 1979 and 1986 (Ogari & Asila 1990). Catch rates of Nile Perch in kg/hr from these three data sets were combined to provide an indicator of total Nile perch biomass increase during its population explosion. Since the absolute catch rates of the Ugandan, Tanzanian and Kenyan trawls were not equivalent because of differences in mesh, design, operation and vessel, the values for each data set were expressed as relative catch rates. All of the data were then combined and smoothed with a moving average (Figure 2). Consequently, we estimate Nile perch abundance in 1985 to be 8.36 times the 1979 level. This value was used to constrain the surplus production fit.

Analysis methods

Yield-per-Recruit

Data on mean length at age, growth rate and natural mortality were taken from the literature. The von Bertalanffy growth parameters we used were L_∞ = 205cm; k = 0.19, (Asila & Ogari, 1987) taken from a year towards the end the Nile perch population explosion rather than before or during the increase when growth might arguably have been different. Although there are several other values in the literature, these values were derived from a large set of fish samples, and Lmax, the largest fish landed, was about 200 cm long (Okemwa 1984). More recently a two-phase growth model has been fitted to Nile perch growth (Hughes 1992), but in practice the inflexion in this more accurate growth model makes little difference to a yield-per-recruit analysis. The length-weight relationship was taken as W = $0.000006L^{3.17}$(Ligvoet *et al.* 1988), making W_∞ = 127.8 kg. The baseline value for natural mortality rate, M, was taken as 0.3 (Ligvoet & Mkumbo 1990).

Isopleths of yield-per-recruit and mean-weight-of-fish-in-the-catch were calculated using the growth and mortality rates above (Beverton & Holt 1957). Fishing mortality for various past years was estimated using the mean weight isopleths by plotting reported mean weights in the catch on the wieght isopleth plot. Fishing mortality rate was then read off at the value corresponding to this point on the fishing mortality axis.

Uncertainty in the growth and mortality values used was examined using the bootstrapped variance of the optimal age of entry, t_{opt}, at the peak yield-per-recruit (Y/R) at high fishing mortality, F = 3. Since this is a somewhat theoretical figure, we also examined the effect on optimal fishing mortality, F_{max}, at the peak Y/R for the current age of entry, t_c = 1.5 year. 2000 bootstrapped sets of parameter values were chosen using a Monte Carlo technique and the sensitivity of t_{opt} and F_{max} recorded (Crystal Ball software, Decisioneering Inc., Denver, Colorado, USA). We subjected W_∞ to Normal error equivalent to 95% limits of ±20%; the von Bertalanffy growth rate, k, to a lognormal error 10%: lognormal errors were chosen to avoid negative parameter values. Since we had no clues as to its likely error distribution, the natural mortality rate, M, was set to be equally likely within a uniform distribution range of 0.2 to 0.6.

Parameter	*Error distribution*	*95% limits*
W_∞	normal	±20%
k	lognormal	±10%
M	uniform	0.2 - 0.6

Surplus Production

We fitted a non-equilibrium Schaefer surplus production model with constrained optimisation using the 'Solver' algorithm in the 'Excel' spreadsheet (Microsoft Inc.). This technique supercedes the method we used for previous work on this data (Pitcher & Bundy 1994). For each year, stock biomass was calculated from previous year's biomass increased by the population growth rate and depleted by catch. Values optimised in the Solver search were asymptotic population biomass, B_∞; the population biomass logistic growth rate, r; and the initial 1979 Nile perch biomass. (Note that the initial biomass is not 'virgin' in sense of B_∞ here on account of the population explosion.) This enables us to calculate cpue for each year from the estimated q and the year's biomass. The iterative Solver fit then minimised the sum of squares of the differences between observed cpue from the catch/effort data and the calculated cpues to obtain the best overall estimate of catchability, q (method due to C.J.Walters, pers. comm.). Alternative fits were performed with and without biomass constraints from the research surveys, and for the two effort scenarios.

Uncertainties in the catch and effort data set were investigated by examining the sensitivity of MSY and f_{opt} using Monte Carlo bootstrapping from the catch and effort error distributions. The COV of the catch and effort estimates was assumed to be 10% as explained above. 1000 Monte Carlo estimates were run for each of the two effort scenarios (Crystal Ball software).

Approximate estimators

In addition, some approximate methods of maximum sustainable yield estimation were used. These methods do not require a time series of catch and effort data, but do need biomass estimates. Biomass was taken from independent surveys or from the surplus production fits. In each case we investigated the sensitivity of these methods to the uncertainty in biomass.

Gulland's formula	$0.5MB_\infty$
Cadima 1	0.5(Y+MB)
Cadima 2	0.5ZB
Pauly (1982)	$2.3\ B_\infty W'^{-0.26}$
Beddington and Cooke (1983)	graphically determined

where M = natural mortality, B_∞= virgin biomass, B = current biomass, Y = current yield, Z = total mortality, W' = (W_∞- Wmat)/2 and Wmat = weight at maturity. The first 3 methods are detailed in Sparre *et al.* 1989. Beddington & Cooke estimates were determined using B_∞, L_∞, k and M in the published nomograms. Each of the first four methods was subjected to bootstrapped Monte Carlo sensitivity analysis to errors in the parameters. The error structures were assumed to be similar to those used for the yield-per-recruit and surplus production analyses as follows:

Parameter	*Error distribution*	*95%cls*
B_∞	normal	±10%
B	normal	±10%
Y	normal	±10%
M	uniform	0.2 - 0.6
Z	lognormal	±10%
W_∞	normal	±10%
Wmat	normal	±10%

Results

Yield-per-recruit model

The yield-per-recruit assessment plot (Figure 3) shows that at F=3 the optimum Nile perch fishery would increase the age of first capture to 4.6 years when Nile perch attain about 120 cm long and 10kg in size. Alternatively, at the current size and age of entry (1.5 yrs, 50cm, 1.5 kg), optimal fishing mortality should be around F_{max} = 0.4. This is equivalent to the current legal minimum mesh size of 12.5cm (Ogutu-Ohwayo 1992), although Nile perch smaller than this are frequently caught inshore. A reasonable target zone for management with an $F_{0.1}$ of 0.3 would be age of entry 2.5 years at 78cm and 6 kg (equivalent to an 18cm mesh net).

The mean sizes of Nile perch landed in Uganda (Masese) and Tanzania (Mwanza) are shown in Figure 4a. The equivalent fishing mortality rates are shown below in Figure 4b. Length-based analysis by Asila & Ogari (1987) suggested that F averaged 1.3 between 1981 and 1985, a value that is compatible with our figures. Figure 4 illustrates the great historical increase in fishing mortality from the late 1970s and early 80s. Since we read the F values from an isopleth plot that assumes an equilibrium fishery, the mortality values must be taken as imprecise, but the clear suggestion is that by the end of the 1980s, fishing mortality was in excess of a desirable management target level. Furthermore, the mesh size for inshore nets is catching male fish at around the age/size at maturity, and female fish before maturity, a practice that can lead to instability in recruitment and possible population collapse (Pitcher & Hart 1982).

These general conclusions are not altered significantly by the results of the bootstrapped sensitivity analysis. The 95% confidence limits on topt of 4.3 years are 3.0 to 5.5 years, while F_{max} at tc=1.5 years lies between 0.13 and 0.69 and $F_{0.1}$ between 0.1 and 0.65. Over 85% of the variance in optimal age and F_{max} is contributed by uncertainty in the value of M; about 15% is due to uncertainty in k, while W_∞ makes less than 0.5% contribution to the errors.

Surplus production model

Fitted Schaefer parameters for fits constrained and unconstrained by survey biomass and for the two effort scenarios are listed in Table 1. We are inclined to lend more credence to the constrained fits, not just because of the additional non-fishery information that has been used, but also because the trawl survey data suggest that the pre-population-explosion 1979 Nile perch biomass is more likely to have been nearer to 10% rather than 30% of later biomass levels. The population growth parameter is high, but we might expect that for an r-selected species. Figure 5a illustrates the fitted equilibrium yield curve for the normal effort scenario with the data points superimposed, while Figure 5b shows the estimated biomass of the Nile perch population in the whole lake together with the catch and total effort data for comparison. The lower effort scenario produces, as expected if the same catch results from lower effort, somewhat higher MSY and optimum effort estimates.

SCENARIO FOR TARGET BOATS	STANDARD		LOWER	
CONSTRAINTS	*none*	*biomass*	*none*	*biomass*
B_{1985} is 8.3*B_{1979}		✔		✔
B_{1987} is 500k to 700k tonnes		✔		✔
fitted values				
B_∞	1049266	697186	1870895	773834
r	1.06	1.61	1.05	1.61
MSY	278605	281409	489025	312381
f_{opt}	19467	17940	34608	19812
MSY as % of B_{1979}	32.4	10.8	33.2	11.0
min sum sqs	487	551	499	641

Table 1. Results of fitting the non-equilibrium Schaefer surplus production model to the catch and effort data for the whole lake. Method of fitting and of incorporating constraints is outlined in the text. Scenarios are alternative effort extrapolations from boats targeting Nile perch. Biomass constraints are derived from research trawl surveys in all three riparian countries, and are explained fully in the text.

Estimator	lower CL	upper CL
standard effort scenario		
MSY	269600	317600
f_{opt}	16640	20960
lower effort scenario		
MSY	306430	318224
f_{opt}	18741	20794

Table 2. Bootstrapped 85% confidence limits for MSY and f_{opt} from the surplus production assessment.

Confidence limits from the error bootstrapping analysis are given in Table 2: since some of the results produced skewed distributions of MSY estimates, we have taken 95%tiles for simplicity.

This assessment, which is not altered by the results of the sensitivity analysis, suggests mild over-fishing (Figure 5a). Walters (pers. comm.) suggests that optimum F should be divided by $\exp(0.5cv^2)$ to reflect uncertainty in the data. If we do this the recommended target value for fishing effort reduces slightly to 16311 to 20545 boats.

Approximate Estimators

MSY estimates from the approximate methods are given in Table 3. Values vary from 93,128 tonnes per year (Beddington and Cooke) to 465,567 (Pauly) with a median of 240,874 tonnes. Confidence limits from the Monte Carlo error analysis suggest that most of these estimates are not significantly different, with the exception of the Pauly estimator, which is high, and Beddington & Cooke, which is low.

As might be expected, the two Cadima estimators are most sensitive to the mortality rates (89% and 81% of variance in the MSY estimate to M and Z respectively), but insensitive to error in biomass, as is the Gulland formula (98% to M, 1.4% to B_∞. By contrast, Pauly's estimator is most sensitive to errors in B_∞ (94% contribution to variance).

Estimator	MSY	lower CL	upper CL
Gulland	143,235	60,789	225,681
Cadima1	247,305	197,277	297,333
Cadima2	222,189	172,813	271,565
Pauly	465,567	419,317	511,817
Beddington & Cooke	93,128	-	-

Table 3: Comparison of approximate assessments of MSY (sustainable tonnes per annum), and the increase in yield consequent on the introductions, using a range of different methods, for Lake Victoria Nile perch. Confidence limits (+/- 95%) were obtained by Monte Carlo bootstrapped sensitivity analysis using the method outlined in the text. For B_∞ and current B, estimates from the surplus production model fit were used.

Discussion

Our assessment suggests considerable depletion of the Nile perch biomass by the fishery, the 1990 biomass being about half of B_∞. For MSY, only two of six approximate estimates are outwith the general range of sustainable levels of exploitation suggested by the surplus production and yield-per-recruit analyses. Consistency between the yield-per-recruit, surplus production and most of the approximate assessment methods lends credibility to our results that was not so evident for our previous analyses of this data using older methods (Pitcher & Bundy 1993). But our overall assessment, that the Nile perch fishery in Lake Victoria is currently overfished, is not altered by the new analysis.

The current (1990) effort is within the confidence interval for Fopt, but we are not confident that as it stands this would be a sensible management target. The estimated catchability translates the 95% confidence limits of $F_{0.1}$ from the yield-per-recruit analysis into a target effort zone of 3,500 to 15,600 boats, while the equivalent criterion (effort equivalent to an equilibrium yield 90% of MSY) from the surplus production analysis suggests a target effort range of 13,000 to 15,700 boats. A conservative compromise is to recommend a reduction to an effort of 14,000 boats, representing an approximate 20% reduction on the 1990 fishing effort.

We have carried out projections of catch and stock biomass using the surplus production assessment for four different effort scenarios from 1990 (Figure 6):

Scenario a: constant effort at 1990 level;
Scenario b: effort increases at 5% pa from 1990 level;

Scenario c: effort increases at 7% pa (the 1983-1990 rate) from 1990;
Scenario d: effort reduces to 14000 boats by 1993 and held constant.

It is evident that scenario c leads rapidly to a dramatic collapse of Nile perch biomass and the probable destruction of the fishery. But it is instructive that the catch is maintained at over 300,000 tonnes almost until the last couple of years (Figure 6). A more moderate increase of effort in scenario b depletes biomass to 10% of B_{∞} by the year 2000 and by then reduces catches to about half of MSY, but should not wipe out the fishery within this time frame provided minimum sizes limits are implemented. Constant effort in scenario a keeps the Nile perch stock at around half of B_{∞} and the yield at around MSY. In practice, the difference in cpue from scenarios a and b would be indistinguishable from background error for many years. Figure 6 shows that scenario d tends to reduce short-term catches by up to 30%, but produces the highest cpue and therefore profit, and is the safest in terms of maintaining long-term high catches. Scenario d also produces a stock biomass that should be resilient to uncontrollable lake-shore fishing for undersized fish and should provide the best buffer against unforeseen limnological changes.

Our assessment gives a direct and dramatic indication that increasing effort at the rate of the late 1980s could soon lead to a catastrophic stock collapse. But a more modest increase leading to moderate growth overfishing or the maintenance of the 1990 effort should be sustainable. Food and spawning habitat for the juvenile and adult Nile perch seem assured, in contrast to the threat to the Nile tilapia represented by the invading water hyacinth.

A potentially most serious symptom, exemplified in the yield-per-recruit analysis, is the harvesting of immature Nile perch by the inshore netting sector. This could lincrease the variance of recruitment leading to instability. Consequently, we recommend that this sector should be restrained as much as possible through the enforcement of minimum Nile perch size limits a little larger that the current 12.7cm mesh (Oguto-Ohweyo 1992). We recommend a minimum landing size of 3kg (about 16cm mesh, Nile perch length about 60cm, age just under 2 years). Female Nile perch have an average maturation at 3 years old at a size larger than this at about 6kg, but some trade-off with the inshore catch of Nile tilapia should be allowed. Calculation of a precise optimal minimum size limit forthe two fisheries requires more precise data from both fisheries.

In the fitted surplus production model, increase in our fitted biomass is a year too early when compared to data from the fishery in Uganda and Tanzania. But the trawl surveys suggest that peak biomass in 1983 is a reasonable lake-wide average, although the documented expansion was a year later in far south of the lake at the Mwanza Gulf survey site. Since our assessment represents a lake-wide averaging of stock, catch and effort we are not too concerned by this. More detailed local information would be needed to partition our lake-wide effort recommendations into their local components.

Our fundamental assumption is that CPUE mirrors stock size, and this may be compromised in an expanding population, although increasing CPUE might justifiably be expected and so the bias may not be too severe. An additional problem is that the almost continuous spawning means that annually recorded catch and effort data may not be fully appropriate partitioning for the time series data.

Reductions in fishing effort for artisanal fisheries are not easy to implement, and in the case of subsistence artisanal fisheries, may be held to be unethical. But the Nile perch fishery in Lake Victoria now has all the trappings of a commercial harvesting operation and the necessary reduction in effort could perhaps be implemented with the co-operation and support of the processing sector.

The critical problem in the management of the Nile perch fishery continues to be lack of resources. Neither finance or people have been available to effectively implement management policies. The fishery is diverse and extensive, comprising many official and unofficial landing sites, and it requires many field officers to regulate the fishery and to collect fisheries data. Moreover, there is a lack of coherent international organisation: at present decisions have to be reached independently by the three riparian countries. There is a recent move toward lake-wide management (FAO 1992), but the crucial political decisions have yet to implemented.

Continued, careful monitoring and restriction of fishing effort, and the enforcement of minimum size limits, are essential to the sustainability of the Nile perch resource in lake Victoria. Conservationists have long anticipated a collapse of the Lake Victoria Nile perch fishery: our assessment suggests that their wish could soon be gratified, not for their stated reason of ecosystem instability, but if lake-wide co-ordinated management of this valuable fishery resource fails to implement the required controls.

Acknowledgements

We would like to thank Eric Reynolds and John Craig for making Nile perch data available, and Carl Walters for invaluable advice on assessment. Early work on this project was supported by the

Overseas Development Administration of the UK Government.

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Six figures follow

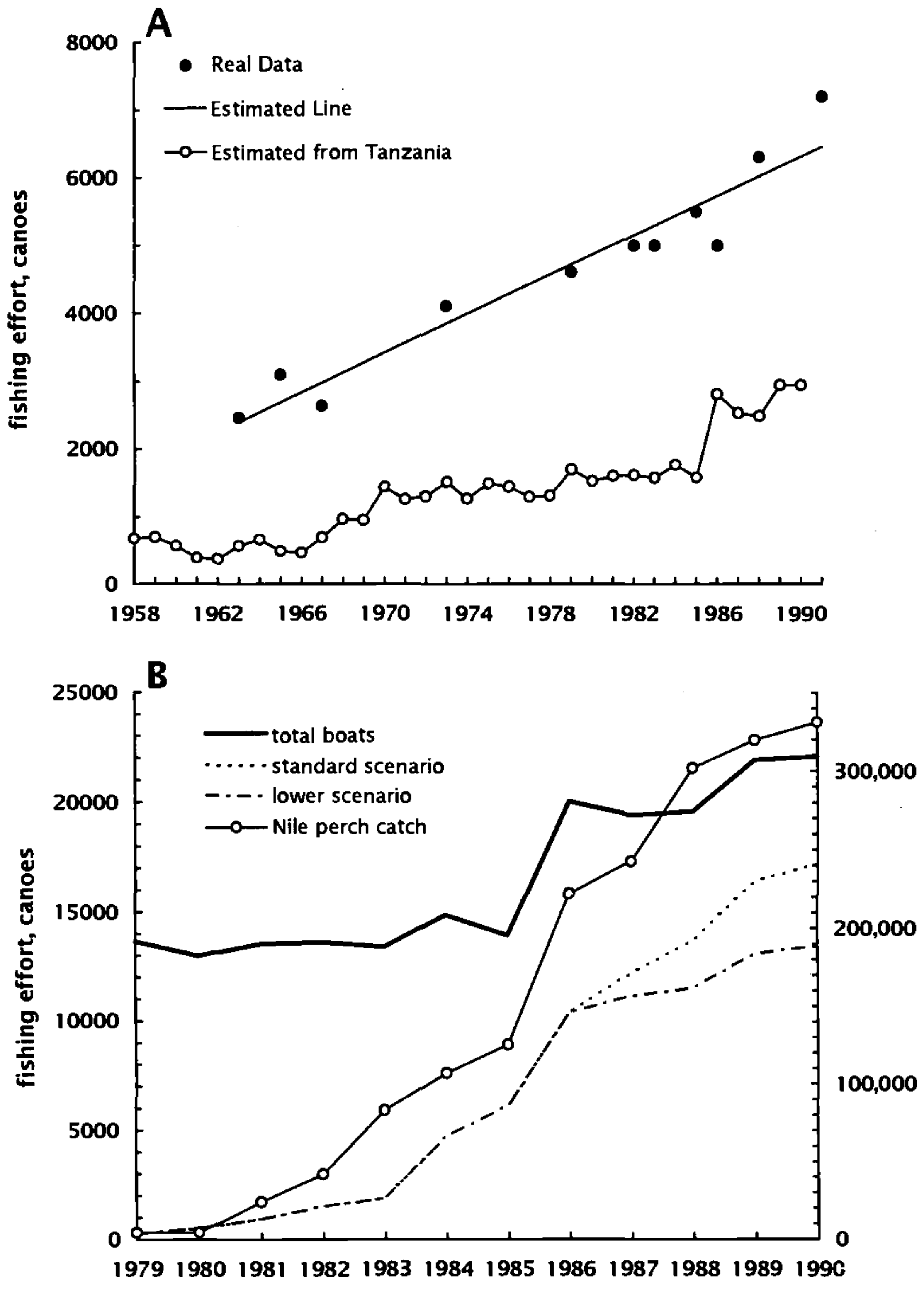


Figure 1. Assembly of Nile perch fishery data for the assessments. : Solid line with open circles is total Nile perch catch (right axis). Broken lines are estimated numbers of boats targeting Nile perch under two different effort scenarios. Solid line is total number of fishing vessels (see text for further details). : Line joining open circles is estimated number of boats in Kenya from the Tanzanian canoe density. Filled circles are surveyed Kenyan boats for all years that were available. Solid line indicates regression used for interpolation in missing years.

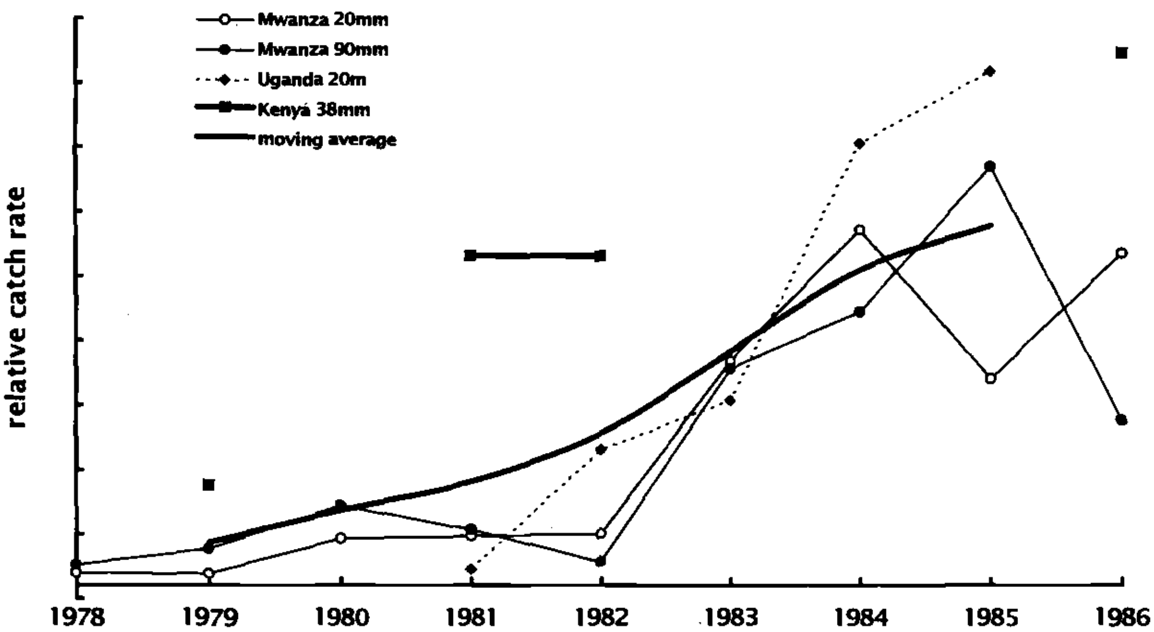
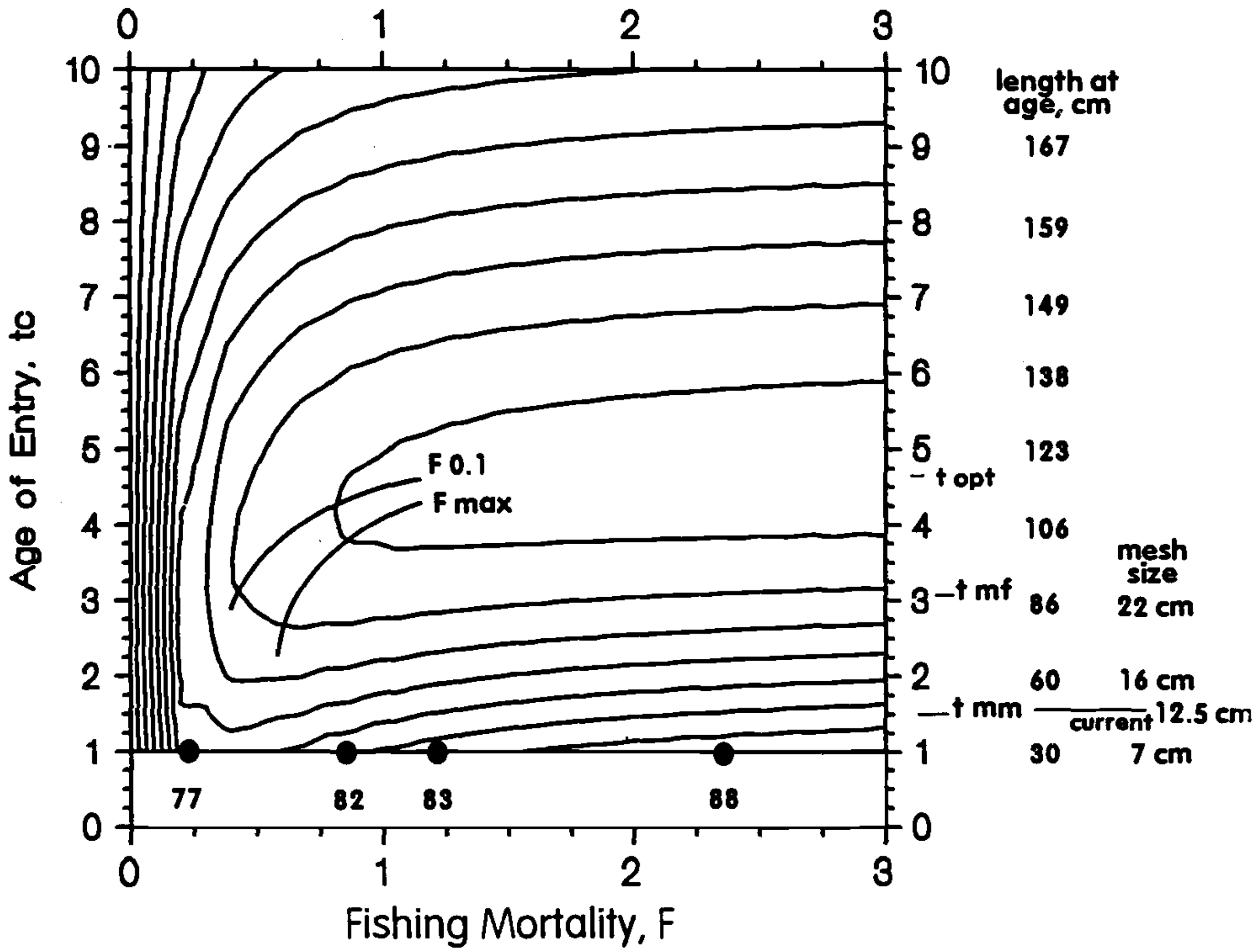
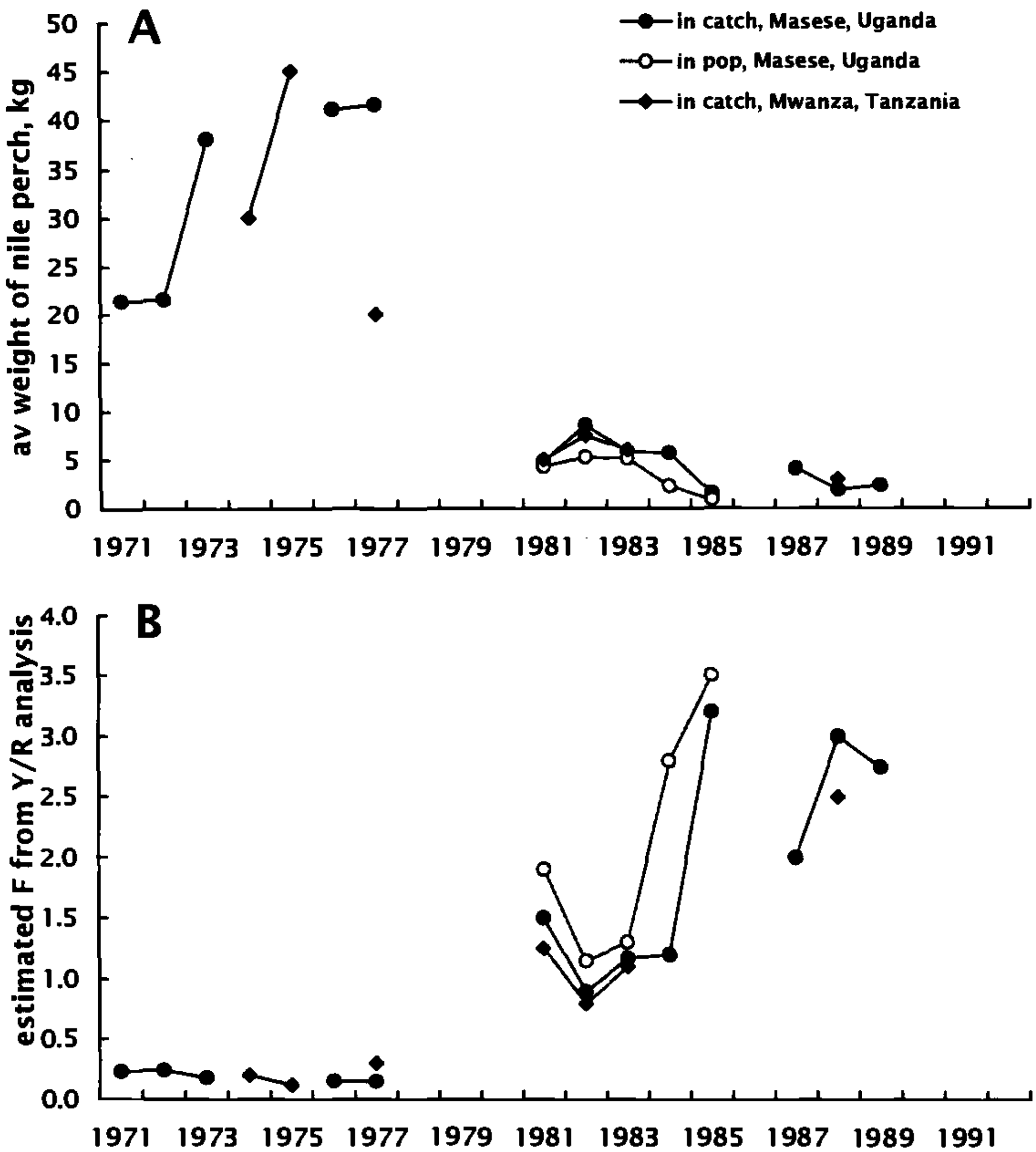


Figure 2. Survey trawl data (relative catch rates) from the three riparian countries used in tuning the fit of the surplus production model. Heavy line is the four sets of trawl catch rates smoothed with a moving average. For further details: see text.



. **Figure** 3. Estimated equilibrium yield-per-recruit isopleths for the Nile perch fishery in Lake Victoria . Parameter values are given in the text. Fmax and F0.1 lines are indicated in the target fishing effort zone. Scales to the right indicate Nile perch ages, lengths and approximate equivalent mesh sizes. tmm = age of male maturity; tmf = age of female maturity; topt = optimal age of entry at F=3. Solid circles along tc=1 line show some of the estimated F values for years indicated



. **Figure 4.** Average weights (A) and estimated fishing mortalities (B) for Lake Victoria Nile perch. Masese, Uganda, weights were obtained from Okaronon (Pers. Comm.) and the Mwanza, Tanzania weights from Ligvoet & Okummbo (1988). Fishing mortalities were read off an isopleth plot of mean weights from the yield-per-recruit analysis as explained in the text.

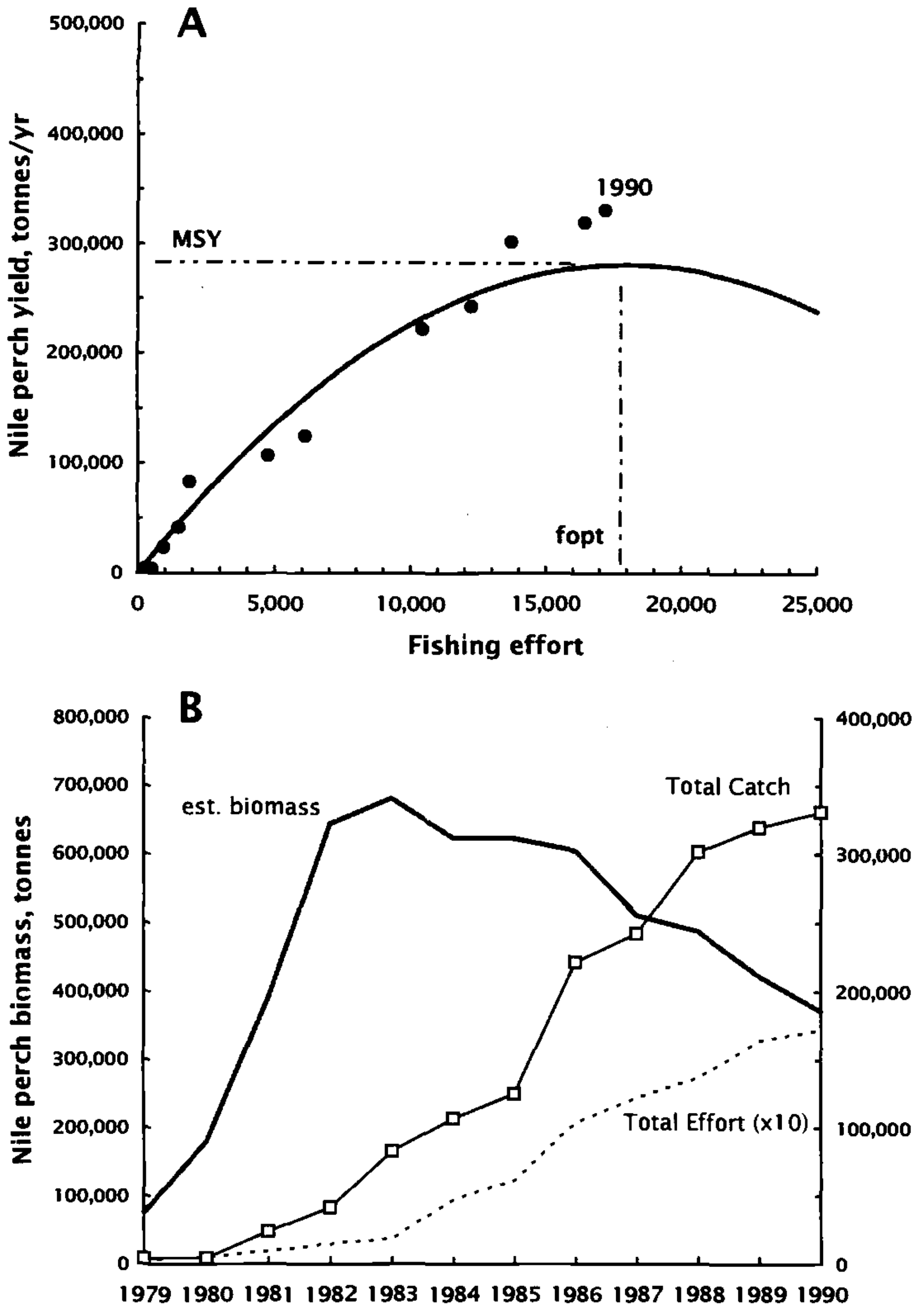


Figure 5. A. Equilibrium yield on fishing effort curve for the surplus production model (standard effort scenario) with the fishery data points superimposed.
B. Estimated biomass of the Nile perch population in the whole lake, together with the catch and total effort data for comparison.

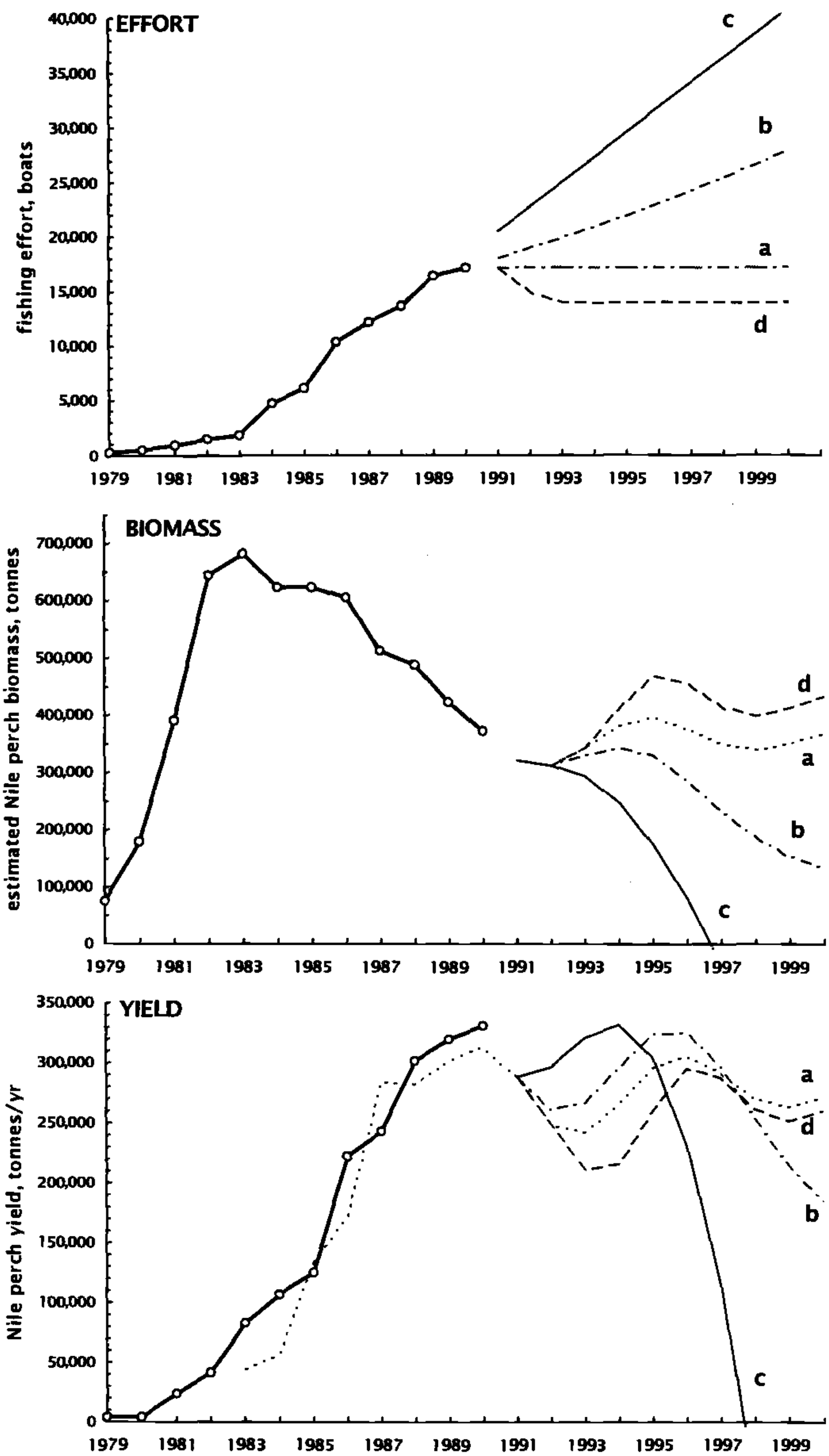


Figure 6. Projections of Nile perch annual yield (bottom) and total stock biomass (centre graph) in four alternative effort scenarios (top graph). Solid lines joining open circles are the data for effort and catch: biomass is as estimated from the surplus production model fit (standard effort scenario). For further details of scenarios a to d, see text.

Results
Introduced Sardines in Lake Kariba

The man-made Lake Kariba, some 5000 km^2 of water bordered by Zimbabwe to the south and Zambia to the north, was formed in 1958 by damming the Zambezi river at Kariba for hydroelectric purposes. The lake has an average depth of 30m (maximum 120m), but over the 30 years there has been 7m variation with rainfall (Marshall 1992). The creation of fisheries, which the indigenous Katonga people were supposed to pursue after forceable removal from their traditional hunting and farming grounds in the Zambezi valley, was a subsidiary aim from the outset (Balon 1974). Although artisanal net and trap fisheries operated around the shore-line for benthic and littoral cichlids, catfish and cyprinids, no species in the riverine fauna was likely to fill the pelagic niche effectively (Jackson 1960, 1961). Some areas were felled to facilitate putative trawl fisheries, but the potential for creating large-scale fisheries from the endemic fauna was vastly oversold (Balon 1974).

The pre-sardine era in Lake Kariba

There was an early large expansion of catches as nutrients in the new lake generated high primary production, but this was followed by reduction in yields and a long period of change in species composition (Kenmuir 1984). The almost empty pelagic zone invited an introduction to occupy the silvery zooplanktivore niche filled by indigenous cyprinid species in Lakes Malawi and Victoria, and clupeids (Pellonulinae) in Lakes Tanganyika and Mweru. *Limnothrissa miodon* and *Stolothrissa tanganicae* are endemic to Lake Tanganyika, where they form the basis of substantial artisanal fisheries in Zambia, Zaire and Tanganyika, and a semi-commercial fishery in Burundi at the north end of that lake. A previous introduction of Tanganyika clupeids in Lake Kivu in 1958-60 had created a thriving artisanal fishery, and an introduction to Kariba was recommended by Jackson (1961).

The introduction of sardines

Subsequent to an early abortive attempt in 1963, around 360,000 juvenile sardines were airlifted from Lake Tanganyika in 1967 and 1968 to a site on the Zambian shore of Lake Kariba (Bell-Cross and Bell-Cross 1971). Within 2 years the fish had successfully invaded Lake Kariba. One of the first indications was the discovery that the stomachs of tiger fish (*Hydrocynus forskhalii*) caught in the annual angling competition were full of the tiny lake sardines (Kenmuir 1971). Only *Limnothrissa miodon*, the more inshore of the two Lake Tanganyika species, has been identified from Kariba.

Balon (1974) disputed the theory that there was no member of the endemic fauna capable of expanding into the pelagic zone, identifying *Brycynus lateralis*, a characin, as having potential for a pelagic fishery, and in fact there are occasional catches of this species (Chifamba, pers. comm.). But in the African lakes, the endemic pelagic cyprinid species tend to be more volatile than the clupeids, probably because juvenile survival is more critical (e.g usipa, *Engraulicypris sardella* in Lake Malawi, Tweddle and Lewis 1990). Currently, it is not thought that *Brycynus* could have established a viable fishery in open waters (Marshall 1992).

Sardine ecology

Like other clupeids, the sardines spend the day near the bottom, in a refuge among the limbs of the famous Kariba drowned trees, and rise 20m to the surface at night (Begg 1976; Figure G4-1), where they feed on zooplankton and some phytoplankton (Begg 1974). 25 day-old larvae occur in 1 m of water along the shore-line while larger and older juveniles are found in progressively deeper water, until they recruit to the fishery at about 120 days old in water 15 m deep (Mtsambiwa 1989). Spawning occurs from September to March (Cochrane 1978), but there is a peak after the input of nutrients from run-off and wind-generated mixing in the rainy hot summer season from December to February (Begg 1970). The extended spawning and recruitment renders assessment using length-based methods difficult (Lewis, pers. comm.).

Ecological consequences of the introduction

There have been considerable changes in the ecosytem as a consequence of the sardine introduction. There has been marked decline in mean size and density of zooplankton (Marshall 1991). The most dramatic suggestion is that the collapse of the floating *Salvinia* weed was brought about by the growing sardine population in the 1960s, as they re-routed nutrients which otherwise would have been used by the floating fern (Marshall & Junor 1981).

The new fishery regime

Commercial fishing for the sardines began in 1969, soon after the discovery of the success of the introduction (Balon 1971). Initially the fishermen experimented with purse seines, trawls and lift nets operated at night with light attraction (Langerman 1979). This latter technique proved the most successful: from 1974 it has evolved into a precisely-timed and skilled operation with 10 m diameter lift nets. Through the 1980s, vessels have been progessively fitted with halogen lamps, sonar, radios and power-operated winches (Chifamba 1991).

Catches of about 500 tonnes in 1974 increased almost linearly to around 8000 tonnes in 1980, growing to around 30,000 tonnes in 1990 (Marshall 1992; Figure G4-2). Seasonally, catches peak in August and, in some years, in April/May (Marshall 1988).

Landings and the number of vessels fishing are recorded reasonably accurately and, in common with many commercial fisheries, monthly returns are a condition of the licence. Additionally, there is a catch bonus system in operation for payment of the fishing crews in Zimbabwe (Chifamba 1991). Under-recording is likely to be minor.

Economics

Fish are rapidly sun-dried on racks around the lake shore, bagged, and marketed throughout Zimbabwe and Zambia. A significant portion are exported and purchased by international aid organisations for relief food. A small percentage are frozen for the hotel and restaurant trade. No detailed economic appraisal of the fishery has yet been published, but at an estimated price of $1.5 per kilo wet weight landed (Murphree, pers. comm.), the annual

value of the sardine fishery must exceed 45 million dollars. (The current price, March 1993, is ZIM$6 per kilo, roughly equivalent to US$1000 per tonne wet weight). The cumulative value of the sardine fishery revenue to date is therefore estimated roughly at around 250 million dollars.

Assessment of the Lake Kariba Sardine Fishery

In 1982, a fit of the Fox (Fox 1970) equilibrium surplus production model gave an MSY of around 8000 tonnes (Marshall 1982), a value long since exceeded and clearly far too low. In 1989 the best fit to the entire data set was was around 25,000 tonnes, but the 1980-89 data gave no convincing MSY. Of the more recent non-equilibrium methods, the almost linear Walter plot (Figure G4a-1) gives little clue as to MSY. Figure G4a-2 is a variant in which recent increases in fishing power of vessels are included, but it is almost equally unhelpful in assessing the fishery. Non-equilibrium fitting of the Fox production model using CEDA gives an MSY of around the same size as the current catch (Table 1: Figure G4a-3), but the fit is not very robust, bootstrapped confidence limits for B(inf) being almost an order of magnitude.

Biomass estimated by acoustic survey provided values around 30,000 tonnes in 1989 and 1991 (Lindrem, pers. comm.), a similar value to calculations in Marshall (1988b). CEDA fit gives a current stock biomass in this region also (about 40,000 tonnes). MSY estimated by approximate methods ranges from 31,000 tonnes (Beddington and Cooke) to 85,000 tonnes (Gulland) with a median value of 63,000 tonnes. We can therefore conclude that current catches are probably below MSY for the sardine fishery.

However, if we are incorrect in assuming that CPUE has tracked stock biomass, we have a significant risk that current catch is actually around the MSY level. Unfortunately age-based assessment to try to confirm this will not be possible until the results of otolith readings from a current project become available.

There are three reasons why catch effort methods of assessment could be misleading. First, the schooling habit of the sardines caught by light attraction could, in common with other fisheries for shoaling species, hold up CPUE even if stocks were declining (Csirke 1988).

Secondly, fishing techniques have been considerably enhanced over operations in the early 1980s (Chifamba 1991), so that measurements of fishing effort in simple units of boat-nights no longer accurately reflect the fishing power of the fleet. However it has proved difficult to make the right adjustments, except for the Sanyati basin near Kariba.

Marshall (1992) has put forward a third reason why the sardine CPUE data may be misleading. The early fall in CPUE may not have been entirely due to stock depletion assumed by surplus production and DeLury fishery models. In the mid 1970s the lake received a large pulse of nutrients from the dramatic decline of the mats of the floating fern, *Salvinia*, whose explosive growth during the first decade of the new lake from 1962 to 1971 attracted much attention from conservationists (Balon 1974). Many fish groups increased during this period, only to return to normal levels later.

The ecological basis of the sardine stock urges caution in allowing a substantial increase in fishing effort. As in most man-made lakes, the hydraulic retention time of Kariba is very short (2-3 years) and most of the nutrient input to the lake is from river flow and run-off during the rainy season (Coche 1974). Marshall (1982, 1988a) has demonstrated strong correlations between sardine CPUE and river flow. The sensitivity of the system to nutrient input is evidenced by the river estuaries and the western inflow of the Zambezi having more zooplankton (Masundire 1989). If exploitation were increased, the volatility in relation to this nutrient input could also increase, and it is possible that the fishery could enter a dangerous regime where collapse is more likely.

Method	est MSY, t/yr
Gulland	85,221
Cadima1	53,750
Cadima2	77,500
Beddington & Cooke	30,679
Pauly	71,500
CEDA	32,079
median	*62,625*
ME - expected	15,000
ME - excess	18,000

Table 1: Comparison of approximate assessments of MSY (sustainable tonnes per annum), and the increase in yield consequent on the introductions, using a range of different methods, for and Lake Kariba sardine. *Methods are as in Table G3b-1.*

Management of the sardine fishery

The main management method in Lake Kariba is the restriction of effort by limiting the number of licences. In Zimbabwe the ownership of 51 fishing companies purchasing 204 licences (Chifamba 1991) is almost exclusively in white hands, and this is a sensitive political issue in Zimbabwe if not in Zambia, where only about 67 vessels operate. A confident assessment of the sustainable yield from the sardine fishery is now essential because of political pressure to extend licences to black-owned cooperatives in order to alter the distribution of equity. This is imperative in the light of the evident success of the first two or three municipally-owned cooperatives in visibly extending wealth to the black community through building shops and schools (Mtsambiwa, pers. comm.)

Some areas around the lake and littoral zones within 1000 m of the shore are closed to fishing operations (Mayabe 1987; Mtsambiwa, pers. comm,), the fishery being policed most actively on the Zimbabwean shore in the easternmost basin. Circumvention of this regulation is not significant because vessels are necessarily conspicuous by virtue of their fish-attracting lights at night.

Although there are indications that the fishery is below MSY, all of these factors urge for caution in any expansion. A small increase in licences, within the likely safety limits, would provide an opportunity for probing adaptive management (Hilborn & Walters 1992) without overshooting MSY into a regime where dangers of collapse are exacerbated (Pitcher & Hart 1982).

Uncertainties in Assessing Kariba Sardines and a comparison with Nile perch

This section refers to the assessments of Nile perch in Lake Victoria and the introduced sardine in Lake Kariba.

In both fisheries there are three sets of uncertainties which affect assessment and management. First, unlike fisheries for endemic species, exploited introduced species do not start from a stable ecological baseline. There was no way of accurately predicting ecological adjustments and explosion in stocks following the introduction of either Nile perch or the sardine. This problem seriously impairs our ability both to assess and to manage the fisheries. There are very profound differences in the ecological impact of the two introduced species. The sardines have altered the zooplankton composition, and possibly other aspects of the Lake Kariba ecosystem, but the lake was man-made and so there is little ethical disapproval to set against the fishery benefits of the introduction. In contrast, the clamour surrounding the loss of biodiversity consequent on the predatory Nile perch introduction has almost drowned out a hearing for the benefits brought by the new Lake Victoria fishery.

Secondly, the natural fish yields expected from lakes in a region may be estimated using various forms of the morphoedaphic index (Ryder 1965, 1982; Henderson *et al.* 1973). Figure 1 is a morphoedaphic plot of African lakes with Lake Victoria and Lake Kariba shown before and after the species introductions. Both lakes are below the expected line prior to the introductions, although for Kariba the exercise is not very robust as it is limnologically very different from Victoria. For both lakes, the very great increase in fish yields is evident. The intersection of the line fitted to all lakes is used in in tables for Nile perch and Karibs sardine above (Tables G3b-1 and G4a-1) to give a rough value of expected maximum yields in the absence of the introductions: in both cases the current fishery provides two to three times as much fish. However, there was no likelihood of predicting this enhancement in fish yields before the introduction.

Thirdly, genetic changes affecting the life history characteristics of both species may have occured since introduction. The smaller size at maturity in the sardines may be a response to the smaller food spectrum in man-made lakes on the Zambezi, as such changes are not evident in sardines introduced to the natural rift valley Lake Kivu (Marshall, 1993). Nile perch from at least two provenances were introduced to Lake Victoria, and the 20-year delay in the Nile perch population explosion may reflect a genetic re-arrangement producing a form with a very high r.

A fourth uncertainty in assessment arises from the artisanal nature of the Nile perch fishery. This is a multispecies, multigear fishery with dispersed landing sites, non-standardised fishing gear and part-time and seasonal fishermen who are indifferent to fisheries legislation. Fisheries data tends to be limited and unreliable: sampling of all landing sites is not possible, therefore total catch and effort is extrapolated from the sub-sample; field staff are often poorly paid and educated with little incentive to produce accurate information (Ogutu-Ohwayo pers. comm.); the resource is shared and scientific methodology varies between riparian states while limited resources constrain research surveys and personnel.

In the face of all these problems, in both of our case studies, traditional assessment methods are found wanting. The best we could do has been to use a wide range of approximate methods to try to assess the past trajectory and current status of the fisheries. The difficulties in assembling viable data are underlined by a wide range of MSY estimates in both fisheries. Our tentative conclusions however, are that the Kariba kapenta fishery is probably under-exploited while the Lake Victoria Nile perch fishery is probably over-exploited.

Furthermore, it is not possible at this stage to forecast precisely the future volatility of the two fisheries to increased levels of effort. In Lake Kariba, with its short retention time, the critical factor for the planktivorous sardine recruitment at higher levels of exploitation will be the gearing between changes in nutrient input during the rainy season. The exploration of this relationship should be of the highest priority for future research. On the other hand, the Nile perch, a predator with a wide food spectrum, should be resilient against increases in fishing provided exploitation of immature fish is controlled. But the Nile perch could be sensitive to further changes in the Lake Victoria ecosystem, such as reduced oxygen levels or littoral expansion of the water hyacinth population.

The commercial kapenta fishery on Lake Kariba is relatively easy to control, with a small number of well-organised ports and conspicuous licenced fishing vessels. In contrast, in Lake Victoria, the vast area of the artisanal Nile perch fishery defies serious management. More recent developments, with Nile perch fishermen contracted to processing companies, ease this situation, but continued catches of juvenile Nile perch call for more effective control of small mesh inshore nets directed at ndagaa and the Nile tilapia.

In addition to creating important new food resources and engendering large direct economic benefits, both fisheries have significantly enhanced their local economic infrastructure. The benefits of the Nile perch are perhaps more widespread in the community than the Kariba sardines at present.

In face of the dire nutritional and economic consequencies of collapse, cautious management strategies are recommended for both fisheries. For Nile perch, effort should be reduced and catches of immature fish minimised. For sardines, small increases in effort should be allowed as probes to the system, an adaptive management strategy (Hilborn & Walters 1990). An alternative management strategy might produce the maximum ecological information. We could allow fishing to proceed unchecked until the stocks collapsed. While such an overshoot might provide good post-hoc estimates of MSY, it would clearly be unacceptable. There is concern that overcapitalisation of the post-harvesting sector around Lake Victoria could push the Nile perch fishery to this fate (FAO 1992). The virtually unregulated fishery in Lake Victoria highlights the need for greater resources to be devoted to management.

Two pages of figures (1-5) follow

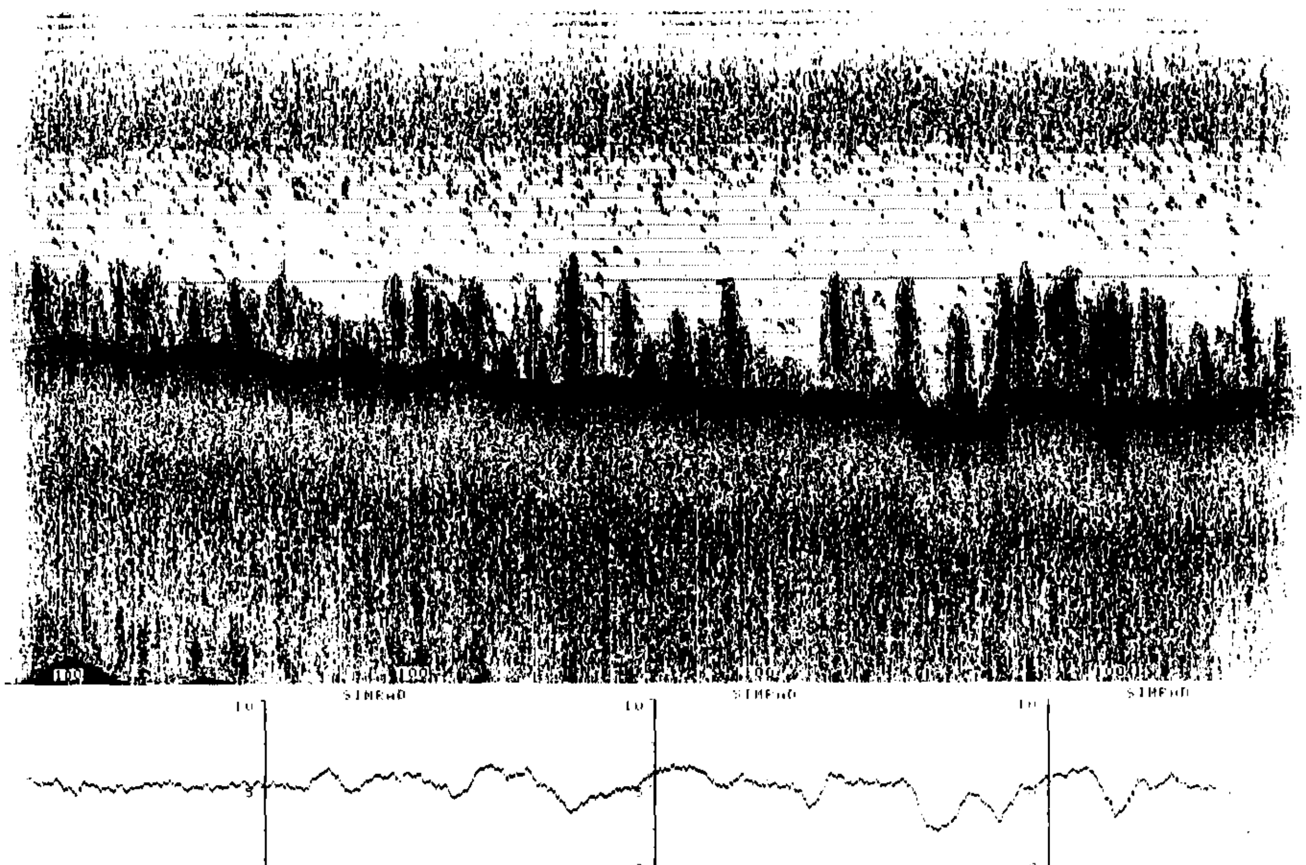


Figure 1. Sonar trace (120 KHz) from Lake Kariba showing a thick dotted band midwater 15 to 25m deep, indicating the abundance of sardines. The darker marks projecting from the bottom represent the petrified trees drowned in the lake.

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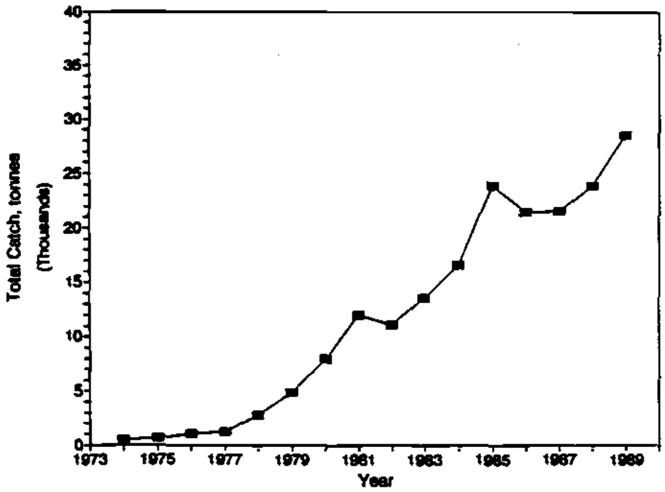

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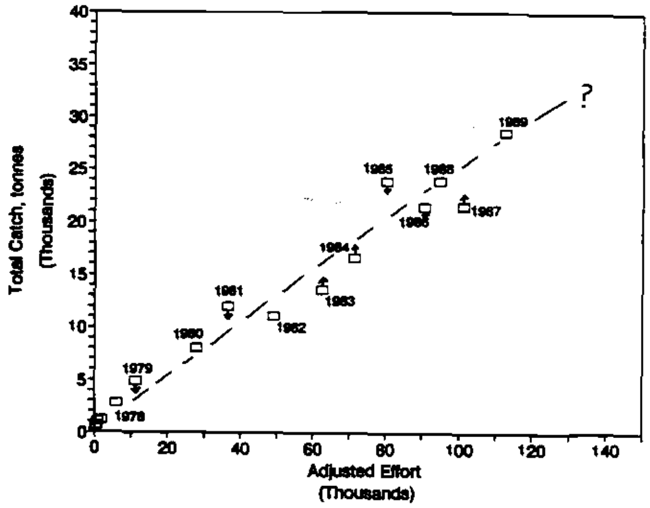

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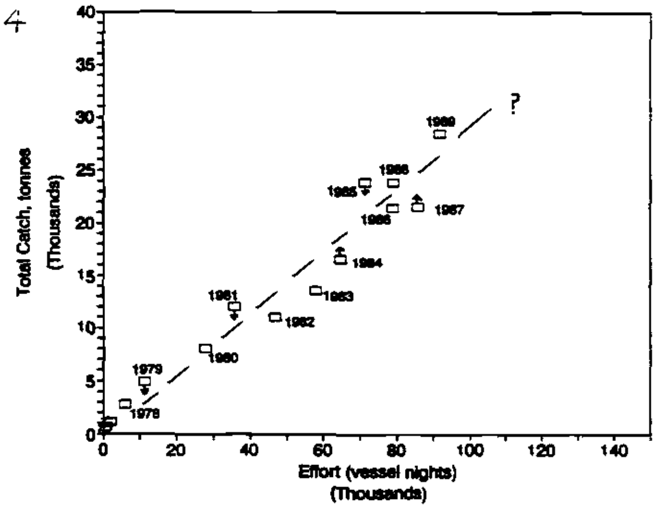

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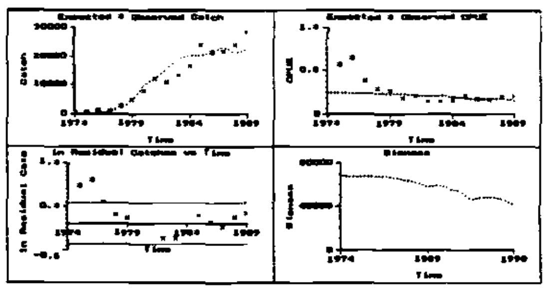

Figure 2. (top left) Total recorded catch of sardines in Lake Kariba 1974 - 1989, complied from Zimbabwean and Zambian statistics by Marshall (1992)

Figure 4. (Bottom left). A Walter plot for the Kariba sardine fishery using effort figures adjusted for increasing fishing power of the vessels.

Figure 3. (Top right) A Walter plot for the Kariba sardine fishery. Upward arrows indicate years where catch/effort is below sustainable, downward arrows years where catch/effort is above sustainable. There is little indication of MSY on this plot.

Figure 5. (Bottom right) Diagnostics for the Fox non-equilibrium surplus production model fitted to Kariba fishery data.. Boxes (clockwise) show expected and observed catch, expected and observed cpue, estimated biomass history and residual from estimated catches verus time.

Results
Impact of Species Changes on Fisheries in Lake Malawi

Of all the Great Lakes in the African Rift valley, Lake Malawi has the best and longest-standing fisheries information base. Extensive catch and effort data has been systematically recorded since 1976, considerable numbers of Malawian fisheries scientists have been trained, and several expatriate fisheries scientists have worked long-term on the lake.

Nevertheless there remain considerable uncertainties about the accuracy and scope of some of the data, and there are still gaps in our knowledge concerning some of the important fisheries in the lake. Moreover, the limnology and ecology of the lake has been well studied in comparison to other Great Lakes, but again there are significant areas of ignorance, especially of the pelagic system. This summary is prepared for the project on the basis of work by the Malawi Government fisheries laboratory at Monkey Bay, and the FAO fisheries project, principally Dennis Tweddle and Dr George Turner (see Turner 1993), and the preliminary results from Dr Andrew Menz' SADCC/ODA pelagic resources project. (Menz, pers. comm.)

Lake Malawi, taken together with Lake Malombe and the Upper Shire river immediately to the south, produces an estimated 30,000 to 50,000 tonnes of fish annually, representing about 70% of the total fish catch and half of the animal protein eaten in Malawi, one of the poorest countries in Africa. Aboout 80% of this catch is taken in the southern portion of the lake where mechanised fisheries have developed over the past 20 years.

taxonomic group	*local name*	*notes/features*	*% of catch*
cyprinids			15
Engraulicypris	usipa	pelagic zooplanktivore	15
Labeo	nchila	anadromous, formerly 2nd largest fishery in lake	
silurids			7
Bagrus	kampango	giant catfish, high value smoked	
	others	other catfish	
cichlids			76
tilapias		mainly phytoplanktivores	17
Oreochromis lidole	chambo	off-shore	
O.squamipinnis	chambo	inshore/offshore	
O.karongae	chambo	inshore	
	kasawala	juvenile chambo	
haplochromines			59
pelagic			3
Rhamphochromis	ncheni	at least 15 spp in different gears	
Diplotaxodon	ndunduma	off-shore, *D. Limnothrissa,* zooplanktivore comparable to sardines	
semipelagic			24
Copadichromis	utaka	inshore planktivores,mainly 4 species poorly described, probably over 150 species	
demersal			32
	kambuzi	inshore haplochromines, juveniles of off-shore demersal species	
Lethrinops	mbaba	esp *L. Microdon* & 4 other spp large demersal	

Table 1: Principal taxa of fish caught in Lake Malawi fisheries, with local names and brief notes on their ecology. Information from Tumer, 1993 and FAO, 1992.

These fisheries critical to human well-being take place in a lake that displays some of the most stunning biodiversity on earth. Lake Malawi holds more than 500 endemic species of cichlid fish, representing some 5% of all known species of vertebrates. Managing the fisheries of Malawi for maximum economic and nutritional gain to an expanding and impoverished human population, and preserving the inheritance of biodiversity for the future scientific study of what Mackaye has termed the 'Notre Dame' of adaptive radiation, are goals that easily conflict.

Malawi contains a monophyletic species flock of maternal mouthbrooding haplochromines adapted to a vast array of trophic niches. From a theoretical perspective Turner considers the Malawi fish fauna to represent the last chance on the planet of elucidating the mechanism of sympatric speciation. Similar species flocks of haplochromines in Lake Victoria have been impoverished by introduced species. Lake Tanganyika's haplochromines are polyphyletic and the lake has been split into several basins with changes in water level. Tectonic events in Malawi, although recent and frequent have not split the lake up into separate basins and so, Turner argues, fish must have remained in effective sympatry.

The recorded catch has remained virtually stable over the past 20 years despite very significant increases in fishing effort and in gear composition, and, as has become apparent only recently through George Turner's work, important shifts in species composition. Although total catch was accurately recorded, the original catch recording system based on fishing boats proved to be rather poor in tracking changes in effort, and has recently been replaced in the south of the lake by a new scheme based on fishing gears.

The catch recording system is barely congruent with the actual taxonomic categories of fish, and it is only the recent work by Turner that has made any impact on the knowledge of what species are caught, by which gear and where. Surprisingly, no data of this type had been gathered since the work of Lowe in the 1950s and Jackson in the 1960s.

Some species found to be of great importance in the catch are undescribed taxonomically. For example, the most recent taxonomic key to the haplochromines (1989) mentions few of the commercially important species. In particular, it was hardly suspected prior to Turner's work that an undescribed species of zooplanktivorous *Diplotaxodon* would turn out to be the principal species caught in the midwater trawl fishery. The main taxonomic categories are set out in Table G6-1.

A plethora of different fishing gears are in use in Lake Malawi, but there are effectively three sectors in the fishery.

- A mechanised industrial fishery of trawlers and purse seiners in the south of the lake;
- A commercial artisanal fishery using seine and gill nets of various types;
- A subsistence fishery using traps, cast nets and lines.

Table 2 gives summary of the main gears and the fish taxa caught in them. The subsistence fishery is undocumented and the catch unrecorded. The mechanised commercial fishery is quite well documented, but only some sectors of the commercial artisanal sector have reliable catch data.

Some of the taxonomic groups, such as the planktivorous utaka *Copidachromis*, are caught in several different gears, making assessments more difficult.

gear type		*Malawian/other name*	*main taxa in catch*	*% of catch*
trawls				
	midwater[m]	semipelagic	tilapias, *Diplotaxodon limnothrissa* *Rhamphochromis* sp	3
	demersal[m]	stern	*Lethrinops* spp, *Rhamphochromis* sp	3
	pair trawls[m]		poorly-known haplochromines, *Rhamphochromis* sp, catfish	9
Seines				
	purse[m]	ringnet	tilapias	2
	open water	chirimila	day - utaka: night - lights + mosquito net lining - usipa,	33
	large mesh	chambo	tilapias, may be operated with kambuzi at shore or from boat	2
	beach	kambuzi	usipa (North), utaka (South) juvenile chambo	29
	inshore	nkatcha	small mesh, inshore/beach, two boats + diver, semipelagics, benthics	*(with above 29)*
gill nets			tilapias, catfish	18
longline[s]			catfish	?
handline[s]			haplochromines	?
trap[s]			haplochromines, catfish	?
scoop[s]			haplochromines, cyprinids	?
cast[s]			haplochromines, cyprinids	?

Table 2: Fishing gear and types of fish caught in the main fisheries of Lake Malawi· [m]=mechanised fisheries; [s]= subsistence fisheries; the rest are designated as commercial artisanal, small scale fisheries. Modified from Turner 1993.

Assessments

Assessments have mainly been performed on the larger scale fisheries of the SE arm where data is more reliable and extensive. In the north of the lake, there is no hard evidence to support the contention that the fisheries, mainly chirimila seines for usipa and gill nets set for catfish, are under exploited. In fact, although total catch has remained constant, expansion of the fishing fleet by 50% over 4 years from 1986 to 1990 has brought about a a decline in cpue, so an increased catch from further increase in capacity is unlikely.

1 Chambo fisheries

Some chambo stocks appear to migrate between lake Malombe and the main lake through the upper Shire river. High catch rates in the mid 1980s were attributed to cessation of gill netting in Lake Malombe. The fishery is assessed using effort standardised to purse seine hauls. MSY from the southeast arm of the lake estimated using the Schaefer and Fox surplus production models is about 3,800 tonnes. Current effort is at about the optimum to achieve this, and so no expansion of the chambo fishery could be recommended.

Serious dangers are posed by catches of immature chambo. Over one third of the chambo caught in the trawl fisheries are immature and kambuzi seines catch many juvenile chambo. These factors have virtually wiped out the chambo fishery in Lake Malombe.

2. Midwater trawl fishery

In the SE arm MSY was estimated at 650 tonnes. The fishery appeared to be slightly overexploited.

3. Demersal trawl fishery

Fishing effort has recently been up to twice the optimum needed to obtain the MSY of around 1500 tonnes, so this fishery appears to be severely overexploited.

4. Pair trawl fishery

The correlation between cpue and effort is inconsistent depending on what years are included in the analysis, so at present there is some uncertainty in the assessment. The present fishery appears to be highly sensitive to increases in fishing effort. Pair trawling in the SE arm has been highly profitable, but recent attempts to extend the technique to northern parts of the lake have not been successful.

5. Chirimila nets

This fishery has expanded greatly in the south of the lake, mainly for utaka, and there has been a large drop in cpue. The quality of the data precludes quantitative assessment and the total catch including the nocturnal catch of usipa is unknown, but Turner recommends caution in permitting any further expansion.

6. Kambuzi seines

Expansion of kambuzi seines in Lake Malombe has virtually caused the collapse of other fisheries. The method presently yields around 1000 tonnes in the SE arm, but Turner advocates restricting this gear on account of this record.

Summary of changes in species composition

Although the total catch from fisheries in Lake Malawi has been remarkably buoyant, large increases in effort, changes in the species targeted and general reduction in the mesh size of gear have brought about dramatic changes in the species composition of the fish community. There has been an evident reduction in diversity, the loss of larger species and shifts in the relative abundance of many components of inshore pelagic, midwater and demersal communities.

The anadromous cyprinid *Labeo* formerly comprised the second largest fishery in the lake, but is *Labeo mesops* is now virtually extinct, although smaller species is still caught. Many of the larger demersal haplochromines have been eliminated by the pair trawling: the most common species in the catch now was almost unknown 15 years ago. Many of the species of utaka, *Copadichromis*, seems to have restricted area distributions and so are especially vulnerable to heavy fishing by daytime chirimila seine nets.

Turner identifies the sectors of the fish fauna most at risk from any expansion northward of the heavy fishing pressures recently exerted by the mechanised trawls and the beach seines in the south of the Lake Malawi and in Lake Malombe. Such an expansion would inevitably be accompanied by species extinctions among the demersal and semipelagic haplochromines.

These species are characterised by low fecundity, small and locally-restricted populations and are vulnerable to unselective small-meshed fishing gears. Turner puts forward a strong argument for a vigorous intervention by the scientific community to save these species. Many of the deeper-water species are drab and could generate little excitement among the aquarist, diving and conservationist fraternity, who would doubtless generate much publicity should the spectacular rock-dwelling mbuna haplochromines be threatened. In fact mbuna and other species in the rocky shore communities are very unlikely to be compromised by any fishery practices. Equally the high fecundity and widespread tilapiines and cyprinids and catfish, although greatly reduced in density, are unlike to be exterminated by fishing.

Possible fish introductions

Turner points out that the suggested introduction of the clupeid sardine *Limnothrissa* to Malawi to occupy a supposedly empty off-shore planktivore niche was misguided. Numerous planktivores exist in the form of *the* pelagic cichlid *Diplotaxodon limnothrissa* and the clupeid *Engraulicypris*. Turner equally regards the introduction of large predatory fish to convert 'trash' fish into edible ones as unjustified since the small fish in the lake are all currently used as human food.

The ODA/SADACC project based at Senga Bay has reported that there is no excess of pelagic prodcution available to be cropped by an introduced sardine, and no reason to suppose that the indigenous pelagic fish are under-utilising the resource (Menz, pers. comm.).

The model introduced later in this report confirms this view, suggesting that sardines would be unlikely to increase lake Malawi's present pelagic fish production.

Research priorities

The greatest need is for simple and straightforward guides to the identification of the principal species in the lake fisheries. Such guides exist for rocky shore fish and those fish found in the national parks: what is needed is some equivalent for fisheries identification.

Secondly, basic information of growth and mortality is lacking for many species. Turner advocates giving priority to measuring natural mortality because many fisheries assessment methods are sensitive to changes in M and empirical methods of estimating M have been worked out largely on marine high of high fecundity. In contrast, most Malawi cichlids impacted by fishing have low fecundity fish and protracted parental care.

Results
Thinking the Unthinkable: A Candidate Model for Predicting Sustainable Yields of Introduced Fish Species in African Lakes

This section authored by Tony J. Pitcher comprises a peer-reviewed chapter in the book.

Abstract

This paper sets out a detailed balance sheet of biotic, economic and social costs and benefits for the evaluation of fish introductions in African lakes. A new model for estimating sustainable fishery yields for introduced Nile perch or freshwater sardine is based on using relative primary productivity to scale the sustainable fishery yield per unit area from a reasonably well-studied baseline lake. Implementation of the model employs of bootstrapped confidence limits and comparisons of results from several alternative baseline lakes. The better the information from the baseline lakes the more accurate the model predictions. The results of the candidate model are explored through application to 20 man-made and natural lakes.

Results are convincing and helpful for most of the lakes considered, with the exception of Lake Nasser. In general, the model suggests that new introductions of Nile perch will not result in an increase in fish yield, or higher economic returns. Results illuminate the collapses of overexploited *Lates* fisheries in Lakes Kainji, Kyoga and Tanganyika. The model predicts that introduction of sardines is unlikely to increase pelagic yield in Lake Malawi over indigenous cyprinid and cichlid fish. The situtaion is unclear in Lake Victoria, where an existing fishery for a pelagic cyprinid remains unassessed. In Lake Tanganyika, the model suggests that a considerable increase in sardine yield may be possible. Future sardine fishery yields from man-made Lakes Itezhi-tezhi, Kainji and Cahora Bassa will prove good tests of the model. In conjunction with detailed consideration of the costs and benefits, the model can be used to evaluate new fish introductions to lakes in Africa.

Introduction

In freshwaters world-wide Welcomme (1992, 1988) analyses over 1.5 million introductions of 291 species into 148 countries since 1900. Many of these have been designed to enhance fisheries, although the majority have been carried out for aquaculture. Outcomes have been mixed, and so it would be helpful to ensure that future introductions are beneficial. Adverse effects include predation, competition, hybridisation, introduction of disease and parasites, crowding, stunting and degradation of water quality (Welcomme 1984), and it is evident that there is a need to better predict the ecological role and impact of an introduced species, and to obtain international agreement on its introduction. Guidelines to this effect have been published by FAO (Tiews, 1985). As Welcomme (1986) points out, new introductions cannot be banned, and so this paper aims to assess the impact of potential new introductions of the freshwater sardine or Nile perch to African lakes by evaluating the balance of costs and benefits. A new model based on primary productivity is introduced to estimate likely sustainable yields.

With respect to putative fish introductions, it is worthwhile to distinguish man-made lakes, or impoundments, from natural lakes. Man-made lakes rarely have fish fauna adapted to lacustrine conditions, so many of the ethical and genetic arguments against introducing exotic species do not apply. In man-made lakes ethical and genetic considerations become important only if escape to natural lakes in the same watershed is likely. A second factor is that there should be little risk that the success of existing fisheries is compromised. Cowx & Kapasa (1995) point out that there are 7 man-made African lakes with areas greater than 1000 km^2, another 32 larger than 100 km^2, and 74 larger than 10 km^2. The total area of the large lakes is around 29,000 km^2, and the smaller ones from the list above amount to approximately 15,000 km^2, giving a grand total of around 35,000 km. This adds up to a very large area, equivalent to a man-made lake the size of Lake Tanganyika, or half of Lake Victoria. Many of these man-made lakes may be candidates for establishment of fisheries for introduced sardines and/or Nile perch.

The twelve largest natural lakes in Africa amount to a surface area of around 176,000 km^2, a huge area equivalent to the Gulf of St Lawrence, the Persian Gulf, or one third that of the North Sea. In natural lakes considerations of the value of endemic biodiversity may inhibit new fish introductions. But in reality, unthinkable events may occur under economic and political pressure. Reported adverse affects on biodiversity have lead many to argue that such introductions should not be contemplated (Ribbink 1987) and indeed, at the present time, fresh introductions to natural lakes in Africa are unlikely because most of the region's governments have a brief to support conservation and would be loath to attract the opprobrium attached to the Nile perch introduction that is the legacy of conservation-oriented publications in the mid 1980s. Such perceptions have a tangible economic worth in affecting the cash value of tourism, or the earnings of the aquarium trade. Furthermore, we should also not forget the impact of economic sanctions and pressures imposed on the third world governments by first world governments, organisations and individuals. These pressures may be both official (e.g. threats to the economic relations with whaling or ivory exporting countries by the US), and unofficial in the form of boycotts organised by Greenpeace and the like (e.g. fur trade, ivory, whaling).

It is, nevertheless, possible to envisage future scenarios of such desperate need for protein, or such high economic and political pressure to earn foreign exchange, that new fish introductions to African lakes may be contemplated. This may be especially likely to occur following dramatic change in the political complexion of a regime or a coup d'etat and, moreover, as the human population grows in the region, the likelihood of such a scenario increases.

This paper first considers the costs and benefits that may affect decisions about new introductions; secondly, describes the new model; goes on to assess yields that could be achieved; and finally, surveys the likelihood of new introductions enhancing fishery yields of the major man-made and natural lakes in Africa.

What factors might affect decisions to make new fish introductions?

How can we assess the arguments affecting the decision as to whether to introduce Nile perch or sardines to a new lake? A balance sheet of costs deriving from loss of the endemic fauna needs to be set against the estimated benefits of the introduction.

The relatively minor costs of implementing the introduction are not likely to affect the decision. Moreover, it is evident that establishment after introduction is virtually unpredictable using existing ecological knowledge (see Chapter 1), so it could be argued that introduction should therefore not be undertaken. But if the alternative outcomes are having the benefit of the introduced species, or the *status quo* with no benefits, ecological success or failure of establishment is irrelevant to the decision to go ahead.

On the debit side, a large number of questions may be asked, many of which will be difficult to attach precise values to. Nevertheless, anything not given some measure of quantification will be unlikely to count for much in making the decision. In the first instance, we need to estimate how much of the endemic fauna will survive: we may as well assume a complete loss if a predator is introduced. In each case we need estimates first of the economic value of the present situation, and secondly, estimates of the potential maximum sustainable value for the new resource. The following list of costs is not exhaustive but is intended to illustrate the kind of evaluation that should take place.

1. *Loss of economic value of existing fishery.* What is the current economic value of endemic species? What is the current economic value of the fishery for endemic species? What is the potential economic value if the existing fishery is managed optimally?

2. *Loss of socio-economic value.* How many jobs will be lost in the traditional fisheries? What changes may be envisaged to the equity of the present fishery benefits. Which sectors of the population will be disadvantaged by the loss of the fishery for endemic species?

3. *Costs of satisfying existing fishery sectors.* What part of the future benefits of the introduction would have to be given to the existing artisanal and commercial fishers in order for them to accept the introduction politically?

4. *Instability and non-sustainability of gains* What is the cost of potential ecological instability that would compromise the putative gains from a fishery for an introduced species? What is the likelihood of failure to maintain the early yields from an introduced species?

5. *Loss of genetic diversity.* What would the consequences be if loss in genetic diversity provided less buffering for future environmental change? For example, endemic stocks may be more resilient to the effects of global warming. Increased variance and more frequent occurrence of climatic extremes would probably be a more significant a factor in the tropics than higher average temperatures. This is likely to be seen in lakes as greater variation of water levels, nutrient inputs, wind-driven mixing and the kind of tectonic events that are known to have been important in the recent history of fish faunas in the rift valley.

6. *Loss of aquaculture potential of endemic species.* What is the actual and potential future aquaculture use of species endemic to the region? Are any of the species under threat already being cultured and what is the actual and potential value of this enterprise?

7. *Loss of cultural benefits from endemic fauna.* Do parts of the endemic fish fauna at risk from the introduction have a cultural and ethnic value for aboriginal peoples, or as a national heritage? How can the cost of the loss of this resource be quantified? Does this factor effectively veto any estimated gain from the

introduction, or are there such high levels of economic gain that would over-ride this veto? Could wealth generated from the introduction be injected into critical sectors of the community in compensation for the loss of culture, and if so, how much would buy off the veto? Would the preservation of stocks in artificial culture be an acceptable compromise in mitigation of the loss of culture?

8. *Loss of tourism benefits of endemic fauna.* What is the value of tourism for sport fishing, or to view fish by scuba diving? How would this be affected if the natural fauna were to be lost?

9. *Loss of aquarium trade benefits of endemic fauna.* What is the current and potential value of the aquarium trade in fishes? For the introduction of a predator, the balance sheet would assume this were all lost if the introduction took place.

10. *Loss of medicinal benefits of endemic fauna.* Do some fish have a pharmacological or medicinal value? The present and potential value of rare compounds, pigments or poisons and the medicinal properties of livers, gonads, scales, swim-bladders can be taken into consideration. Of course it is sometimes difficult to know if such properties exist, for example the chance of curing cancer with Dodo livers has been lost for all time, so the calculation must be made with extant knowledge only.

11. *International retribution for loss of endemic biodiversity.* What is the potential cost of sanctions against the destruction of endemic biodiversity? These may arrive as threats to aid and economic support by first-world governments, or as campaigns to boycott goods and tourism run by conservationist lobbies, or in extreme cases the ecoterrorism of groups like Sea Shepherd.

The positive side of the balance sheet affecting the decision is less complex.

1. *Economic gain.* What is direct economic gain to be had from the introduction? This must include estimates of the net value of the fish sold as catch after operating costs have been deducted, using a simple bioeconomic model of the new fishery.

2. *Socio-economic gain in the fishery sector.* What benefits in employment will result? New jobs may be created not only in the fishery but also in on-shore processing, transport and service industries. What sectors of the population will gain form the new fishery and what is the likely extension of equity?

3. *Nutritional gain.* What is the value of the likely nutritional gain to be had from the introduction? This can be costed by looking at the cost of current and projected food imports, the costs of remedies to malnutrition and associated community health service costs.

4. *Sport fishery income.* Are there likely ancillary gains in the creation of a sport fishery? The indirect benefits of increased tourism should be included with the revenue for the sale of licences and fishing gear.

5. *Aquaculture opportunity.* Are there likely ancillary gains to be made in enhancing the opportunities for aquaculture?

If the probable benefits exceed the likely assessed costs by a margin estimated to be a significant improvement on the *status quo*, if the risks are sufficiently understood and quantified, and if the current situation is perceived to be sufficiently bad, the pressure to carry out a new introduction may be irresistible irrespective of the existence of international codes of practice.

Estimation of sustainable yields from new introductions

Before we can analyse possible further introductions in the African lakes, we must have a way of estimating the likely sustainable yields of the new fisheries. This paper considers only two species, Nile perch (*Lates niloticus*), a centropomid predator, and the freshwater (inshore) sardine (*Limnothrissa miodon*), a zooplanktivorous clupied, since there is good information and assessments about successful fisheries for these introduced species. Nile tilapia (*Oreochromis niloticus*), a herbivore, is a third candidate species for further introduction, and has already been frequently introduced often as an aquaculture subject around the world (Welcomme 1998). However, fisheries information from successful Nile tilapia fisheries in Africa is not yet good enough to support an analysis at this stage.

Relating lake fish yield to primary production

Fishery managers would find it convenient if fish yields could be related to primary production in some simple fashion. This concept has been attacked as unhelpful and simplistic from two directions.

First, limnologists do not support the idea because the type and rate of primary production bears a complex relationship with the nutrient profile, hydrology and morphology of lakes.

Secondly, fish ecologists attack the concept because the use of total fish production ignores the details of trophic community structure and large differences among and between the ichthyofauna of tropical and temperate lakes. For example, Briand (1985) emphasised the differences among freshwater communities resulting from depth, primary production, transfer efficiencies and variance in physical parameters. Evans *et al.* (1987) summarize ecological complexity in the North American Great Lakes, concluding that production of fish species is strongly influenced by the structure of trophic interactions.

Despite these misgivings, the practical fishery manager can hold a different perspective. Estimating the total yield from a fishery with a reasonable level of confidence is a legitimate goal and if predictions can be made with moderate precision, there may be no need to be over concerned with details of ecological relationships.

The morpho-edaphic index (MEI: Ryder 1965, 1978, 1982, Ryder *et al.* 1974), has undergone a revival recently with up-to-date statistical analysis (Badjik & Schnieder 1991, Schnieder & Headrich 1989). But it is unlikely that more rigorous statistics can overcome the problem that the MEI is not very successful for African lakes (Henderson & Welcomme 1974, Henderson *et al.* 1973). However, although predictive precision is not high, the increase in fish yields consequent on introduction are especially clear from a MEI-style plot adapted from Fryer and Iles (1972) classic book on the African Great lakes (Figure 1).

There is a contrast between these two lakes here: in the case of Lake Kariba, increased fish yield is a consequence of the introduced sardines filling an empty niche. In Lake Victoria, catch increased as the fishery expanded, although on the basis of ECOPATH modeling Moreau (1995) suggested that there has in addition been an increase in overall fish production rate.

In contrast to the lack of predictive success with the MEI, there has been some success in approximate prediction of total fish yield from average primary production rates in both temperate and tropical lakes. There has been a considerable amount of recent work on this topic since Melack (1976) published a significant relationship from 8 tropical lakes. Oglesby (1977) demonstrated that logarithmic regressions of total fish yield on primary production rate in 34 lakes differing widely in provenance, climate and size, provided better predictors than the morpho-edaphic index. Using more modern statistical treatment, Downing *et al.* (1990) confirmed this finding using data on primary production, phosphorus and the MEI from 20 contrasting lakes world-wide.

Most models have shown a logarithmic relationship of fish yield with primary production since at higher production levels, rate of increase of fish yield falls off. At very high production levels, fish yields seem to reduce further; for example, Laing *et al.* (1982) fitted a logistic curve to fish yield and primary production in Chinese lakes and fish ponds. The most thorough published investigation appears to be that of Oglesby *et al.* (1987), where a dome-shaped model best fitted the data from 21 North American lakes that differed by an order of magnitude in levels of primary production. However, Oglesby *et al.* found that *Stizostedion* (walleye), the main target species in the investigation, was replaced in lakes with primary production lower than about 2 mg/m^3 chlorophyll and higher than 11 mg/ m^3 by other predatory fish taxa, namely coregonid/salmonids and centrarchid/cyprinid communities respectively. Hence, Ogelsby thought that the dome-shaped relationship would apply to any one taxon, but that a second overall relationship gave total fish yield that increased with the log of primary production. The overall relationship was acheived as one taxon supplanted another in the same niche. Leach *et al.* (1987) review MEI, primary productivity, and a range of other indices involving algae, benthos, climate and morphometry as ways of predicting potential fish yields in the North American Great Lakes and conclude that primary production is one of the most useful approximate indicators. Unfortunately, for the African lakes, Crul (1992) concluded that the basic limnological information needed to use even the less sophisticated fish yield prediction models was lacking in most cases.

The Sustainable Yield Prediction Model

In order to get around these problems, we can use fishery information from a successful fish introduction to enable us to make a short cut. The candidate model put forward here uses estimated sustainable yield per km^2 from a baseline lake where the species forms a successful fishery as a 'predictor of ecology'. Here we are concerned with a *gedankenexperiment* of predicting, not the sustained yields of endemic fish, but possible yield of an introduced species should successful new establishment occur in a target lake. The model assumes that, if successful colonisation occurs, then the ecological similarities are sufficient to make a prediction based simply on the ratio of the log primary production levels in the target and baseline lakes. In the model, all of the minutiae of ecological interations are subsumed within the production parameters and the fact that the species is fully established in the baseline lake. Hence, the only necessary information for this model are the sustainable yield in the baseline lake and the primary production levels in the two lakes.

The sustainable level of the fishery in the baseline lake is assumed to be assessed with known confidence limits and the technology and economic infrastructure of the fishing industry in the target lake will be equivalent to the baseline lake.

One simple method might be to use the yield per unit area in proportion to the ratio of productivity in the baseline lake and the target lake. This makes the assumption that fish production is linearly related to primary production:

$$Y = a\,P \quad \text{......} \quad 1a$$

where, Y = potential fish yield
P = primary production
a = slope

Using this relationship to predict fish yield in a target lake, given production in the baseline lake and the two primary production figures, we get:

$$Yt = Yb/Ab * At * (Pt/Pb) \quad \text{......} \quad 1b$$

where, Yt = estimated annual sustainable yield in target lake, tonnes/yr;
Yb = sustainable annual yield in baseline lake, tonnes/yr;
Ab = area of base lake, km^2;
At = area of target lake; km^2
Pt = average primary production of target lake, gCm^2/day;
Pb = average primary production of base lake, gCm^2/day.

The calculation takes the annual yield of fish per km^2 in the base lake and multiplies this by the area of the target lake. The result is then scaled by the ratio of primary productivity in the two lakes.

However, as we have seen from the review of the literature above, fish yields are better modelled using a logarithmic relationship with increasing primary productivity. The relationship of primary production to fish production is therefore:

$$Y = a \ln P \quad \text{......} \quad 2a$$

With reference to the baseline lake, the model now becomes:

$$Yt = Yb/Ab * At * \ln(Pt+1)/\ln(Pb+1) \quad \text{...} \quad 2b$$

where,
Yt = estimated annual yield in target lake, tonnes/yr;
Yb = sustainable annual yield in base lake, tonnes/yr;
Ab = area of base lake, km^2;
At = area of target lake; km^2
Pt = average primary production of target lake, gCm^2/day;
Pb = average primary production of base lake, gCm^2/day.

The addition of 1 to the primary production values in equation 2b ensures that the logs do not become negative for lakes where primary production is less than 1 gCm^2/day. In addition, the curve intersects the linear model at the values for the baseline lake.

Sources of data

Primary production values used in the model have been taken from the literature and evaluated using Lowe-McConnell (1987). Sustainable yields of African lake fisheries are 90% of published MSY values where available, or are 90% of approximations of MSY made using available catch figures. Sources of data on primary production rates are Craig (1992) and Vanden Bossche & Bernacek (1990a and 1990b). Sustainable fish yields for Lakes Victoria and Kariba are taken from Pitcher & Bundy (1994 & 1995b); Lake Tanganyika from Hecky (1992) and Coulter (1992), Lake Turkana estimated from Kolding (this volume), and Lakes Albert and Chad estimated from figures in Craig (1992).

This model might be refined by including more differences among the lakes with regard to nutrients, morphology etc, or perhaps by incorporating some form of the morpho-edaphic index. But in order to do this we would need more data on sustainable catches from fisheries resulting from successful introductions. Such data may be available for sardines in about 10 years time as fisheries become established in Cahora Bassa and Itezhi-tezhi.

Assessment of uncertainties in the estimates made using the model

Each estimation of potential yield was subjected to 2000 bootstrapped estimations using the error distributions of the principal model parameters, Pt, Pb and Yb (Crystal Ball Software, Decisioneering Inc., Denver, Colorado, USA). In this way 95% confidence limits deriving from estimation error were attached to each yield estimate.

Sustainable yield values

Estimates of sustainable yield are notoriously subject to a great deal of error. Published error values have been used in a Normal distribution of errors where estimation errors have been assessed, as with Nile perch in Lake Victoria (Pitcher & Bundy 1994), but in other cases uniform distributions around the calculated figure have been taken. Values are shown in Table 1.

Primary production rates

Averaging primary productivity over a year ignores large seasonal increase of the order of 50% as pelagic production is enhanced by nutrients released during seasonal upwelling and lake overturn. But the average annual value is useful for this exercise because these seasonal fluctuations, although reflected in fish growth and mortality, should be effectively integrated in fish production over the year. I have taken a value of 20% for the likely error in estimating average annual primary production. For example, this would mean that in Lake Victoria, for the published mean value of 2.64 gCm^2/day, the confidence limits used in the model are 2.25 to 3.03 gCm^2/day. Although there are few time series of mean lake production, this may not be wide enough to cover inter-annual variation in some lakes. For example, in Lake Malawi (Nkhotakota Bay) primary production averaged 0.9 gCm^2/day in 1992 and 1.4 gCm^2/day in 1993 (A.Menz, pers. Comm.)

Lake Tanganyika energy anomaly

In Lake Tanganyika, most estimators of fish yield provide figures lower than the present and historical catches per km² that are known to have been sustained for many years (Bayona 1992). There appear to be two reasons for this anomaly. First, the great antiquity of the lake appears to have allowed the evolution of highly efficient pelagic species so that carbon accumulates in planktivorous fish rather than as algae and secondly, there is an additional source of energy fixation from heterotrophic bacteria in the immense deep anoxic zone (Hecky *et al.* 1981, Hecky & Fee 1981). Assessing the evidence that fish production levels imply twice the normal trophic transfer efficiency, Hecky (1992) shows that Lake Tanganyika has more affinity to marine and estuarine systems than the other African Great Lakes. For Lake Tanganyika calculations in the model I have therefore included uncertainty on the trophic transfer efficiency multiplier (uniform probability distribution from 1.5 to 2.2 with a median of 2 - see Table 1).

			Baseline Lakes			
species parameter	*Victoria Nile perch*	*Chad Nile perch*	*Turkana Nile perch*	*Albert Nile perch*	*Kariba Sardine*	*Tanganyika Sardine*
Yb	28%	50%	50%	50%	30%	30%
	Normal	uniform	uniform	uniform	uniform	uniform
Pb	20%	20%	20%	20%	20%	20%
	Normal	Normal	Normal	Normal	Normal	Normal
Pt	20%	20%	20%	20%	20%	20%
	Normal	Normal	Normal	Normal	Normal	Normal
rtf	1	1	1	1	1	1.5-2.2,
	fixed	fixed	fixed	fixed	fixed	uniform

Table 1 Uncertainties investigated for the yield prediction model. For each parameter, the first row indicates the 95%tiles of the distribution around the mean; the second row the type of probability distribution employed. Symbols as in text; rtf= relative trophic transfer efficiency assumed in lake.

Choice of Baseline Lake

Results of this model clearly depend upon the choice of baseline lake. In general, I have attempted to compare results using as many baseline lakes as are feasible for each species. There are fisheries for introduced Nile perch in Lakes Victoria and Kyoga, with fisheries for similar natural *Lates* species in Albert, Turkana and Chad. Of these, data from Lake Kyoga is very uncertain given the difficulty of access until quite recently. So Victoria, Chad, Turkana and Albert are used in turn as baseline lakes for Nile perch introductions. Sardine fisheries in Lake Tanganyika (natural) and Lake Kariba (introduced) have been reasonably well-assessed and are used as baseline lakes for sardine introductions; fishery data from Lake Kivu is not good enough to use as baseline.

Results

Results pertaining to possible Nile perch introductions are shown on a logarithmic scale in Figure 2a. The 20 lakes are listed in order of area. For each lake there are four fish yield estimates from left to right, resulting from use of Victoria, Chad, Albert and Turkana as the baseline lake respectively. Arrows indicate the sustainable yields (0.9MSY) used for each baseline lake. Error bars show the 95%tiles from the bootstrapping. Following a similar convention, results for possible introductions of sardines are shown in Figure 2b using Lakes Tanganyika and Kariba as baseline lakes for the model.

Discussion

First, it should be emphasised that use of the model is not intended to imply that a fish introduction would be become established or is feasible on ecological grounds. For example, Lake Chilwa is too shallow and seasonal for either sardine or Nile perch and Lake Mweru has its own three endemic sardine species.

Secondly, the consideration of estimation errors through the bootstrapping technique is not intended to subsume process errors. If the assumptions of the model are not met then its predictions will be invalid. The key assumption of the model is that successful establishment in the target lake means that there is sufficient ecological similarity to predict MSY using relative log primary production levels, within the limits of the estimation errors.

Before surveying the implications for selected major lakes one by one, some general features of the results are discussed.

Nile perch introductions.

Estimates using Lake Victoria as the baseline lake for the model have the lowest estimation errors (Figure 2), which is not surprising since a quantitative assessment of the fishery is available. Using Lake Turkana as baseline produces figures considerably lower. Of all the lakes, sustainable yields of Nile perch in Turkana are the most uncertain as they are based on small artisanal fishery serving fluctuating and small local demand for fish. Kolding considers that environmental factors and lake level have been the most important factors in determining historical catch levels. It is encouraging, however, that using Lakes Victoria, Chad or Albert as baseline lakes for the model produces estimates that are not significantly different. Using the highest and lowest confidence limits from the three yield estimates above we obtain the total yields and rates per km^2 listed in Table 2.

Approximate world market prices for Nile perch sold as frozen fillets produce the range of possible economic returns listed in Table 2. Clearly, not all catch from a fishery will be sold as frozen blocks, but prices for other Nile perch products will clearly be geared to this price. Totals are given for natural and man-made lakes.

In natural lakes Table 2 indicates that the total annual economic return could be $175 to $767 million from 144,000 to 632,000 tonnes per annum sustainable yield. From man-made lakes the total yield might be worth $35 to $165 million from 29,000 to 136,000 tonnes. These figures are at the same time both pessimistic and optimistic. Assuming no additional catch from any other remaining fisheries in the lake is pessimistic. Assuming that all these introductions were both approved and established is optimistic.

LAKE		Total Yields low	Total Yields high	t/km2/yr low	t/km2/yr high	Value, US$ low	Value, US$ high
George		672	3111	0.90	4.15	816,798	3,780,426
Kainji	*m*	1261	5829	0.99	4.55	1,532,201	7,081,908
Kossou	*m*	1412	6548	0.88	4.09	1,715,788	7,955,807
Bangweulu		746	3487	0.36	1.68	906,310	4,236,517
Edward		3143	14426	1.35	6.20	3,819,331	17,528,018
Kivu		1157	5336	0.49	2.25	1,405,253	6,483,206
Cahora Bassa	*m*	1980	9094	0.74	3.41	2,406,236	11,049,052
Kyoga		3165	14658	1.17	5.43	3,845,946	17,810,034
Itezhi-tezhi	*m*	2975	13700	0.80	3.70	3,614,170	16,645,991
Mweru		1086	5073	0.23	1.09	1,319,541	6,163,262
Chilwa		2768	12937	0.55	2.59	3,363,305	15,717,850
Kariba	*m*	4318	19836	0.80	3.70	5,246,187	24,100,139
Nasser	*m*	9265	42590	1.49	6.85	11,257,273	51,746,442
Albert		11970	30226	1.76	4.45	14,543,812	36,724,852
Turkana		8943	41076	1.18	5.43	10,865,298	49,907,834
Volta	*m*	8397	38959	1.02	4.71	10,202,360	47,334,663
Chad		10626	41890	1.06	4.19	12,910,798	50,896,112
Malawi		12997	60232	0.42	1.96	15,791,111	73,181,502
Tanganyika		15575	72355	0.47	2.19	18,923,454	87,911,818
Victoria		70999	326935	1.04	4.81	86,264,252	397,225,888
man-made	*7*	*29,608*	*136,555*			*35,974,215*	*165,914,003*
natural	*13*	*143,848*	*631,743*			*174,775,210*	*767,567,319*
TOTAL	*20*	*173,456*	*768,297*			*210,749,425*	*933,481,322*

Table 2. Estimated yields of introduced Nile perch: high and low values were obtained from the bootstrapped model described in the text. Nile perch world market price of $2700 per tonne frozen blocks from Infofish, March 1993, assuming 45% wet weight conversion to blocks; m= man-made lakes.

Sardine introductions.

With Lake Tanganyika as baseline the yield predictions are about twice as high as using Kariba. This may simply be because both inshore (*Limnothrissa)* and off-shore (*Stolothrissa*) species of sardines are included in the Lake Tanganyika figures. If reduced by half they are similar to the Lake Kariba baseline for *L. miodon*. However, I have no way of knowing what appropriate reduction factor should be, and, following the procedure outlined for Nile perch model above, hence have used the Kariba baseline to generate the likely range of economic returns from sardine introductions in Table 3.

The March 1993 price of Kariba sardines was about ZIM$6 per kilo, wet weight (or US$12 per kilo dried). This is approximately US$1000 per tonne wet weight caught.

In natural lakes Table 3 indicates that the total annual economic return could be $0.9 to $1.3 billion from 889,000 to 1,267,000 tonnes per annum sustainable yield. From man-made lakes the total sardine yield might be $188 to $263 million from 188,000 to 262,000 tonnes per annum. These figures are subject to the same qualifications as for Nile perch above.

The major west African man-made lakes, Kainji, Kossou and Volta, contain endemic clupeids from the original riverine fauna, comprising *Pellonula, Sierrathrissa and Cynothrissa* species. The 'sardine' model predictions, of 51-72,000 tonnes in Volta and 7,600 to 10,800 tonnes in Kainji are in close accord with previous estimates of the potential clupeid fishery yields from these lakes (60,000 and 10,000 tonnes respectively, Marshall 1984).

		Total Yields		t/km2/yr		Value, US$	
LAKE		low	high	low	high	low	high
George		4098	5792	5.46	7.72	4,097,857	5,791,857
Kainji	*m*	7693	10830	6.01	8.46	7,692,745	10,829,948
Kossou	*m*	8613	12172	5.38	7.61	8,613,021	12,172,307
Bangweulu		4515	6537	2.18	3.15	4,514,767	6,536,995
Edward		19098	26752	8.21	11.51	19,097,631	26,751,921
Kivu		6986	9950	2.95	4.20	6,986,115	9,949,651
Cahora Bassa	*m*	12013	16862	4.51	6.33	12,013,384	16,861,679
Kyoga		19405	27164	7.19	10.06	19,405,482	27,163,514
Itezhi-tezhi	*m*	18041	25416	4.88	6.87	18,040,711	25,415,665
Mweru		6600	9492	1.42	2.04	6,600,049	9,492,433
Chilwa		16896	24086	3.38	4.82	16,895,797	24,085,708
Kariba	*m*	26775	36225	4.99	6.75	26,775,000	36,225,000
Nasser	*m*	56568	78718	9.10	12.66	56,567,563	78,717,850
Albert		39820	56182	5.86	8.26	39,819,627	56,181,752
Turkana		54478	76088	7.20	10.05	54,477,629	76,088,038
Volta	*m*	51414	72482	6.22	8.76	51,413,774	72,482,029
Chad		64402	90305	6.44	9.03	64,402,041	90,305,209
Malawi		78639	112468	2.55	3.65	78,639,473	112,468,068
Tanganyika		147256	225600	4.46	6.84	147,256,484	225,600,484
Victoria		433216	605647	6.37	8.91	433,215,834	605,647,390
man-made	*7*	*188,102*	*262,654*			*188,102,312*	*262,654,129*
natural	*13*	*888,423*	*1,266,113*			*888,422,670*	*1,266,113,370*
TOTAL	*20*	*1,076,525*	*1,528,767*			*1,076,524,981*	*1,528,767,499*

Table 3. Estimated yields of freshwater sardine: high and low values were obtained from the bootstrapped model described in the text. Ranges for Kariba were from assessment. Sardine values are taken as $1000 per tonne (see text). m= man-made lakes.

Man-made Lakes

The three man-made lakes in the Zambezi basin seem ideal candidates for introductions as high falls prevent colonisation up the Shire river to Lake Malawi, there are no natural lakes in the rest of the basin, and existing river fisheries are very minor. *Limnothrissa miodon* has been introduced to Kariba and Itezhi-tezhi, and colonised Cahora Bassa down the River Zambezi from Kariba. Model predictions for Lakes Nasser, in the lower Nile basin, and Kainji, Nigeria, are also considered here.

Lake Kainji

Yield from the lake exceeded 30,000 tonnes per year in the early 1970s, of which more than half was Nile perch. By 1977 (the last year for which good records are available) total catch was down to around 10,000 tonnes of which only about 3000 tonnes was Nile perch. This has been represented as the 'collapse' of the Nile perch fishery (Turner, *in press*), but comparison with the model suggests that this may be more a fishing down of virgin biomass rather than a pathological collapse from overexploitation. The model predicts a Nile perch sustainable yield of between 1300 and 5000 tonnes per year and sardines from 7,700 to 10,800 tonnes. Total yield from Nile perch and sardines would be approximately 9,000-15,000 tonnes per year. The sardine fishery appears to have expanded (Turner, pers. comm.). New data on the fishery should be available within the next couple of years and will provide a test of the model.

Lake Kariba

Introduced sardines presently provide a catch of around 5.5 tonnes per km^2, which is approximately the maximum sustainable (Pitcher & Bundy 1994), constitutes a respectable yield for any fishery, and is worth around $31 million annually to Zambia and Zimbabwe. The present model estimates a range of 5 to 6.75 tonnes per km^2, representing annual catches between 27,000 and 36,000 tonnes (Kariba baseline, so CLs obtained from bootstrapped errors on primary production and yield figures). If the estimated 10 tonnes per km^2 sustainable from Lake Tanganyika could also be achieved in Kariba, we would see a larger harvest of around 45-70,000 tonnes from the whole lake, but this is unlikely as the Tanganyika figure includes both species of sardine. The off-shore sardine, *Stolothrissa*, failed to establish in Kariba (Marshall 1992). The relatively shallow depth of Lake Kariba (c30 m) makes it more akin to the inshore regions of Tanganyika where *Limnothrissa* rather than *Stolothrissa* is predominant.

One option in this man-made lake would be to introduce Nile perch. The sardine population is evidently able to withstand a lot of predation, including tigerfish (*Hydrocynus forskhalii*, newly turned pelagic), birds, crocodiles and man. So *Lates* probably would not wipe out the sardine fishery. The choice of gear for the perch fishery would be tricky because of the drowned trees, but some sort of long-line that would float at sardine depth above tree level might be devised. The effect on the tigerfish sport fishery on Kariba would be unpredictable, but a recreational fishery for large *Lates* would also be popular, so sport fish income might be maintained in the lake even if tigerfish were reduced by Nile perch competition. The Nile perch would presumably also colonise the Zambezi and Cahora Bassa, but at present would not be able to get up the Shire river into Lake Malawi. (However, there are rumours of a new falls by-pass canal under construction that would alter this situation.) An alternative, not covered by the existing model as we have no baseline, is to introduce one of the pelagic *Lates* species from Tanganyika that co-exist with sardines, such as *Lates stappersi*.

According to Table 2 above, the model suggests that we might expect about 12,000 tonnes (confidence limits 4,500-20,000) of Nile perch. The Nile perch fishery could create a lakeshore processing industry, and frozen block exports worth between $5 and $24 million per year. If the sardine fishery were completely lost, the conclusion is that there is obviously no economic gain to be made from introducing Nile perch. If we assume optimistically that a reduced sardine fishery of half the current amount can coexist with Nile perch, then we get a total 95% likelihood band of $18 to 42 million in revenue. This means that there is a 55% chance that post-Nile perch introduction lake income would be less than the current fishery, and clearly, these are not very encouraging odds.

But this conclusion is sensitive to the sardine price: at half the assumed sardine price, Nile perch begins to look more attractive ($16 million from sardines alone versus $13-30 million from Nile perch plus a reduced sardine fishery, with an 80% chance of increasing revenue). This calculation becomes much less convincing, however, when we realise how sensitive it is to the size of the remaining sardine fishery, a very uncertain figure.

In summary, none of these considerations favour introduction of Nile perch to Lake Kariba.

Cahora Bassa

Due to the recent war in Mozambique, there is as yet no fishery in Cahora Bassa. According to Marshall (1992) there are many uncertainties in setting up a sardine fishery. Particularly, volatility in sardine production levels may be exacerbated by large amounts of suspended clay especially in the shallow upstream end of the lake. The same problem may cause difficulties in light attraction to the lift net gear.

Potential annual sardine yield predicted by the model is 12,000 to 17,000 tonnes, rather more than the 8,000 tonnes predicted by Bernacek (1984), but in line with Marshall's views (1992). Nile perch might produce around 2-9,000 tonnes, worth in the order of $2-11 million, but indications against its introduction are the same as in Kariba.

Lake Itezhi-tezhi

There is very little published information on Itezhi-tezhi, apart from Cowx & Kapasa (1993). Assuming primary production equal to Lake Kariba, the model estimates 18,000 to 25,000 tonnes of sardines worth $18-25 million annually to Zambia. This estimate should be modified once primary production figures for the lake become available. Actual sustainable yield once the fishery is operating will provide a good test of this model.

Lake Nasser/Nubia

In 1981 the reported catch from Nasser/Nubia was about 35,000 tonnes, 90% of which was tilapias and the rest mainly cyprinids (Abdel-Latif 1984, Ali 1984). Recent figures appear not to be available in the published literature. The model suggests that the productive Lake Nasser (including Lake Nubia) might produce over 56-78,000 tonnes of sardines, but this ignores the reported low utilisation of phytoplankton. The zooplankton feeding fish community appears to be very small (Abdel-Latif 1984) and so the future for a sardine introduction, suggested by Marshall (1984), seems uncertain until the fisheries ecology of Lake Nasser is investigated in more detail.

Nile perch, naturally present in the lake since impoundment of the Nile by the Aswan High dam, comprised only about 500 tonnes of the catch in1984. Therefore, with the very limited information available, the model applied to Lake Nasser appears misleading.

Possibly a Nile tilapia version of the model would be more useful for Lake Nasser as, overall, the performance of the sardine and Nile perch models are less than satisfactory in this lake. Another option for lake Nasser might be the introduction of Malawi Chambo (*Oreochromis lidole*), which could feed on the high production of blue-green phytoplankton (Pitcher *et al.* 1989). We need up-to-date and reliable information about current fisheries in Lake Nasser to improve the evaluation.

Potential total yield from African man-made lakes

It is worth considering the potential fish yield for all the man-made African lakes. Unfortunately, primary production and sustainable fishery yields are available for only a few of 104 man-made lakes referred to by Cowx & Kapasa (1994). However we have sufficient information on the seven largest man-made lakes in Table 2 and 3 with which to draw some tentative conclusions.

The model predicts a total potential sardine yield in the 7 largest man-made lakes of approximately 188,000 to 262,000 tonnes per year (without Nasser 161,000 to 183,000) equivalent to 7.9 to 11.0 tonnes per km^2 overall. At a value of $1000 per tonne this is worth in the region of $200 million per year. Adding the smaller man-made lakes in at a conservative average of 4 tonnes sardines per km^2 produces another 30- 65,000 tonnes. For Nile perch, the model predicts a total of 29-136,000 tonnes, worth about $36-166 million a year under the assumptions set out above. Evidently, the sardines are a more valuable harvest. Alongside the model predictions, evaluation of the costs and benefits of introductions are generally favourable for sardines in most of these man-made lakes. Conversely, evaluation does not support Nile perch introductions, but this conclusion may be sensitive to sardine price.

Natural Lakes

I consider here the model results and evaluation of sardine and/or Nile perch introductions for six major African lakes: Kyoga, Victoria, Tanganyika, Malawi and Kivu.

Lake Kyoga

In the mid 1970s, 70,000 tonnes of Nile perch were harvested annually from Lake Kyoga, a yield of 26 tonnes/km^2 (Twongo 1988). By the late 1980s, catches had reduced to around 15,000 tonnes. This history is generally represented as a 'collapse' of a unstable Nile perch fishery (eg. Witte *et al.* 1992). Yet the model estimates 3,000 to 15,000 tonnes as the likely sustainable yield of Nile perch in Lake Kyoga. So although the Lake Kyoga catch history may indeed represent a collapse in the sense of a fishery-driven stock reduction, the early high yields are only what would be expected in fishing down a virgin stock. Reduction of effort during the years in which access to the lake was problematical because of security problems in Uganda may have been a blessing in disguise, as the current Nile perch catch levels appear to be about right. Most of the catch (about 80%) presently comprises the introduced Nile tilapia (Oguto-Ohwayo 1990), and so, with reliable catch data, Kyoga might make a suitable baseline lake for estimating sustainable yields of that species.

Lake Victoria

Model prediction of Nile perch yields (Table 2) are 71,000 to 327,000 tonnes. Although this band encompasses the MSY assessment, the lower range of values within the CIs reflects the use of the uncertain Chad and Albert baselines. Clearly in this case the more precisely estimated MSY value from the full assessment of Nile perch in Lake Victoria (Pitcher & Bundy 1995) is more credible and useful. Nevertheless, the model results reinforce alarm that the present Nile perch fishery exceeds even the upper limit of the model predictions for sustainable yield.

Potential yields of introduced sardine yields may be considered in relation to the endemic cyprinid *Rastrineobola* (ndagaa, omena) (Table 3). The model estimation of pelagic sardine yield (Kariba baseline) is 433,000 to 606,000 tonnes per year (6.4 to 8.9 tonnes km^2), which could be worth about 2-6 times as much as the present Nile perch fishery. Unfortunately, there is almost no information available from the emerging *Rastrineobola* fishery. Assessments of potential ndagaa yield should be compared with this sardine figure when they become available. If the endemic *Rastrineobola* is unable to match this figure, sardine introduction might be contemplated. If it failed, the *status quo* would prevail. If it succeeded, pelagic yield would be enhanced. The presence of *Caradina* would ensure sardine nutrition, but it is likely that competitive exclusion between the sardines and ndagaa would mean that only one of the two species would survive.

There seems to be no ethical case against new introductions in a lake that has undergone such drastic man-made changes, many of which predate the Nile perch upsurge (Hecky 1993), and which is continuing to change as the water hyacinth invades and as nutrient enrichment from the industries along the northern lakeshore accelerates. It is important to remember that the traditional Lake Victoria fisheries were severely depleted by over-exploitation long before the Nile perch exploded (Bruton 1990, Bundy & Pitcher 1995). The rationale behind the Nile perch, tilapia and the failed carp introductions was to mitigate this over-exploitation. Rather than considerations of biodiversity, a paramount consideration for any new introduction to Victoria is that it should not disrupt existing successful fisheries for Nile perch, tilapias and the emerging harvest of small pelagics.

In this respect, other introductions and restorative management programmes might be worth considering. Introduction of fish such as air-breathers that could withstand low oxygen in the new lake regime might be considered. Carp failed to establish, but other benthic grazers and small predators from SE Asia or South America might be usefully canvassed (cyprinids, characins, catfish, anabantids or snakeheads). Some consideration could be given to encouraging species of high value in the traditional fishery. This has already been suggested for lost endemic haplochromine species (Ribbink 1987). Haplochromine species proven to survive Nile perch predation may be helped by establishing suitable habitat refuges and reserves. Nevertheless, it would be worthwhile putting some effort into the restoration of some of high-value traditional fishery species such as *Oreochromis esculentus*, the air-breathing *Protopterus* and mormyrids. This might be through small-scale ranching and aquaculture enterprises associated with habitat reconstruction or lakeshore pond culture. Feasibility studies would be required at the start, and one problem to be solved is the hybridisation that may have occurred between *O.esculentus* and *O.niloticus*. Experimental 'mesocosm' experiments might help in this venture.

Lake Tanganyika

A potential sardine yield of 147-226,000 tonnes of sardines is predicted by the Kariba baseline model, and this is more than the present reported catch of around 70,000 tonnes. But these figures represent only 4.5-6.8 tonnes per km^2, while a range of independent sustainable yield estimates based on primary production and on sardine biomass suggest a lake-wide average of $10t/km^2$ (Coulter 1990, Hecky 1990, Marshall 1992), as used in the Tanganyika baseline model described above. In fact, total pelagic yields of up to 19-30 t/km^2 may be achievable in the productive Burundi and Zambian regions at the north and south ends of the lake respectively. The problem with the Kariba-based model here is first, that it is based only on *Limnothrissa* whereas as pelagic catches in Lake Tanganyika include *Stolothrissa* and small pelagic *Lates stappersi*. Secondly, the higher energy transfer efficiency in the Tanganyika ecosytem makes the model predictions more uncertain. A considerable potential expansion of sardine catches is evident from both the model and the published assessments sardines in this lake, although care about under-reporting of catch statistics and local depletion of stocks has to be born in mind.

The model predicts a 'Nile perch' catch of between 16-72,000 tonnes, but application of the model is complicated by the presence of four endemic *Lates* species. The only one of these currently sustaining large catches is *Lates stappersi*, a specialised pelagic predator that seems to be resilient to overfishing because its fry outcompete sardines and it can switch its diet from sardine to shrimps (Coulter 1990). The larger pelagic species *L. microlepis*, declines rapidly when fished. The model is not relevant to these species.

Catches of the large benthic species *L. angustifrons* and *L. mariae* declined rapidly in areas where they were exploited in Zambia and Burundi (Coulter 1990). Data shows that the species closest to Nile perch, *Lates mariae*, considered the keystone of the unexploited fish community (Paine 1969), declined in abundance in the SW arm of the Zambian sector of the lake during expansion of the artisanal gill net fishery in the 1960s. The Nile perch model sheds some light on this decline, suggesting a sustainable yield of 0.5 to 2.2 t/km^2. Catch data for 1972 given in Coulter (1990) for the 2000 gillnets in the SW arm imply a *L.mariae* catch of 2.2 to 4.1 t/km^2, if we assume fishing 250 nights per year (or 3.2 - 6.0 t/km^2 for 365 nights fishing). The model suggests that catches may have been at least twice the estimated sustainable level given above, which calculation can show is roughly equivalent to a nightly catch of 1 to 4 kg of *Lates* per net rather than the 6-10 kg per net kg actually caught at that time. A much more rapid decline in *L. mariae* catches (and mean size) in the SE Zambian arm was likely due to the expansion of a nocturnal pelagic purse seine fishery operating with light attraction ('chiromila' net). Although this gear targets pelagic sardines and *L.stappersi*, Coulter (1990) points out that nocturnal vertical migration of *Lates mariae* renders the species vulnerable to this gear. If these analyses are correct, the recorded decline of *L. mariae* in the Zambian sector from overfishing is not surprising, but is no reason to extend the tendency to decline to all *Lates* fisheries irrespective of fishing effort. If the model is correct, reasonable sustainable catches of large endemic *Lates* are possible in Lake Tanganyika.

In Tanganyika not only is there a strong ethical case against any introductions by virtue of the unique cichlid fauna, but there is also no question of empty niches as the pelagic zone is fully occupied. The main management thrust should be to increase its endemic fish production towards its potential, whilst regulating all fisheries more carefully in the areas exhibiting symptoms of over-exploitation. Coulter's (1990) estimate of potential sustainable yield of 10 t/km^2 is at the lower end of the range of possible fish yields: even at this level Lake Tanganyika is potentially one of the richest fish producing lakes in the world.

Lake Malawi

In Malawi, the ethical case against fish introductions based on the intrinsic value of species flocks of endemics may be tempered by the need to feed a large undernourished population growing at a rate of 3% per year, the problem exacerbated by refugees from the war in Mozambique. Despite a highly fertile food production base, these factors have placed a severe strain on the agricultural and fisheries production of the country. One politician has been reported as saying "..of course we do not want to spoil the lake, but we cannot afford to keep it simply as a living museum".

The existing lake fisheries, which currently supply 50% of the animal protein in the country, cannot be significantly increased (Turner 1994). At one stage it was thought that pelagic planktivores might be underexploited, but recent work by ODA (Menz, in prep and pers.comm.) has shown that this is not the case. There is some scope for increasing aquaculture in the country, but this is unlikely to contribute more than about 10% of requirements at most. Accordingly, at some stage it may be expedient to consider if the current fish production from Lake Malawi could be increased by species introductions.

As in Lake Victoria, the potential yields of introduced sardines have to be considered in relation to an endemic cyprinid *Rastrineobola sardella* (usipa). The model suggests that sardines established in Malawi could provide 79,000 to 112,000 tonnes, or 2.6 to 3.6 tonnes per km^2. But it seems likely that existing pelagic planktivores, including usipa, two groups of cichlids and a catfish currently produce more than this. *Diplotaxodon limnothrissa* is a previously unreported meso-pelagic species that comprises 65% of the demersal trawl fishery (Turner 1994a & b). Pelagic surveys (A.Menz pers.comm.) have revealed unexpectedly large numbers of *Rhamphochromis* (2 species), *Synodontis* and two species of *Diplotaxodon*. Together these species could likely provide an annual catch 1.5-2 times the amount estimated for sardines. In fact, usipa alone may produce a catch of this magnitude in some years (Lewis & Tweddle 1990). Usipa year class strengths vary quite widely (Tweddle & Lewis 1990) and food limitation on recruitment was confirmed by Menz (p.c.), who carried out twelve lake-wide surveys in 1992-3 finding many usipa larvae but very few adults. Recent invertebrate surveys (Menz p.c) analysed by ECOPATH modelling suggest that there is no excess of secondary production in the form of lake fly larvae (*Chaoborus edulis*) available to be cropped by a sardine, an intoduction suggested by J.Turner (1982). Trophic transfer efficiency is estimated at 8.2%, about what one would expect for a system with 4-5 trophic levels. So the prediction of the new model here supports the both the ECOPATH finding and Iles' (1960) speculation that usipa is limited by zooplankton production and that there is no reason to suppose that a clupeid could do any better.

The model suggests that a sustainable Nile perch catch in Lake Malawi would be between 13-60,000 tonnes, worth between $16 and $73 million if all converted to frozen fillets. There is no large fast-moving predator in the lake, so the perch would find an empty niche and it is unlikely that there would be any difficulty in establishment, as the lake teems with suitable pelagic and benthic prey. Successful establishment of Nile perch in Lake Malawi would drastically alter the ecosystem and quite likely, as a worst case scenario, bring about the collapse of most existing fisheries. Exceptions might be usipa and other pelagic zooplanktivores, because the Victoria *Lates* coexists with a pelagic cyprinid. A number of the inshore tilapias would probably survive, as *Oreochromis spp.* does in Lake Victoria. Some rocky shore species of haplochromines would probably find refuges, but other fish of commercial significance could be assumed to be lost. Almost certainly the balance sheet for the introduction should assume that the off-shore chambo (*Oreochromis*) species would be eaten to extinction. Most would regard these drastic changes to the Lake Malawi ecosystem as totally unacceptable on ethical grounds.

But two further questions are important for the balance sheet of such an introduction in Malawi. Would more money be earned? Would more fish be produced?

The current value of the catch in Malawi amounts to 75-100,000 tonnes at 0.5 Kwacha per kilo, giving a total value of 37-50 million Kwacha, or about $13-17.5 million dollars (Mkoko 1992). Virtually all of this income is made internal to the country on a small local scale. The model suggests that the Nile perch catch would be worth 1.5 to 4 times more than this and moreover, would be in forex. The Nile perch fishery would also create a number of jobs in lakeshore processing factories, and, as in Lake Victoria (Harris *et al.* 1994) there would be large socio-economic changes. The answer to the first question is therefore that such an introduction of Nile perch might increase sustainable revenue. Short term economic gains as Nile perch hoovered up the most vulnerable prey might be large, and the temptation to expand the fishery infrastructure at this stage should be resisted.

On the other hand, given the likely destruction of most of the existing fisheries, comprising a sustainable 75-120,00 tonnes, long-term sustainable yield is not going to be increased by introducing Nile perch. Since the immediate and primary need is food protein in Malawi, the introduction could not be justified on these grounds. Furthermore, since in calculating the estimated value of the Nile perch above it is assumed that all of the catch is sent for export, the Nile perch fishery would not alleviate the present food and protein shortage. Some of the money earned could be used to buy grain or other vital foodstuffs, and some of the revenue might filter back into the local economy through job creation, but the Lake Victoria situation suggests that socioeconomic benfits would be patchy (Harris *et al.* 1995). Of course, a portion of the catch could be exported and the rest eaten at home, and a whole range of trade-offs of this kind might be envisaged. As in Lake Victoria, the high price of Nile perch for the export market would likely mean that the total amount of fish consumed at home is likely to be less than prior to the introduction, except perhaps during the initial years after establishment.

In summary, the balance of costs and benefits favours neither a sardine nor a Nile perch introduction in Lake Malawi.

Lake Kivu

The model predicts 7,000 to 10,000 tonnes of sardines (3 to 4.2 tonnes per km^2), which have, of course, already been introduced. Potential catch has been estimated widely at between 3,000 and 67,000 tonnes, but the model is in accord with Marshall's (1992) calculation that the most likely value is in excess of 6,000 tonnes. The actual (recorded) Kivu catch of 2500 tonnes from Rwanda and Zaire seems so much less than the potential catch of this lake that management should be directed at this shortfall in the first instance. Sardine introduction was followed by major changes to the plankton community. There is a small species flock of haplochromines in the lake but the effects of the sardine introduction on them are unknown (Marshall 1992).

Nile perch might yield only 1,100 to 5.300 tonnes, worth $1.4 to $6 million. As in Malawi, this would only be worth doing if there was some indication that the sardine fishery would survive. At present so little is known of the ecology and of the existing fishery in the lake that few of the questions germane to the decision could be answered with any confidence.

Total Fish Yields of Large Natural Lakes in Africa

The thirteen largest natural lakes in Africa listed in Tables 1 and 2 amount to a surface area of around 176,000 km^2, an area equivalent to the Gulf of St Lawrence, the Persian gulf, or one third that of the North Sea. The estimated total sardine yield from the model is of 0.9-1.3 million tonnes, and Nile perch yield of about 132-631,000 tonnes. The approximate total value of this catch would be between $1-2 billion. However, in nearly all cases the balance of costs and benefits considered here does not favour fresh introductions of either Nile perch or sardines.

A test of the model: estimating yields from haplochromine fisheries.

It has been argued (G.F.Turner, pers. comm.) that the upsurge of Nile perch has forced the Lake Victoria fishery to forego yields of haplochromines. Turner has made the interesting suggestion that the present model may be put to the test in estimating what the sustainable yield of the Lake Victoria haplochromine fishery could have been had the introduced Nile perch not taken over. Lake Malawi is a suitable baseline lake for the model since there is a long-established and well-assessed fishery for haplochromines (Turner 1995, Turner *et al.* 1995). Alternatively, the SE arm of Lake Malawi, the shallow most productive region, might be used.

The model estimates that Lake Victoria could produce haplochromine yields of around 5 to 8 tonnes per km^2, equivalent to 260,000 to 770,000 tonnes of fish. Malawi itself might produce between 40,000 and 140,000 tonnes of haplochromines at 2-4 tonnes per km^2. The upper range of these figures appears to be unrealistic as they are based on the SE arm of Lake Malawi and it is probably not wise to use small portions of lakes in the model. Using the whole of Lake Malawi as baseline produces more a believable range of estimates for Victoria of 266,000 to 550,000 tonnes.

Thus, the Nile perch, whose sustainable yield is in the order of 280,000 tonnes (Pitcher & Bundy 1995), has meant that up to 270,000 tonnes of sustainable yield from Victoria's haplochromines may have been foregone, although it is perhaps relevant to point out that the confidence limits of this estimate include zero.

Conclusions

A new model for estimating sustainable fishery yields for introduced Nile perch or freshwater sardine is based on using relative primary productivity to scale the sustainable fishery yield per unit area from reasonably well-studied baseline lakes. Implementation of the model employs of bootstrapped confidence limits over several baseline lakes. Overall, the candidate model performs convincingly in a range of man-made and natural lakes: for example it illuminates the collapses of overexploited *Lates* fisheries in Lakes Kainji and Kyoga and Tanganyika. The better the information from the baseline lakes the more accurate the model predictions are likely to be. Future sardine fishery yields from Lakes Itezhi-tezhi, Kainji and Cahora Bassa will prove good tests of the model. In conjunction with more conventional evaluation, the model can be used to assess costs and benefits of new fish introductions to lakes in Africa.

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Two figures follow

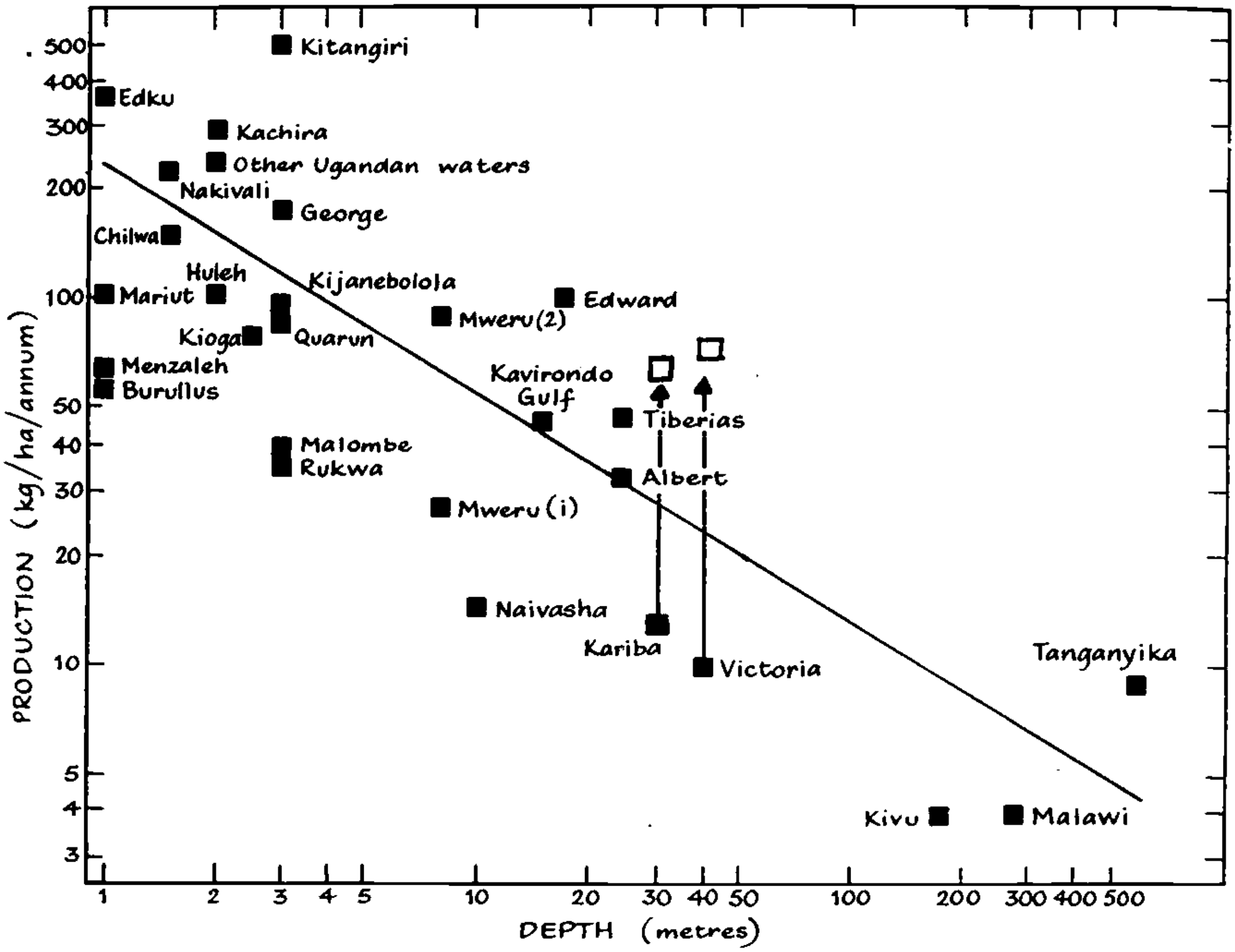

Figure 1. Plot of fish yield per unit area against mean depth for a group of African lakes showing the enhanced fish yield (open squares) achieved through the introduction of Nile perch in Lake Victoria and sardines in Lake Kariba (adapted from Fryer & Iles 1972). Closed and open circles represent estimated sustainable fish yield figures before and after introduction. Vertical scale is kg/ha/year, divide by ten for tonnes/km^2/yr as used in text. Victoria 'before' figures from Fryer and Iles ignore the possibility of a large trawl fishery for haplochromines as suggested by George Turner.

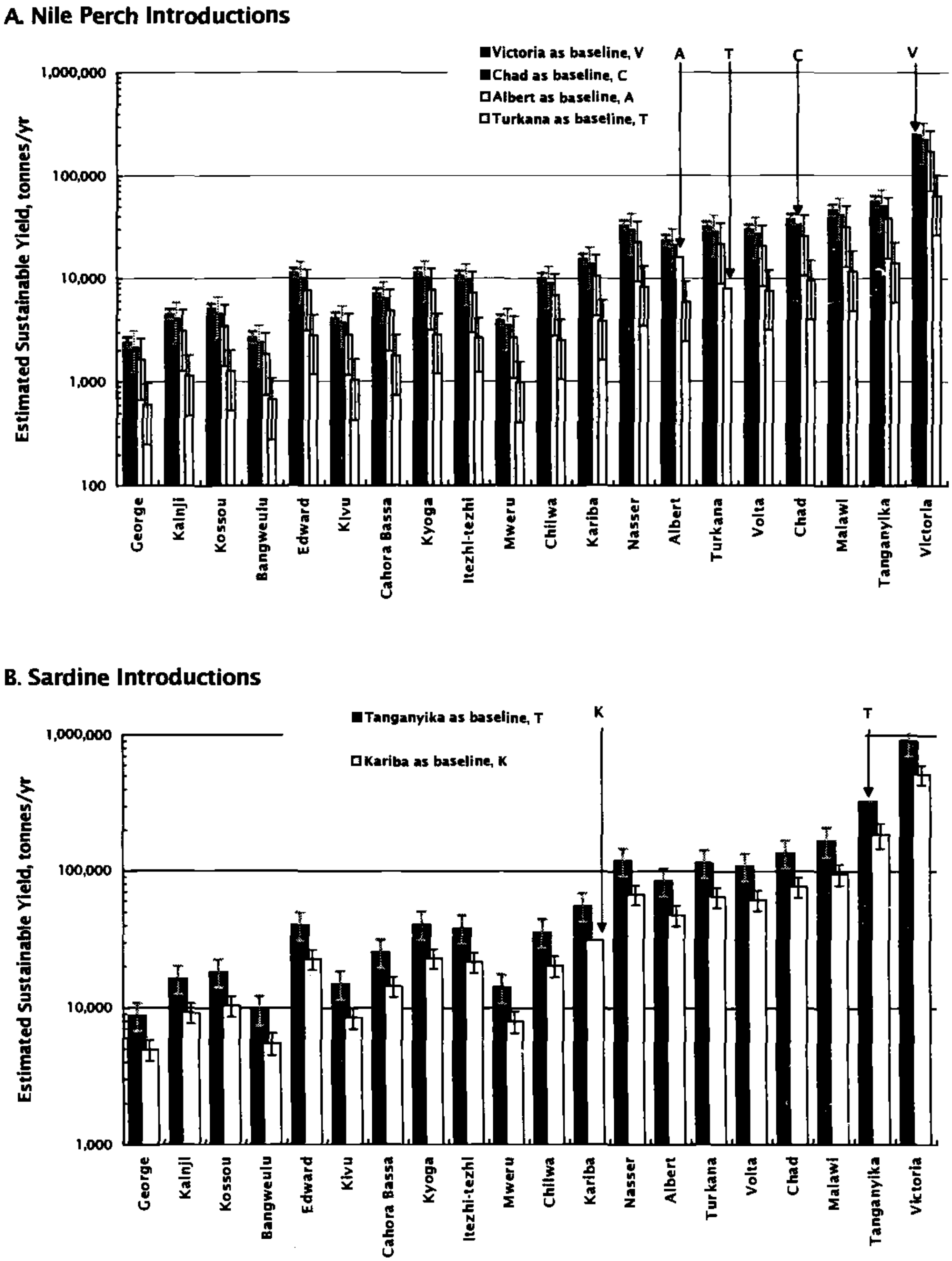

Figure 2. Sustainable yields for fish introductions to 20 African lakes as estimated by the relative log primary production model described in the text. Columns show estimates for each lake, bars show bootstrapped 95% confidence limits. Baseline lakes for each run of the model are indicated by arrows. A. Nile perch intorductions, with 4 altermative baseline lakes. B. Sardine introductions, with 2 alternative baseline lakes.

Conclusions and Recommendations

Conclusions

It is generally forgotten that the Rio Convention had two objectives: in addition to the often-quoted preservation of biodiversity there is sustainable use. This project has attempted to provide a balanced view of these two objectives in fish introductions in the African lakes.

Establishment of just two species in the twelve major natural lakes and the seven largest man-made lakes in Africa lakes could provide of the order of 1.3 to 2.4 million tonnes of fish per year. A yield of this magnitude would be worth around 2 billion dollars and would represent a doubling of existing catch. But the model developed under this project suggests that potential yields from most of the natural water bodies, including existing introductions, could probably match this figure both in terms of biomass and economic worth if more effectively managed.

When one looks in detail at the issues that would determine introductions in individual lakes, there emerge a number of cases where the benefits in terms of fish yield would not be sufficient to outweigh the damage to endemic faunas that already sustain successful fisheries. The notable cases here are those of Lake Malawi and Lake Tanganyika, both lakes that have not been subjected to introductions. It is important that this case against introductions in Malawi and Tanganyika is made on grounds of ecological economics and not emotive conservation. It is also important to realise that the conclusions about introductions are sensitive to fish prices, and in a world short of high quality protein, and with a need for increased economic activity in developing countries, fish prices are likely to rise in relative terms. Evaluations of fish introductions under the guidelines put forward here, are therefore labile and subject to continuous review.

Of about 50 fish species introduced to African lakes, many have not established themselves. But comparison of the failures and successes is not especially illuminating. This area of applied ecology is not sufficiently well-developed to make confident predictions about the success of future introductions or about the impacts on endemic faunas. We do not know which are the relevant features of the ecology of the introduced species, or of the ecosystems into which they were placed. However, we do have sufficient tools as applied ecologists to make reasonable predictions about the likely size of catches, and assess the associated uncertainties, should full establishment take place.

Reversal or mitigation of established introductions of Nile perch or freshwater sardines seems pointless. It will be more cost effective to manage existing fisheries for maximum benefit and establish economic priorities. Preservation of threatened species of fish through establishment of sanctuaries or aquarium breeding programmes can evidently reduce the impact on biodiversity at small cost. In the African lakes with their valuable cichlid fauna, the world aquarium trade could provide financial support for such projects. Establishment of sanctuaries will benefit existing fisheries in addition to threatened ones and should therefore be encouraged.

It is notoriously difficult to increase production of capture fisheries by altering natural phenomena. For example, salmon enhancement projects in Canada and US have been enormously expensive failures (Hilborn & Walters, *in prep.*). Unlike the situation in Africa, the salmon fisheries of the Pacific North West deal with relatively simple well-understood ecosystems. Salmon are large, easily-measured fish whose ecology has been subjected to unprecedented study, and are caught in well-documented and regulated fisheries operating in closely-defined geographical areas. If simple schemes of breeding and enhancement do not work here, they are unlikely to be robust enough to work in Africa.

On the other hand, fisheries production has sometimes been enhanced inadvertently by intuitively-obvious but almost entirely undocumented events that have barely been studied. For example, it is amazing that almost no strategic ecological study has been directed at the 30-50% enhancement of fish production in the southern North Sea.

An applied scientist may view with dismay the discovery that the vast output of conventional aquatic ecology has almost nothing to offer by way of insight or empirical prediction concerning the success, failure or impacts of introductions. This may be because of its long-standing concentration on the minutiae of single-species autecology.

Latterly, the new disciplines of behavioural ecology and eco-physiology have had some spectacular successes in testing evolutionary hypotheses concerning the trade-offs of adaptation of behaviour and physiology within the natural environment. For example, large scale field and enclosure experiments have established the general rules that fish (and other animals) use when they forage and how these rules impact habitat choice, life history dynamics and interaction with predators (see review by Hart, 1992). But it is still hard to see how one could use such theoretical insight to make specific predictions about establishment after introduction.

One helpful development here might be to borrow the mesocosm experiment paradigm from contemporary ecology. Prior to an introduction, experiments covering a range of food, predator and competitor regimes might be set up in the kind of extensive pond facilities used by Werner, Mittelbach or Persson's groups (see Hart 1992). Key parameters of the models used in foraging and habitat choice might them be established and some insight of the likely outcome of the introduction gained. The practical difficulties in doing this would be large for open water pelagic species, simply on account of the large size of pond required, but it might be more feasible for predators like Nile perch or herbivores like the Malawi Chambo. A competition experiment between *Rastrineobola*, or *Engraulicypris*, and the clupeid sardine *Limnothrissa*, would be of interest to set up in such a controlled mesocosm if the practical husbandry problems could be solved. There are quite a few problems, for example short term experiments of a few months might not match what might happen in real breeding populations. However, this type of approach is one positive suggestion that can be made. Detailed advice from one of the world experts in this type of experiment would be required as part of a feasibility study in this area.

Since with introductions and human exploitation one is dealing with ecosystem effects through predation and competition, one might expect more theoretical help from community ecology. With a few exceptions, community ecology seems to have gone nowhere since energy flow modeling in the 1960s and 70s. For example, cascade theory has not been very successful in predictions for African lakes. The study of diversity has been embroiled in methodological wrangles and esoteric theory, but as a practical science, has hardly lifted itself from the level of inventory. One encouraging exception is the simplified ecosystem model of ECOPATH (Christensen & Pauly 1993). ECOPATH offers quantitative insight of major system flows and stabilities and has been applied to Lake Victoria in this project.

Although it offers no help in predicting establishment, another initiative has been the development of approximate predictors of fish yields and potential yield. The availability and accuracy of data used to estimate the parameters required is often a constraint. Methods relying on the physical properties of the water bodies are easier to use and some have had reasonable success. For introduced sardines, the model developed under this project may soon be tested on Lake Itezhi-tezhi in Zambia.

The use of more biotic indicators, and more attributes of the water body that can be measured from satellite, seem to be two profitable areas for further work. One can recommend both methodological studies, such as the verification of suitable frameworks for empirical and statistical testing, and more conceptual studies, such as the search for easily-measured correlates of fish growth and production.

There is evidently much scope for innovative work here, for example measuring colonies of fish-eating birds (Wanink & Goudswaard 1992) is easier than measuring fish, and yet might be used as an accurate indicator. Other possibilities might be the relative abundance and sizes of key plankters like copepods, diptera and cladocera in relation to current primary production levels. Macrophyte growth may be related to juvenile fish survival.

How might sets of indicators like these be built into a model that could be used to monitor the status African water bodies? I suggest that the development of such a model aimed at monitoring the status of water bodies in Africa and elsewhere would be a valuable new ODA initiative.

Bruton (1990) puts forward a balanced view of conservation of fishes in the African lakes. The results of this project support his recommendation that higher priority should be placed on assisting African scientists to monitor and assess the fish resources of the lakes. It is evident that there are many well-educated, innovative fishery scientists in the region, 13 of whom have published under the auspices of this project. Yet it is evident that their training and focus is often driven by international funding that gives insufficient emphasis to applied fishery objectives. ODA has a good record in this respect, but perhaps could do more to persuade other donors, both in Europe and North America, of the value of increasing African competence in commercial and artisanal fisheries assessment. Perhaps the emerging South Africa will be able to help in this regard.

To encourage this type of work, ODA might also consider finding some way to help sponsor an African fisheries journal. To some extent, the Malawi publications associated with this project have attempted to address this problem, but this, and the EC initiative at Jinja to revive the former East African fisheries journal, are too limited geographically.

Revisiting the Project Aims

Aim 1. What factors determine whether or not an introduced species becomes established? Broadened to become multidisciplinary and to include the establishment, assessment, management, economics and socioeconomics of the fisheries in *the lakes, as well as the progress of establishment of introduced species.*

In its original form, this aim has not been advanced other than reviews of the field by myself and John Craig. In its extended form, the project has accomplished new work on Lakes Victoria and Kariba, encouraged publication of new work on Lakes Victoria, Malawi, Turkana and Naivasha, provided a candidate model and guidelines for evaluating introductions, and sponsored an innovative model of Lake Kariba that accounts for the small size of introduced sardines in the lake.

Aim 2. If a species does establish itself, what changes are likely in the existing fauna? Broadened to encompass insight of faunal, ecological, habitat and genetic changes as a consequence of introduction.

In its original form, the project has sponsored analyses of Lakes Victoria & Kariba (Karenge & Kolding), and Marshalls work on all sardine introductions. In its broadened form, the project has established related work on the genetics of Nile perch and sardines through Carvalhos group.

Aim 3. To what extent and under what circumstances, does exploitation lead to large sustained changes in species composition? Broadened to cover insight of ecological, species and genetic changes as a consequence of exploitation. The work also considers the effects of the current fishing regime, likely future trends and changes in management of the fishery.

The project has provided a forum for publication of work by FAO team on Lake Malawi and NORAD on Lake Turkana. Unfortunately the ODA /SADACC work on Malawi was completed too late to be included in the book.

Aim 4. What are the particular threats to the unique fauna of certain lakes by introductions or heavy exploitation?

Aim 4 is effectively subsumed under 1, 2 and 3 for all the major lakes.

Aim 5. If an introduction is proving undesirable, what measures are there which might reverse or contain the effect? This aim provides a specific focus on mitigation of faunal and genetic change resulting from introductions and exploitation, but has been broadened to include explicitly economic and socioeconomic effects.

The project has provided a forum for publication and discussion of the economic and socioeconomic analyses of Lake Victoria by the FAO team.

Recommendations

1. Support work that aims to test the candidate model for evaluating introductions using the outcomes of sardine fisheries in man-made lakes.

2. Support research aimed at exploring easily-measured indicators of fish population status. This might be done in conjunction with NORAD in Zimbabwe/Zambia, in Lake Malawi where ODA already has a presence, and in Lake Victoria through Ugandan, Kenyan and Tanzanian contacts and alumni.

3. Encourage international management of African lake fisheries through contacts with FAO and local fishery research laboratories. This might be done by establishing an ODA African fisheries newsletter, perhaps with the help of other donor agencies, and with the help of the new African Fisheries Society.

4. Provide outlet for scientific work by sponsoring a journal for African Fisheries research. The above might be a pilot scheme for this.

5. Sponsor more training of African fisheries scientists. Since ODA already sponsors many masters students, further workshops along the lines of the one included in this project are suggested.

6. Look at feasibility of mesocosm experiments to examine Nile perch, Nile tilapia or sardine interactions with indigenous species.

7. Sponsor work to look at optimal management of the Nile perch/Nile tilapia fishery in Lake Victoria.

8. Sponsor the publication of a book comprising a revised and extended version of Dr Brian Marshall's report on sardine fisheries carried out under this project.

9. Help African fishery scientists to attend the planned workshop in Lake Kariba aimed to improving the Walters & Degisi model developed under this project.

10. Sponsor publication of a book on Lake Malawi that will be equivalent in scope and quality to the Coulter book on Lake Tanganyika that was published jointly by the BM and OUP in 1990. Dr George Turner and Dr Andrew Menz would be a suitable editors.

ANNEX 1
Summary of Characteristics of Major African Lakes

19 lakes are included, one on each page, giving details of location, depth and area, conductivity, pH, primary production, fish fauna, main commercial species, status of introductions and, where available, approximate yield figures and the main ecological considerations *(modifed from from Craig 1990 and 1992)*

Lake Albert (Mobutu)

Country:	Zaire and Uganda	Natural lake
Geographical information:	Western Rift	
Latitude : 01°50'N	**Area**: 6800 km2	**Volume**: 140 km3
Longitude: 30°40'E	**Maximum depth**: 58 m	**Mean depth**: 25 m
pH: 8.9 to 9.5	**Secchi depth**: 2.0 - 6.0 m	
Conductivity:	730 micromhocm-1 at 20 °C	Stratified
Primary productivity:	0.8 to 3.8 gCm-2 day-1	970 gCm-2yr-1

FISH

Total number of families: 14	Total Number of species: 46	
Non-cichlids	No. of genera: 26	No. of endemic genera: 0
	No. of species: 37	No. of endemic species: 2
Cichlids	No. of genera: 2	No. of endemic genera: 0
	No. of species: 9	No. of endemic species: 4
Introductions:	None	

Main commercial species: *Alestes, (A. baremose), Hydrocynus, Lates (L. macrophthalmus* - lives offshore*), Bagrus, Oreochromis niloticus, O. leucostictus, Sarotherodon galilaeus, Tilapia zillii* and *Citharinus citharus.*

Total landings:	12548 tyr-1 in 1963
	12532 tyr-1 in 1988 (Orach-Meza et al. 1990)
Fish production:	125 kgha-1 (1.3 gCm-2yr-1) (Hecky et al. 1981).
Fishing gears used:	gillnets, beach seines, longlines, rod and line
Ecological considerations:	Fish species similar to riverine Nile fish

Lake Bangweulu

Country: Zambia Natural lake
Geographical information: natural shallow lakes, swamps and seasonally inundated floodplains
Latitude: 10°55'S **Area**: 2072 km2
Longitude: 30°10'E **Maximum depth**: 10 m **Mean depth**: 2.5 m
pH: 7.0 to 8.3 **Secchi depth**: 0.8 to 1.05 m
Conductivity: 14 to 35 micromhocm-1 at 20 °C
Primary productivity: 270 gCm-2yr-1

FISH

Total Number of species: 68

Non-cichlids	No. of genera: 31	No. of endemic genera: 0
	No. of species: 59	No. of endemic species: 3
Cichlids	No. of genera: 5	No. of endemic genera: 0
	No. of species: 9	No. of endemic species: 1

Introductions: none
Main commercial species: cichlids, mormyrids, clariids, bagrids, mochokids, characids
Total landings: 12000 to 15000 tyr-1
Potential fish yield: 10 to 35 kgha-1yr-1
Fishing gears used: gillnets

Lake Cahora Bassa

Country: Mozambique
Location: Middle Zambezi
Latitude: 16°00'S
Longitude: 31°00'E
pH: 7.0 to 8.2
Conductivity: 112 to 132 micromhocm-1 at 20 °C
O2: 6.0 to 7.0 mgl-1
Other physical information: High clay loadings
Area: 2665 km2
Maximum depth: 156 m
Drawdown 6 m
Man-made: Dam closed in 1974
Volume: 70 km3
Mean depth: 21 m
Outflow to Volume ratio 2:1

FISH

Introductions: *Limnothrissa miodon* by natural migration down the River Zambezi.
Main commercial species: *Hydrocynus vittatus, Labeo spp, Limnothrissa miodon, Clarias gariepinus, Oreochromis mortimeri, Distichodus schenga*
Potential yield of *L. miodon* of 8000 tyr-1 (Petri and Kapetsky 1983).
No time series data available.
Fishing gears used: gill nets
Fishing density in 1984: 0.46 fishermen per km2
Critical density: 1.5 per km2

Fisheries development has been impaired by warfare, lack of government infrastructure inputs, insufficiencies of fishing gears and crafts, inappropriate processing practices, difficulty in marketing catch and conflicts between fishermen and some official bodies.

Lake Chad

Country:	Chad and Nigeria	Natural
Latitude: 13°55'N	**Area**: 10000 to 25000 km2	
Longitude: 13°40'E	**Maximum depth**: 12 m	
pH: 7.1 to 8.3	**Secchi depth**: 0.15 to 1.27 m	
Conductivity:	40 to 88 micromhocm-1 at 20 °C	
Primary productivity:	0.7 to 2.7 gCm-2day-1	370 gCm-2yr-1

FISH

Total Number of species: 93

Non-cichlids	No. of genera: 41	No. of endemic genera: 0
	No. of species: 84	No. of endemic species: 8
Cichlids	No. of genera: 3	No. of endemic genera: 0
	No. of species: 9	No. of endemic species: 1

Introductions: none

Main commercial species: *Lates niloticus, Hyrocynus vittatus, Alestes baremose*

Total landings: 22400 tyr-1 (Welcomme 1972).

Ecological considerations: The lake has been subjected to serious droughts as it lies just south of the Sahara and has oscillated in size over the years. Fish biomass has varied as a result of lake size from 30 to 5620 kgha-1. Fish species strongly influenced by inflowing rivers into which many fish enter to spawn. Lake now almost dried up due to climatic conditions.

Lake Chilwa

Country:	Malawi	Natural
Latitude: 15°30'S	**Area**: Chilwa basin 7500 km2	
Longitude: 35°30'E	**Maximum depth**: 2.5m variable	
pH: 8.6 openwater	8.7 midswamp	7.6 land edge of swamp
O2 in mgl-1: 5.2 openwater	1.1 midswamp	0.0 land edge of swamp
Conductivity: micromhocm-1 at 20 °C	**Secchi depth**: 0.2 m var	
1200 openwater	1250 midswamp	1000 land edge of swamp
Generalised water balance, 1961-1971		
Rainfall: 893 mm	Inflow: 410 mm	Evaporation: 1303mm
Temperature: 21 to 31 °C		

FISH

Total number of families:	Total Number of species: 13	
Non-cichlids	No. of genera: 6	No. of endemic genera: 0
	No. of species: 8	No. of endemic species: 0
Cichlids	No. of genera: 3	No. of endemic genera: 0
	No. of species: 5	No. of endemic species: 0
Introductions: none		
Main commercial species: *Clarias mossambicus, Barbus paludinosus and Oreochromis shiranus chilwae*		
Total landings:	100 to 9800 tyr-1 Depends on water level	
	159 kgha-1yr-1 1976	
	Third of national fish landings in Malawi	
Fishing gears used:	gillnets, beach seines	

Ecological considerations: in times of drought fish take refuge in lagoons and streams. Clarias mossambicus can withstand desiccation and high conductivity.

Year	Mean Depth (m)	Tot Biomass (t)	Sarotherodon %	Barbus %	Clarias %
1965	1.08	8820	48	26	26
1968	0.00	97	4	7	89
1970	1.05	4166	8	35	57
1973	0.02	1903	?	?	?
1976	2.00	19746	14	52	34

Lake Edward (Idi Amin)

Country:	Zaire	Natural Lake
Geographical information:	Western Rift	
Latitude: 0°25'S	**Area**: 2325 km2	**Volume**: 78 km3
Longitude: 29°40'E	**Maximum depth**: 117m	**Mean depth** 34 m
pH: 8.7 to 9.3	**Secchi depth**: 1.8 to 3.0 m	
Conductivity:	840 micromhocm-1 at 20 °C	
Primary productivity:	4.3 gCm-2day-1	

FISH

Total number of families: 8	Total Number of species: 13	
Non-cichlids	No. of genera: 10	No. of endemic genera: 0
	No. of species: 17	No. of endemic species: 2
Cichlids	No. of genera: 5	No. of endemic genera: 1
	No. of species: 60	No. of endemic species: 59

See Lake George data

Lake George

Country: Uganda Natural Lake
Geographical Info: West limb Rift Valley. Outflow Kazinga Channel to Lake Edward
Latitude: 0°02'N **Area**: 270 km2 **Volume**: 0.7 km3
Longitude: 30°25'E **Maximum depth**: 3.0 m **Mean depth** 2.5 m
pH: 8.5 to 9.5 **Secchi depth**: 0.4 m
Temperature: 25 to 35°C **O2**: Can be supersaturated 259%.
Conductivity: 200 micromhocm-1 at 20 °C
Primary productivity: 5.4 gCm-2day-1 1500 gCm2yr-1

FISH

Total number of families: 8 Total Number of species: 77

Non-cichlids	No. of genera: 10	No. of endemic genera: 0
	No. of species: 17	No. of endemic species: 2
Cichlids	No. of genera: 5	No. of endemic genera: 1
	No. of species: 60	No. of endemic species: 59

Introductions: None

Main commercial species: *Oreochromis niloticus, Bagrus docmac, Clarias lazera, Protopterus aethiopicus*

Total landings: 12031 tyr-1 in 1963 and 5936 tyr-1 in 1988

Fishing gears used: Gill nets for cichlids. Minimum size limit 5". Use canoes for fishery. Baited longlines for predators.

Biomass: 45000 to 55000 fishha-1 and 29+5 gm-2.
Haplochromis nigripinnis 30000 ha-1 and 6.7 gm-2, *H. angustifrons* 15500 ha-1 and 2.1 gm-2, *H. squamipinnis* 172 ha-1 and 0.4 gm-2, *Oreochromis niloticus* 130 ha-1 and 3.7 gm-2 and P*rotopterus aethiopicus* 6 ha-1 and 1.5 gm-2

Ecological considerations: Stratified by day but this breaks down at night a eutrophic lake where reduction in oxygen can lead to fish kills. 95% of the total biomass in open water is phytoplankton. Standing crops of other organisms not high but fluctuate little throughout the year. Species composition of the open water dominated by blue-green algae and three herbivores, one cyclopoid copepod and two fish. Inshore areas carry a greater variety of animals which are preyed upon by a great multiplicity of fish, particularly haplochromids.

Lake Itezhi-tezhi (Kafue Gorge)

Country: Zambia Man-made Dam closed 1977
Geographical info: Kafue River
Latitude: 15°45'S **Area**: 3700 km2 **Drawdown** 7 m
Longitude: 26°30'E

FISH

Number of species: 67
Introductions: *L.miodon* in 1992, not yet fished.
Main commercial species: *Oreochromis andersoni, O. macrochir, Clarias gariepinus, C. ngamensis, Serranochromis angusticeps, Tilapia rendalli, T. sparmani, Schilbe mystus, Hepstus odoe Labeo molybdinus.*
Total landings: 8634 tyr-1 in 1978 (16% of Zambia's production).
less than 1000 tonnes in 1988
Fishing gears used: gillnets, beach seines

Lake Kainji

Country: Nigeria Man-made Dam closed 1968
Geographical info: River Niger
Latitude: 10°00'N **Area**: 1280 km2 **Volume**: 15.8 km3
Longitude: 4°35'E
Maximum depth: 50 m Mean depth: 12.3 m Drawdown 10 m
pH: 6.0 to 8.0 **Temperature**: 23 to 31 oC
Conductivity: 73 micromhocm-1 at 20°C **Secchi depth**: 0.1 to 3 m
Primary productivity: 890 gCm-2year-1 Nutrient poor
Generalised water budget: Rainfall: 660 to 1352 mm Inflow: 80000 x 106 cum Evaporation: 1500 to 2000 mm. Outflow to volume ratio 4:1 High compared to other reservoirs - cf Volta, Kariba Stratified: February to May in deep areas. Incomplete stratification May to November. Homothermy and oxygen well distributed December to January

FISH

Total number of families: 22 Total Number of species: 101. Similar species to Lake Volta
Introductions: none?
Main commercial species: *Sarotherodon galilaeus* (dominant in the catch), *Lates niloticus, Bagrus bayad, B. docmac, Oreochromis niloticus, Tilapia zillii, Hydrocynus forskahlii, H. brevis.*
Total landings: 4500 to 6000 Tyr-1 28000 tyr-1 in 1970 and 1971 then declined and stabilised by 1974/75. 4500tyr-1 in 1978.
Yield: 35 kgha-1yr-1 similar to that of the floodplains
Biomass by species/group/area: cichlids 105 kgha-1, bagrids 36 kgha-1 (Average inshore biomass 240 kgha-1.
Pelagic fishery may now be exploited, two small clupeids (*Pellonula afzeliusi, Sierrathrissa leonensis*) abundant, total biomass of 18 kgha-1
Fishing gears used: Cast nets from the shore and canoes.
Untilt recently lack of adequate fishing methods for clupeids

Ecological considerations: H. forskahlii feeds on clupeids and H. brevis feeds on cichlids. Most mormyrids declined or disappeared after filling although a few species increased after the initial decline.

Lake: Kariba

Country: Zimbabwe and Zambia — Man-made Dam closed 1958
Geographical information: Zambezi River
Latitude: 17°15'S **Area**: 5364 km2 **Volume**: 156.5 km3
Longitude: 27°55'E **Maximum depth**: 120 **Mean depth**: 29.2 m
Conductivity: 80 micromhocm-1 at 20 oC
Secchi depth: 1 to 12 m
Generalised water budget: Rainfall: 5.0 km3 Inflows: 60.9 km3 Evaporation: 8.6 km3
Outflows: 46.6 km3 Outflow to volume ratio 1:3 Low

Stratified October to June. Hypolimnion: Anaerobic during stratification. Becomes aerobic at turnover time (July) when nutrients are released and zooplankton increases at this time (Marshall 1988a).

pH: 8.0 surface; 6.8-7.0 hypolimnion **Temperature**: 17° (June) to 30°C (January)
Primary productivity: 1.7 gC2m-1day-1 Nutrient poor

FISH

Total number of families: 16 Total Number of species: 40
Introductions: Clupeids *Limnothrissa miodon* and *Stolothrissa tanganyicae* from Lake Tanganika (latter was not successful), 1967 and 1968.
Main commercial species: *Hydrocynus vittatus, Limnothrissa miodon, Clarias gariepinus, Tilapia rendalli, Serranochromis*. Now brown squeaker increasing.
Total landings: 1500 in 1974 , 26000 in 1985,35000 in 1991
MEI yield: 23.2 kgha-1yr-1.
Artisanal fishery for other species 4.6 kgha-1 or 2000 tyr-1.
Biomass of inshore fish <10000t Range 31 to 650 kgha-1 (Marshall and Langerman 1988).
Fishing gears used: Artisanal gillnet fishery and commercial/industrial pelagic fishery with lights and lift nets

Ecological considerations: Potential for an eel fishery (Balon 1975) and squeaker fishery (Chifamba pers. comm.). Zooplankton thought to be 3 to 44 times lower depending on taxon approximately 10 yr after introduced clupeid became abundant.

Lake: Kivu

Country: Zaire and Rwanda Natural lake
Geographical information: Western Rift
Latitude: 1o45'S **Area**: 2700 km2 **Volume**: 583 km3
Longitude: 28o55'E **Maximum depth**: 489 m **Mean depth**: 240 m
pH: 6.5 to 9.5 **Temperature**: Surface 24, minimum at 70 m of 22.8oC
O2: 6 to 7.5 mgl-1 to a depth of 20 m, 3 mgl-1 at 50m and anaerobic at 70 m.
Conductivity: 1240 micromhocm-1 at 20 oC **Secchi depth**: 2.5 to 9.35 m
Primary productivity: 0.66 to 1.0 gCm-2day-1, 240 to 540 gCm-2yr-1 Nutrient poor
Residence time of water: 110 yr Refill time (runoff alone) 190 yr
Stratified permanently

FISH

Total number of families: 16 Total Number of species: 40

Non-cichlids	No. of genera: 3	No. of endemic genera: 0
	No. of species: 9	No. of endemic species: 0
Cichlids	No. of genera: 2	No. of endemic genera: 0
	No. of species: 8	No. of endemic species: 7

Introductions: *Limnothrissa miodon, Stolothrissa tanganyicae* from Lake Tanganika (latter was not successful) from 1958 to 1960 (Spliethoff et al. 1983).
Main commercial species: *L. miodon*
Welcomme (1972) estimated an MSY of 30000 tyr-1 of clupeids. After one year of exploitation by the artisanal fishery yield was 42 kgha-1yr-1 - 13500 tyr-1 (Spliethoff et al. 1983)
Fishing gears used: For *L. miodon* artisanal light attraction and lift nets

Ecological considerations: Success of introduction due to lack of predators and the abundance of pelagic plankton.

Lake Kyoga

Country: Uganda — Natural lake
Geographical information: Inter Rift
Latitude: 1o30'N **Area**: 2700 km2 **Volume**: 16 km3
Longitude: 32o45'E **Maximum depth**: 8 m **Mean depth**: 6 m
pH: 7.2 to 9.0 **Secchi depth**: 0.9 m
Conductivity: 245 to 365 micromhocm-1 at 20 oC
Primary productivity: xx gCm-2day-1 Very high phytoplankton biomass 20 to 40 microg-1 Chl a (Ogutu-Ohwayo and Hecky 1990)

FISH

Families and species: as for Lake Victoria into which it drains

Introductions: *Lates niloticus*. Tilapias: About 4 nonindigenous species introduced from 1951 onwards including: *Oreochromis leucostictus, O. niloticus, Tilapia rendalli* and *T. zillii*. *O. leucostictus* does not appear to have competed with indigenous fish of more open water. It occupies pools and shallow areas behind papyrus beds. *T. zillii and O. niloticus* displaced the endemic O. variabilis and *O. esculentus* by 1970. *O. niloticus* is a superior competitor as it has a wider food spectrum, is more fecund, has a faster growth rate,grows to a larger size and lives longer than endemic *Oreochromis* spp. (Fryer and Iles 1972). Possible hybridisation between *O. niloticus* and *O. variabilis*.

Main commercial species: As for Lake Victoria

Total landings: 4500t in 1956; 160000t in 1977 (introduced species contributed about 80% of the latter); 68000 t in 1988.

Fishing gears used: Gillnets, beach seines, longlines

Ecological considerations: In the last decade there has been a steady drop in the water level (1.5 m) which has caused a reduction in the breeding and nursery areas. Not all areas have been exploited to their full potential due to political reasons.

Lake Malawi (Nyasa)

Country: Malawi, Mozambique and Tanzania — Natural lake
Geographical information: Western Rift
Latitude: 10o45'S — **Area**: 30800 km2 — **Volume**: 8400 km3
Longitude: 34o30'E — **Maximum depth**: 756 m — **Mean depth**: 426 m
pH: 7.7 to 8.6 — **Secchi depth**: 17 m
Conductivity: 220 micromhocm-1 at 20 oC
Primary productivity: 0.24 to 1.14 gCm-2day-1
Generalised water budget: Rainfall: 1000 mm Inflows: 490 mm Evaporation: 1300 mm Stratified permanently. Some mixing caused by wind action.
Temperature: Epilimnion 23.0-27.3; Hypolimnion 22.5-oC
O2: Hypolimnion 430 m Anoxic and rich in nutrients. — Age: about 1 to 2 million years

FISH

Total number of families: 11	Total Number of species: 545	
Non-cichlids	No. of genera: 19	No. of endemic genera: 1
	No. of species: 45	No. of endemic species: 28
Cichlids	No. of genera: 23	No. of endemic genera: 20
	No. of species: 500	No. of endemic species: 495

Introductions: none
Main commercial species: Haplochromine spp., *Oreochromis* spp, *Rhamphochromis* spp
Estimated sustainable fish yield: 30-120,000 t

Total landings: 12445 tyr-1 in 1968. About 30000 tyr-1 (Malawi waters) in recent years of which 25% is caught by the commercial sector (Tweddle and Magasa 1989).

Fishing gears used: Commercial demersal trawling began at the south of the lake in 1968. 160 fish species occurred in the catch, 80% were small cichlids. 11 species of large catfish including *Bagrus meridionalis* and minor species (mormyrids, cyprinids and large *Oreochromis* spp) were caught. 20% of the species disappeared from the catch in 4 years, 1971-74. A bottom gillnet fishery in the south catches *Labeo* spp, *Bagrus meridonalis* and *Oreochromis* spp in order of importance. *Labeo* and *Bagrus* declined continuously from 1950s through 1970s. 40 kg to 5 kg per net in the south east arm (this is the most productive area of the lake) and from 20 kg to 3.5 kg in the south west arm (Turner 1976). Those species that spawn in inflowing streams (*Labeo* spp, *Clarias gariepinus*) are particularly vulnerable when they congregate in the lake before entering the streams. Commercial fishery now consists of ringnetting, midwater trawling and demersal trawling. Artisanal gillnet fishery.

Two groups of haplochromines in inshore areas: sand dwellers and rock dwellers. Purse seine catches decline with distance offshore - one mile 1/2 nearshore catch and three miles offshore 1/4 catch of nearshore. Haplochromis spp make up 72% of the nearshore catch.

Pelagic fish: *Engraulicypris sardella* (usipa); *Diplotaxondon limnothrissa. Chaoborus*, the midge larvae found in the pelagic zone. No relationship found between spawning stock and year class strength (ycs) of E. sardella (FAO 1982). The ycs is highly variable. Total pelagic fish biomass estimated from acoustic gear = 86 to 94 kgha-1 and from purse seine catches = 75 kgha-1. Yield = 30 to 40 kgha-1. Acoustic surveys, purse seine catches and monofilament net catches indicated that pelagic fish population was too small to support a commercial pelagic fishery. Lake Tanganyika has a pelagic fish biomass 1.6 times greater than Lake Malawi although secondary productivity is similar. Hypothesis put forward that secondary productivity is fully ultilised by the clupeids in Lake Tanganyika whereas a large proportion of secondary production in Lake Malawi is 'lost' through its consumption by Chaoborus. Recent ODA/SADACC project has disproved this hypothesis.

Ecological considerations: Lake Malawi National Park formed in 1984 to protect endemic species and populations.

Lake Mweru

Country: Zaire and Zambia — Natural lake
Latitude: 8o50'S — **Area**: 5200 km2
Longitude:28o50'E — **Maximum depth**: 37 m **Mean depth**: 12 m
Conductivity: 70 to 150 micromhocm-1 at 20 oC
pH: 6.6 to 9.3 — **Secchi depth**: 0.76 to 1.22 m

FISH

Total number of families: 16 Total Number of species: 94

Non-cichlids	No. of genera: 39	No. of endemic genera: 0
	No. of species: 83	No. of endemic species: 4
Cichlids	No. of genera: 5	No. of endemic genera: 0
	No of species: 11	No. of endemic species: 1

Introductions: none?
Main commercial species: *Tilapia, Auchenoglanis, Chrysichthys, Gnathonemus, Mormyrus*
Total landings: 12445 tyr-1 in 1968
Fishing gears used: gill nets

Lake Nasser/Nubia

Country: Egypt and Sudan Man-made Assam Dam closed 1964
Geographical information: Nile River
Latitude:23o50'N **Longitude**:32o50'E

	Area(km2)	**Volume** (km3)	Max depth (m)	Mean depth (m)
Nasser				
160 m Level	2585	55.6	110	21.5
180 m "	5238	132.5	130	25.2
Nasser and Nubia				
160 m Level	3057	65.9	110	21.6
180 m "	6216	156.9	130	25.2

Outflow to volume ratio 1:2
Conductivity: 198.5 to 265.5 micromhocm-1 at 20 oC
pH: Nasser 7.8 to 8.9 Nubia 8.2 to 9.1 **Secchi depth**: Nubia 0.10 m (Aug), 0.22 m (March)
Temperature: Nubia 15 oC (Feb) to 30 oC (July) **O2**: Nubia 7.5 to 10.7 mgl-1

FISH

Total number of families: Nubia 10 Total Number of species: Nubia 26
Introductions: none?
Main commercial species: *Sarotherodon galilaea, Labeo niloticus, Oreochromis niloticus, Hydrocynus forskalli, Lates niloticus, Alestes baremose, Eutropius niloticus*
Commercially important at start but now negligible in occurrence *Distichodus, Citharinus, Bagrus*
Estimated sustainable fish yield: Nasser 10000 and Nubia 5000 tyr-1
Total landings: Nasser and Nubia 600 tyr-1 (Both well below potential Nasser open water areas under-utilised). 7000 tyr-1 Nasser (Henderson and Welcomme 1974)
Fishing gears used: gill nets

Lake Tanganyika

Country: Burundi, Tanzania, Zambia and Zaire Natural lake
Geographical information: Western Rift Age: 2 to 4 million years
Latitude: 5o15'S **Area**: 33000 km2 **Volume**: 18800 km3
Longitude: 29o40'E **Maximum depth**: 1470 m **Mean depth**: 570 m
pH: 8.6 to 9.2 **Secchi depth**: 3.3 to 22 m
Conductivity: 566 to 620 micromhocm-1 at 20 oC
Primary productivity: 0.40 to 3.10 (0.8) gCm-2day-1 (Hecky and Kling 1987) 1040 gCm-2yr-1 290 gCm-2yr-1 given by Hecky and Fee (1981).
Temperature: Epilimnion 23.5 to 27 oC; Hypolimnion 23.25 to 23.35 oC
O2: Hypolimnion anoxic
Stratified permanently. Thermocline may break down in certain years due to strong winds. Hypolimnion: 1200 m deep
Generalised water budget: Rainfall on lake surface:900 mm Inflows: 530 mm Evaporation: 1350 mm Outflow: 80 mm Residence time of water: 430 yr Inflow to volume ratio 1:1500 Refill time (runoff alone): 1000 yr

FISH

Total number of families: 14	Total Number of species: 240	
Non-cichlids	No. of genera: 42	No. of endemic genera: 8
	No. of species: 75	No. of endemic species: 52
Cichlids	No. of genera: 37	No. of endemic genera: 33
	No. of species: 165	No. of endemic species: 164

Introductions: none
Main commercial species: *Limnothrissa miodon, Stolothrissa tanganicae, Lates mariae, L. microlepis, L. angustifrons, Luciolates stappersi.*
Est. sustainable fish yield: 300000 tyr-1, 240000 tyr-1 clupeids and 30000 tyr-1 L. stappersi
Total landings: 73000 tyr-1 (22.5 kgha-1)
After 7 yr in the 1960s, at the south of the lake, purse seine pelagic catches of Lates sp. were halved but clupeid catches approximately doubled. There was a similar change in the north end of the lake. Total biomass of Lates sp. = total biomass of clupeid prey (approximately). Pelagic clupeid abundance now cyclic in periodicity of several years alternating with strong oscillations of L. stappersi which has become the dominant predator. Top benthic predator, L.mariae, also caught in the pelagic zone by purse seines, has diminished considerably.
Biomass by species/group/area: clupeid 529 kgha-1
Fishing gears used: Commercial purse seines in the pelagic zone. Gill nets of mostly small mesh size for benthic fish. Artisanal inshore fishery uses beach seines, handlines, longlines, weirs and gillnets.

Ecological considerations: Benthic fish populations occur down to 200 m depth on the extensive shelf areas at the south and comprise c. 60 species. Population numbers have not declined in the unexploited south west arm of the Sumbu National Wildlife Park. Primary production is not high compared to other lakes but lake fisheries yield (125 kgha-1yr-1) is very high. The great antiquity of the lake may have allowed selection of very efficient pelagic species resulting in a highly efficient pelagic ecosystem where carbon accumulates at the top of the trophic pyramid and not in the algae (Hecky et al. 1981). However estimates of heterotrophic bacterial production equal or exceed algal primary production. The immense volume of anoxic deep water is the probable source of energy fixed in reduced substances and allowing high rates of bacterial production. Chaoborus, the lakefly is not present in Lake Tanganyika as it is in Lake Malawi.

Lake Turkana (Rudolf)

Country: Kenya and Ethiopia Natural lake
Geographical information: Eastern Rift. Semi-desert region. Influenced by River Ono in Ethiopia

Latitude: 3o30'N	**Area**: 7200 km2	**Volume**: 273 km3
Longitude: 36o05'E	**Maximum depth**: 120 m	**Mean depth**: 31 m

pH: 9.4 to 10.0
Conductivity: 3000 to 3500 micromhocm-1 at 20 oC
Primary productivity: 0.25 to 6.2 gCm-1day-1 northern sector 1315 to 6220, central sector 194 to 3936 and southern sector 259 to 293 gCm-2yr-1

FISH

Total number of families: 15	Total Number of species: 47	
Non-cichlids	No. of genera: 22	No. of endemic genera: 0
	No. of species: 35	No. of endemic species: 6
Cichlids	No. of genera: 3	No. of endemic genera: 0
	No. of species: 12	No. of endemic species: 11

Introductions: none
Main commercial species: *Lates niloticus, Oreochromis niloticus, Citharinus, Alestes*
Total landings: 2045 in 1968, 3510 in 1974 tyr-1
Biomass by species/group/area: Lates niloticus made up 22% of the total gill net catch in early 1970s, 348 tyr-1 in 1972/73 and 470 tyr-1 in 1973/74. Standing crop of N. niloticus 1900 t
Fishing gears used: Gill nets, beach seines and traditional methods. 19 species featured in the developing fishery since 1963. Fishery mostly inshore (<15m depth). 1963 to 1965 Sarotherodon spp. and L. niloticus exploited using beach seines.

Ecological considerations: Similar fish fauna to Lake Albert, basically Nilotic. 12 species riverine and confined to the region of the Ono Delta. Seasonality leaves growth checks on boney structures in many fish. Lates longispinus, a dwarf and offshore living species, comparable to the offshore form of Lates in Lake Albert.

Lake Victoria

Country: Uganda, Kenya and Tanzania Natural lake
Geographical information: Inter Rift Age: 250000 to 750000 years
Latitude:0o50'S **Area**: 68000 km2 **Volume**: 2700 km3
Longitude:32o50'E **Maximum depth**: 79 m **Mean depth**: 20 m
pH: 7.1 to 9.0 **Temperature**: 23.8 to 26.0oC
Secchi depth: 1.3 to 8.2 m Currently 1.5 to 2.5 m due to greatly increased phytoplankton biomass
Conductivity: 96 micromhocm-1 at 20 oC
Primary productivity: offshore 1.08 to 4.20 gCm-2day-1 offshore 950 gCm-1yr-1
Generalised water budget: Rainfall on lake surface: 1260 mm Inflows: 330 mm
Evaporation: 1310 mm Outflow (R. Nile): 280 mm Stratified seasonally. Hypolimnion: Oxygenated. Now can become seasonally deoxygenated

FISH

Total number of families: 12 — Total Number of species: 288

Non-cichlids — No. of genera: 20 No. of endemic genera: 1
No. of species: 38 No. of endemic species: 16

Cichlids — No. of genera: 8 No. of endemic genera: 4
No. of species: 250 No. of endemic species: 247

Introductions 1: *Lates niloticus*. First official stocking of Nile perch was 35fish from Lake Albert planted off Entebbe Pier, Uganda in May 1962. In September, 1963 339 fish from Lake Turkana were put into the lake near Kisumu, Kenya. However Nile perch were unofficially stocked before this date. In May 1960 a perch was caught at Bugungu just above the Ripon Falls and another in Waigala Hannington Bay in November 1960 (Acere 1984).

Introductions 2: *Tilapias*: About 4 non-indigenous tilapine species introduced, from 1951 onwards, from Lake Albert into Uganda, Kenya and Tanzania waters, including: *Oreochromis* leucostictus, O. niloticus, *Tilapia rendalli* and *T. zillii*. *O. leucostictus* does not appear to have competed with indigenous fish of more open water. It occupies pools and shallow areas behind papyrus beds. *T. zillii* and *Oreochromis niloticus* displaced the endemic *O. variabilis* and *O. esculentus* by 1970. *O. niloticus* is a superior competitor as it has a wider food spectrum, is more fecund, has a faster growth rate, grows to a larger size and lives longer than endemic *Oreochromis* spp. (Fryer and Iles 1972). Possible hybridisation between *O. niloticus* and *O. variabilis*.

Main commercial species: 1971 *Oreochromis, Bagrus, Clarias, Haplochromis* and *Protopterus*.
1990 *Lates niloticus, Rastrineobola argentea* and *Oreochromis niloticus*.

Total landings: 110000 t in 1968; 296000 t in 1985

Fishing gears used: Gill nets, beach seines, longlines, trawling. Gill nets are mostly home-made and of no standardized materials and dimensions making the establishment of an accurate index of fishing difficult (Ligtvoet et al 1987). Traditional gillnet fishery for 'tilapias', *Bagrus, Clarias*, and Protopterus. In 1983 (FAO 1983c) 54000 fishermen using about 11000 boats (4000 in Kenya, 4000 in Tanzania and 3000 in Uganda). Trawl fishery started in the early 1970s in the Mwanza area (Tanzania) to exploit *Haplochromis* in the deeper parts of the lake. Beach seine fishery for *Rastrineobola* started in the Kenyan and Tanzanian sections but expanded to include a lamp fishery with ringnets and Danish seines and become a genuine pelagic fishery. Gill nets (mesh sizes from 6 to 16 inches, 153 to 305mm), for Lates niloticus. Other minor, seasonal/local fisheries.

Ecological considerations: Overfishing within both shallow inshore areas and river mouths increased use of small mesh gillnets and unrestricted use of beach and mosquito seines. The seasonal fisheries of the River Nzoia, Kenya depend on the ascent of Lake Victoria fish (Barbus and Labeo). Growth: Nile perch 1984 Loo= 257 cm, k= 0.09 and to= -1.

Lake Volta

Country: Ghana Man-made. Akosombo Dam closed in 1964
Geographical information: on River Volta
Latitude: 7o10'N **Area**: 8845 km2 **Volume**: 165 km3
Longitude: 0o30'W **Maximum depth**: 75 m **Mean depth**: 18.6 m
Outflow to volume ratio: 0.25:1 (low) Drawdown of 3 m
Stratified: thermocline persistent but not permanent at c. 17 to 20 m
Epilimnion: Fully oxygenated (up to 140%) Hypolimnion: oxygen 0 to 5%
Primary productivity: 0.8 to 5.2 gCm-2day-1 930 gCm-2yr-1

FISH

Total number of families: ? Total Number of species: ?
Introductions: none ?
Main commercial species: *Alestes, Citharinus, Distichodus, Labeo, Lates niloticus, Sarotherodon galilaeus, Oreochromis niloticus, Tilapia zillii.*

Estimated sustainable fish yield:	40000 tyr-1 (Adeniji 1981). Based on MEI 2.77 kgha-1yr-1
Total landings:	36 to 42000 tyr-1 1971 - 1984, 60000 tyr-1 in 1969
Fishing gears used:	gill nets

Ecological considerations: Pelagic clupeids (Pellonula afzeliusi and Cynothrissa mento) underexploited and tilapias overexploited. Mormyrids virtually disappeared after filling.

ANNEX 2
Participants at the London Meeting, March 1992

Breakdown by country: UK 21; Zimbabwe 6; USA 4; Uganda 4; Malawi 3; Netherlands 3; Kenya 3; Burundi 3; Zaire 2; South Africa 2; France 2; Cameroon 1; Tanzania 1; Japan 1; Norway 1; Zambia 1. Total 58 recorded participants.

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PHOTOGRAPH (next page)

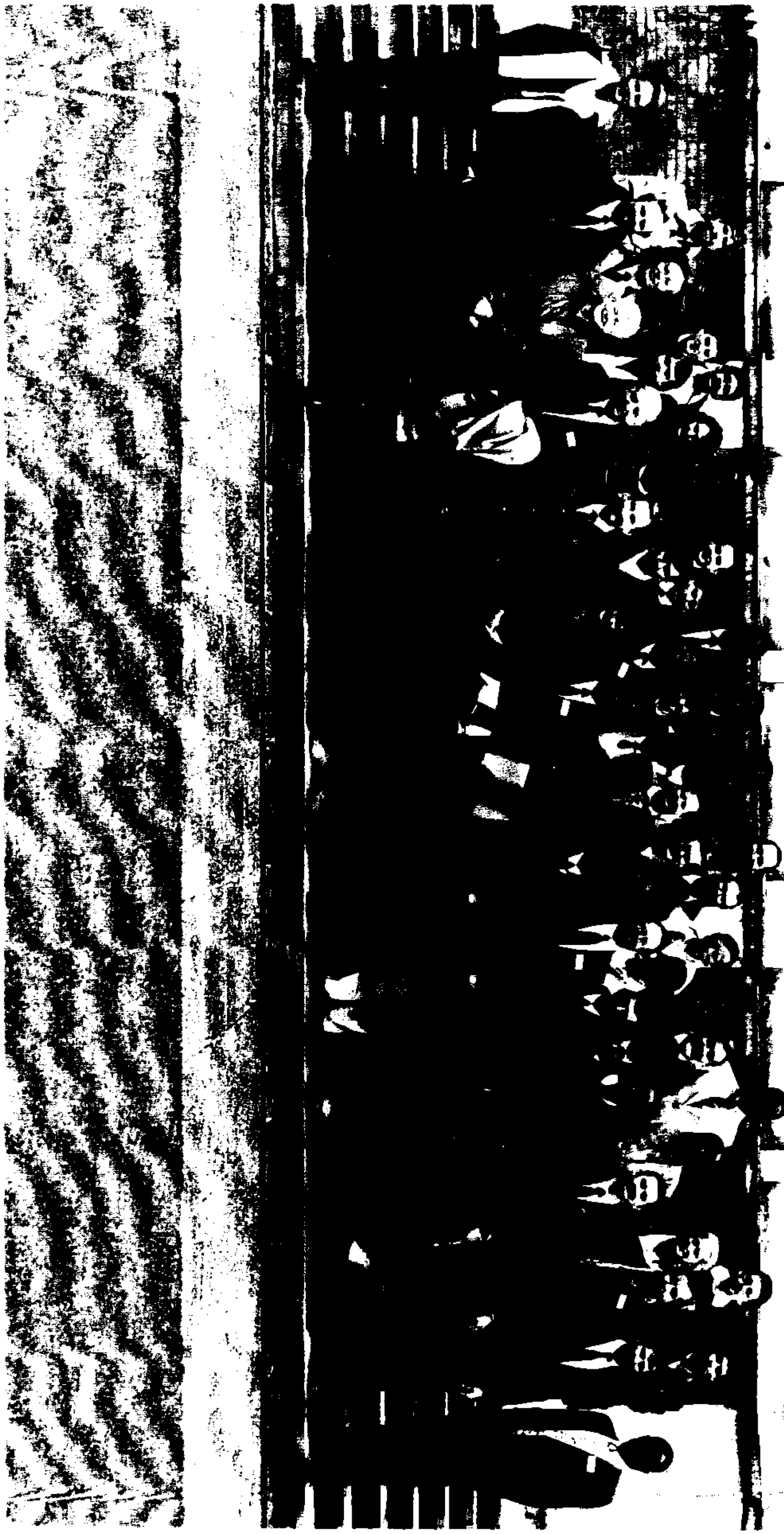
4th row: Pearce, Makwinja, Cooper, Kudhongania, Karenge, Dondo, Chifamba, DeLeon, Hickley, Sanyanga, Chitamwebwa, Hauser

3rd Row: Harris, Shaw, Naish, Petit, Temple, Ribbink, Cowx, Fakahou, Gashgaza,Bundy, Mannini

2nd row: Kawanabe, Tweddle, Ogari, Moreau, Oguto-Owayo, Ochumba, Marshall, Nsibula, Mbinzereki, Turner

Front Row: Kolding, Roest, Lowe-McConnell, Wiley, Ben Tuvia, Redding, Djama, Mtsambiwa, Ssentongo, Pitcher, Witte, Masundire, Sznober, Reynolds, Twongo

missing: Beverton, Beales, Blake, Carvalho, Hart, MacKaye, Stauffer, Stauffer, Tarbit



ANNEX 3
Abstracts of Papers Delivered at the London Symposium

Carvalho, Gary R & Lorenz Hauser

General Impacts of Fish Introductions: an African Perspective

Centre for Fish Genetics, School of Biological Sciences University College of Swansea, Singleton Park, Swansea, SA2 8PP, UK

The need to strike an appropriate balance between the often conflicting demands of exploitation and conservation in fisheries management are nowhere more apparent than in African freshwaters. Demand for fish products is excessive, representing as they do a major source of affordable protein for many rural and urban communities. African freshwaters, especially the Great Lakes of East and Central Africa, offer not only invaluable and potentially abundant natural fish resources, they also contain an exceedingly diverse and complex fish fauna with unparalleled trophic specialization and degree of endemism. The persistence of this high biodiversity has been threatened by many activities of man, including pollution, catchment development, overfishing and fish introductions. The present review considers the genetic impacts of introduced fish in African lakes and outlines the major processes threatening the genetic diversity and integrity of both introduced and indigenous species. Long-term effects of a reduction in genetic diversity are considered, both in terms of a species' ecological success and of the productivity of its fishery. We suggest major topics for future research and describe briefly the molecular methods for monitoring and evaluating genetic impacts.

Chitamwebwa, D B R

The Impact of Exotic Fish Introduction and Environmental Changes on Fish Species in Lake Victoria

Tanzania Fisheries Research Institute, Seta Station, PO Box 46 Shirati, Tanzania

In the period 1950-60 four cichlids: *Tilapia zillii*, *T. rendallii*, *Oreochromis niloticus* and *O. leucostictus* and a predator *Lates niloticus* were introduced into Lake Victoria with the purpose of improving the lake's fisheries. The cichlids were to utilise the abundant planktonic food in the lake while the predator was to convert the small, bony haplochromines into flesh of more economic value. Also, in the early 1960s the lake level rose by two metres following very heavy rains that fell in East Africa. Consequently, many species of rooted macrophytes were lost from the lake through submergence beyond their tolerance level.

The effects of competition, change in environment caused by loss of littoral vegetation and predation resulted in the decline and disappearance of many indigenous species. The lake's fisheries are now dominated by *L. niloticus*, *Rastrineobola argentea* and *O. niloticus*. The second species above is the only indigenous species of economic importance and its fishery evolved in mid sixties.

Currently, there are signs of recovery of some species as the lost macrophytes are reappearing. On the whole, the fisheries in the lake are in a state of flux.

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de Iongh, H H

Impact of Kapenta Introductions in Lake Kivu

Centre for Environmental Studies, POB 9518, 2300RA Leiden, Netherlands

The freshwater clupeid *Limnothrissa miodon* was transplanted with success from Lake Tanganyika to Lake Kivu during 1958-60. An artisanal fishery to exploit the clupeid stock started in the beginning of 1980. Biological research revealed information about growth rate, condition factor K, fat content, migration, distribution and reproduction of *Limnothrissa*. An obvious relation was found between fat content and sexual activity with the seasonal fluctuations of plankton production. The main spawning peak coincided with a plankton bloom caused by the turnover of the Lake at the end of the dry season in September. At that time a small percentage of clupeids had fat in their body cavity. It was concluded that horizontal migration is determined by feeding habits.

A limnological sampling programme in Lake Kivu, confirmed a seasonal increase of the pelagic plankton biomass at the end of the dry season during the windy period of August/September. Examination of stomach contents of different length classes of *Limnothrissa* proved that the Kivu clupeid is not a strict planktonophagic species. Its diet is adapted to its life cycle and inshore/off-shore migration patterns. In pelagic waters of the lake it is an exclusive plankton feeder, while in littoral waters it has more littoral bound feeding habits. Cannibalism was observed among individuals larger than 100 mm, near the margins of the lake.

Echo soundings and periodic observations of stomach contents support the hypothesis that *Limnothrissa* feeds in the late afternoon and di-

gests its food during the night, while a second feeding/digestion cycle starts in the early morning at sunrise.

Consecutive echo-sounding surveys in the Lake provided estimates for the stock of clupeids, in terms of standing stock and maximum sustained yield. During 1980-92, with support of FAO, a viable artisanal fishery has developed on the lake, using catamarans and trimarans with liftnets. Socio-economic benefits of the artisanal fishery are compared with those of semi-industrial purse seining.

The impact of *Limnothrissa* introductions on the Lake ecosystem is further discussed.

Kolding, Jeppe

Changes in Species Composition and Abundance of Fish Populations in Lake Turkana, Kenya

Department of Fisheries and Marine Biology, University of Bergen High Technology Centre, 5020 Bergen, Norway.

Major changes in the relative abundance and structure of the fish populations in Lake Turkana between 1974 and 1987 are evaluated and discussed. The investigation is based partly on two experimental fishing surveys in the north-western part of the lake and partly on long term trends in the catch rates and composition of the commercial fishery. A general reduction in catch per unit effort since the mid seventies was the result, but it is unevenly distributed among the geographic localities and among the various species. Most of the inshore demersal community species (*Labeo horie, Barbus bynni, Citharinus citharis and Distichodus niloticus*) have changed relatively little despite sustaining the heaviest fishing pressure. In contrast some major species from the off-shore pelagic community (*Hydrocynus forskalii, Alestes baremose and Schilbe uranoscopus*) have drastically reduced in abundance. Interestingly this decrease is not caused by the fishery as these species are little or not commercially exploited. Moreover, a few exploited species (*Lates spp. and Synodontis schall*), have increased in abundance.

However, all the sampled stocks display increased stress symptoms indicated by a general decrease in mean individual size, and for some also signs of a decreased mean size at first maturity is observed. A general assessment of the major changes and trends in time is presented and the relative impact of the possible agents of change, environment or fishery, is discussed. The work concludes that the natural environmental changes has the main impact on the fish stocks and that overfishing probably never has been an issue. This has important consequences for management strategies and yield forecasts.

Kudhongania, A W

The Impact of Exploitation, Competition and Predation on the Changing Stocks of Lake Victoria

Uganda Freshwater Fisheries Research Organisation (UFFRO), PO Box 343 Jinja, Uganda

The dramatic decline in fish species diversity in Lake Victoria has been attributed to predation by Nile perch, *Lates niloticus* Linne, without sufficient justification. Exploitation, interspecific competition and hybridisation had profound impact on the decline of the indigenous commercial fish species. The roles of exploitation, competition and hybridisation, and of predation by the Nile perch on changes in species diversity have been discussed. *Lates* was largely responsible only for the decline of the haplochromine stocks.

McKaye[1], Kenneth R, Joseph Ryan, Eric van den Berghe[1], Lorenzo Lopez Perex, Jay R Stauffer Jr.[2]

African 'tilapia' in the Great Lakes of Latin America: Economic Opportunity or Ecological Catastrophe?

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The utilization of freshwater fish resources has long been recognised to be an important source of protein for the rural populace and families living next to natural and artificial bodies of water, and a source of potential foreign exchange for a country. In most of Africa this valuable renewable resource has been overexploited and fish production has fallen. In Nicaragua, Central America, a relatively unique situation exists in which the freshwater fish resource is being underutilised as a protein source. Exceptional opportunities are present to develop this resource and increase the protein consumption of the rural inland population of Nicaragua. Furthermore, the recently introduced Italian species provide outstanding possibilities for South - South (Africa - Latin America) co-operation in understanding the ecological and economic factors which determine whether or not an introduced fish species is beneficial to the local populace.

Few recent figures are available concerning freshwater fish consumption. However, an unpublished Soviet report indicates that 1,000 tons of fish were being captured in the early 80's. Clearly this figure could be increased dramatically without a detrimental effect on the resource. The Soviets estimate that 8,000 tons can be exploited on a sustained basis. Using Soviet figures for productivity (MEPURSS 1983) we calculate that a theoretical yield of over 20,000 tons of fish could be harvested, if an efficient herbivore were present in the ecosystem. Now within this potential harvest are the newly introduced Africa 'tilapia', *Oreochromis niloticus, O. mossambicus, O. aureus.*

These Africa 'tilapia' began appearing in the artisanal catch in 1987-88. They are expanding throughout the lake, and approximately 20% of the biomass presently caught by our experimental gills nets in shallow coastal areas consists of 'tilapia'. The ultimate effect of the tilapia on the native fishes is of course unknown at this time. Whether or not the large marine predatory species which inhabit open portions of the lake will prevent the take-over of Lake Nicaragua by 'tilapia', as has occurred in Florida lakes, is now the subject of research. The results of studies on the impact of species changes in Africa lakes will have a major impact on how this important fisheries will be managed. Furthermore, the examination of this rich underexploited ecosystem will also provide insights into how to mitigate the disturbances caused by introductions and man's overexploitation in the Africa lakes.

Marshall, B E

Why is *Limnothrissa Miodon* Such a Successful, Introduced Species and Is There Anywhere Else We Should Put It?

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The food crisis in sub-Saharan Africa is such that there are compelling reasons for making further introductions of alien species into lakes and reservoirs. This is because some introduced species have dramatically improved their fisheries' productivity. The clupeid *Limnothrissa miodon* is one of them, having been introduced into Lakes Kivu and Kariba where it now supports thriving fisheries. Its capacity to colonise new areas is epitomised by the fact that it had spread throughout Lake Kariba within two years of being stocked. It also established itself in the Zambesi River below the Kariba Dam and invaded Lake Cahora Bassa after its creation in 1975.

The factors responsible for *Limnothrissa*'s success include the presence of a vacant niche, a high investment in reproduction and an appropriate reproductive strategy, and the ability to change its life-history. Its ecological effects include an increase in some species of predatory fish, major changes to the structure of the zooplankton and a possible alteration of the existing patterns of nutrient cycling. It is concluded that this species is probably capable of being successful in almost any lake. Further introductions should be limited to man-made lakes, where stable communities have not yet become established and ecological changes are proceeding rapidly. The possibility that it could cause major, and unpredictable changes in natural lakes with relatively stable, or at least slowly changing ecosystems, suggests that it would be unwise to introduce it into them.

Masundire, Hilary M

Seasonality of Zooplankton Abundance and its Relevance to Kapenta (*Limnothrissa Miodon*) Yields in Lake Kariba, Zimbabwe

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Zooplankton of Lake Kariba are dominated by a small cladoceran, *Bosmina longirostris* and small cylopoid species of the genus *Thermocyclops.* Large zooplankters are rarely encountered. This is probably due to heavy size selective predation by the introduced pelagic freshwater sardine, *Limnothrissa miodon.* Plankton densities show a predictable seasonal pattern. This seasonal pattern in plankton densities correlates very well with *Limnothrissa* catch per unit effort with a three-month lag. It is postulated that kapenta (*Limnothrissa miodon*) catches may be predicted using plankton biomass.

Mbahinzireki, G

Abundance and Distribution of Benthic Organisms in Northern Lake Victoria

Uganda Fresh Water Fisheries Research Organization, PO Box 343, Jinja, Uganda

The paper presents initial results of the abundance and distribution of benthic organisms in an ecologically and environmentally changed northern Lake Victoria. The results suggest that the density of most of the zoobenthos has gone up since the pre-perch era despite the absence of comparative data. Increases in densities were noted for dipteran larvae followed by *Caridina nilotica*, oligochaetes, molluscs and nymphs of Anisoptera and ephemeroptera, in that order. Possible reasons to account for the increase are advanced. Inshore stations hold higher densities than the off-shore station. Type of the sediment and physico-chemical factors seem to influence the production and distribution of these communities. Work continues.

Muchiri[1], S M, D M Harper[2] and P J B Hart[2]

The Feeding Ecology of Tilapia in Relation to Ecological Changes in Lake Naivasha, Kenya

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The tilapias, *Oreochromis* leucostictus and *Tilapia zilli* have been introduced into Lake Naivasha, Kenya and forms the basis of a commercial fishery. Lake Naivasha is characterised by frequent changes in water level and varying amounts of macrophytic vegetation. Changes in the lake ecosystem tend to occur rapidly and have significant ecological consequences.

Using gill nets a study of the diet of the tilapias was made over a three year period at three contrasting sites in the lake. For both species, 40-50% of the food eaten was detritus. The rest of *O. leucostictus*'s diet was composed of 22% phytoplankton, 17% benthic macro-invertebrates and a small proportion of insects. Apart from detritus, the diet of T. zilli included 28% insects and then less than 10% each of macrophytes, benthic macroinvertebrates and non-specified material.

The emphasis on detritus in both species indicates that competition between the two is unlikely. Their diets may also mean that changes in macrophyte or invertebrate abundances do not seriously influence the two fish populations as these elements are not critical to the fish. The quantity of detritus is unlikely to change quickly in response to changes in macrophytes or water levels, so damping out short term ecosystem changes. Feeding ecology is also considered in the context of changes in fishing effort over the study period, as this is more likely to be a force for change.

Moreau, J

Possible Analysis of Species Changes in African Lakes by a Multispecific Trophic Model: Examples of Lake Victoria and Lake Tanganyika: a Call for Cooperation

Department of Inland Fisheries, INP/ENSAT, 145 Avenue de Muret, 31076 Toulouse, France

A multispecific trophic model called ECOPATH II which can be used to describe, on a quantitative basis, the trophic relationships in an aquatic ecosystem is briefly analysed. When properly used, it can help to explain the evolution of fish stocks after an introduction and/or a significant increase of fishing effort. Two examples are provided on Lake Victoria and Lake Tanganyika. The aim of the paper is to demonstrate how a cooperation among specialists of different groups can increase our possibility of following up via a quantitative synthesis of species changes in African Lakes.

Mtsambiwa, M Z

Feeding Behavioural Changes in the Tigerfish *Hydrocynus vittatus* Following the Introduction of Kapenta *Limnothrissa miodon* in Lake Kariba.

Lake Kariba Fisheries Research Institute, Box 75 Kariba, Zimbabwe

Since the introduction of the freshwater sardine *Limnothrissa miodon* into Lake Kariba there has been an increase in the abundance of tigerfish *Hydrocynus vittatis* in the open waters. This is evidenced mainly by the increase in tigerfish as by-catch in sardine catches over the years. The question which remains to be answered is whether the tigerfish has become truly pelagic or whether it undertakes feeding migrations from the inshore region. An experimental programme is underway to address this issue.

N'Sibula, Mulimbwa

Fishery Biology of the Clupeids (*Stolothrissa tanganicae* and *Limnothrissa miodon*) in the North Western End of Lake Tanganyika.

Centre de Recherche en Sciences Naturelles, Station d'Uvira, Uvira, Zaire

Stolothrissa tanganicae and *Limnothrissa miodon* are endemic clupeids of Lake Tanganyika and are very important protein resources. Fishery statistics data show that the catches of these fish species have decreased in the past years (Enoki and Mambona pers. comm.). This could have serious socio-economic implications. The biological information necessary for development of their fisheries is still insufficient.

Sampling surveys for clupeids were carried out by the artisanal unit of the Uvira Research Centre from November 1987 to April 1989. Fishing was conducted at inshore (about 500m from the shore and about 50m depth) and off-shore (more than 7 km from the shore and more than 100m depth) fishing grounds. Growth rates are estimated from the modal progressions of the frequencies distributions. Spawning areas and periods for *Stolothrissa* and *Limnothrissa* are considered. Finally an assessment of growth rates, gonadasomatic index and available cohorts is made.

Ochumba, Peter B O

Limnological Changes in Lake Victoria Since the Nile Perch Introduction

Kenya Marine and Fisheries Research Institute, Kisumu Laboratory, PO Box 1881, Kisumu, Kenya

Lake Victoria presently exhibits traditional symptoms of eutrophication including decreased water transparency, blue-green blooms enhancement, elevated nutrients concentrations and hypolimnetic deoxygenation. Changes in the phytoplankton community altered available food sources to primary consumers but these grazers were considerably suppressed by higher trophic levels. Fish introduction modified the phytoplankton, zooplankton and fish assemblages in Lake Victoria that had the most intensive impact on water quality.

Lake Victoria fish species are threatened by the worsening conditions in the Lake itself and from the rivers in the catchment area. It is suggested that urban, agricultural and industrial pollution and the introduction of predatory Nile perch and competitive Tilapiine species are the major factors for the deterioration of Lake Victoria's ecosystem. *Oreochromis esculentus* is almost extinct and many more haplochromine species are endangered.

Current fisheries legislation and operations aimed at reduction of soil erosion and sedimentation in inflowing rivers in the catchment area are insufficient for significant improvement of the present deterioration of water quality. Localised manual harvest of papyrus, shoreline dredging and sand mining did not sufficiently improve lake conditions.

It is recommended to intensify pressure on algal and detrital matter by stocking the lake with large-bodied cichlids. These grazers are less vulnerable to Nile perch predation and can probably reduce algal and detrital densities. Further and long term monitoring of the lake and its tributary rivers is required for administrative agencies for decision making with regard to protecting the Lake Victoria resources.

Ogari, James

Faunal Changes Resulting From Nile Perch Introduction in Lake Victoria (Kenya Sector)

Kenya Marine and Fisheries Research Institute, Kisumu Laboratory, PO Box 1881, Kisumu, Kenya

Prior to the establishment of *Lates niloticus* (Nile perch), Lake Victoria supported a diverse ichthyofauna with a complex web of interactions among species and a stable ecosystem. The food chain had a wide base with *Bagrus docmac* (catfish) as top predator. Initially predation by *Lates niloticus* was targeted at species which mature at small size and included the haplochromines, mormyrids and characids.

With the establishment of Nile perch in Lake Victoria, a steady, gradual but notable decline or disappearance of indigenous fish species was observed. Due to its large size, the Nile perch had the ability to prey upon a wide size range of the indigenous fish species. As a competitor Nile perch was most successful compared to other indigenous predatory species - hence the decline of the latter species and the displacement of *Bagrus docmac* as top predator,

The drastic change in the composition of fish species has created an unstable ecosystem with short and simple trophic levels. The upsurge of *Lates niloticus* has contributed to the decline of prey with subsequent migration of the Nile perch into deeper waters in pursuit of its prey and also cannibalistic behaviour. Some endemic species apparently have evolved various behavioural patterns in order to evade predation by Nile perch. Zooplankton have become smaller in size whereas phytoplankton appear to be on the increase.

Ogutu-Owayo, Richard

Changes in Diversity and Stability in Fish Stocks in Lakes Victoria, Kyoga and Nabugabo since Introduction of other Fishes

Uganda Freshwater Fisheries Research Organisation, PO Box 343, Jinja, Uganda

Lakes Victoria, Kyoga and Nabugabo had a diverse and similar native fish fauna. Some of the species were initially reduced by overfishing but none had completely disappeared. A large piscivorous predator, Nile perch, *Lates niloticus* (L) and four herbivorous tilapiine cichlids were introduced into these lakes during the 1950s and 1960s. The Nile perch and one of the introduced tilapiines, *Oreochromis niloticus* (L) established themselves. This was accompanied by a reduction and in some cases total disappearance of most of the native species except one, *Rastrineobola argentea* (Pellegrin). The species composition has been stable on the three species; *L. niloticus*, *O. niloticus* and R. *argentea*. These three form the main fish prey of Nile perch and are the main commercial species. A balance between predation and human exploitation is, therefore required for the stability of the fish stocks in these lakes.

Pearce, Martin

Some Effects of Exploitation on the Structure of the Pelagic Community in the South East Arm of Lake Tanganyika

Department of Fisheries, PO Box 55, Mpulungu, Zambia

Commercial purse seine fishing on the pelagic fish community began in the south of Lake Tanganyika in 1962. Initial catches comprised four predatory Lates species and two clupeid species. Initial predator - prey ratios were about 1:1, but this fell rapidly, and by 1967 the predators were less than 10% of the total commercial catch. During this period the species of clupeid commonly found offshore, *Stolothrissa tanganicae*, doubled in abundance. Catches of *Limnothrissa miodon*, the clupeid species which seems to be coast bound, remained fairly constant throughout this period.

The three large *Lates* species, *L. microlepis*, *L. mariae*, *L. angustifrons*, have continued to decline in abundance up to the present time, and the inshore clupeid *L. miodon* has maintained a fairly steady catch rate.

The catches of S. *tanganicae* reached a peak in 1972, since when a decline in abundance which is following a cyclical pattern has been observed. Catches of the small Lates, *L. stappersi* began to increase at the time that S. *tanganicae* abundance started to drop, and between 1973 and 1977 catch rates increased by an order of magnitude. Since 1977 catches of *L. stappersi* have fluctuated in a cyclical fashion but over a long period have stayed at around 50% of the annual commercial catch.

For the past 15 years the pelagic community has virtually consisted of a two species predator - prey system showing inversely related cyclical fluctuations with a periodicity of three years. The catches of the two species over a complete cyclical period are very similar, indicating a return to the pre exploitation predator-prey ratio of 1:1. Since 1986 the amplitude of the tri-annual cycle in catch per effort of *L. stappersi* has reduced, but for S. *tanganicae* has increased.

It is postulated that fishing pressure was responsible for the initial decline in large Lates species, and this allowed the increase in S. *tanganicae* and *L. stappersi* abundance through reduced predation. Because of its shorter life-span S. *tanganicae* was able to increase its population as the *L. stappersi* population also began to increase led in turn to the decline of S. *tanganicae*.

Both S. *tanganicae* and *L. stappersi* include a pelagic prawn as a major item in their diets, and the high predator-prey ratio may be explained by the ability of *L. stappersi* to maintain itself by feeding on the prawns when S. *tanganicae* is scarce.

Because the pelagic fish community is so simple, and because *L. stappersi* is a competitor as well as a predator, it is conceivable that continued heavy fishing on S. *tanganicae* without even heavier fishing on *L. stappersi* may lead to the disappearance of the former from the commercial catch.

Petit [1], Philippe & Antoine Kiyuku [2]

General Change Patterns in the Fisheries of Lake Tanganyika (Burundi Sector) during the Eighties.

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In Burundi, pelagic fisheries are operating during the night. The following species are concerned: the clupeid fishes *Stolothrissa tanganicae* and *Limnothrissa miodon* and their predators: *Luciolates stappersii* and, to a small extent, Lates spp. The aim of the paper is to analyse the evolution of the fishing effort both in industrial and artisanal fisheries during the last fifteen years. It is demonstrated that the importance of the artisanal fishery is now higher than the one of the industrial fishery. Possible reasons and expected consequences are discussed.

Pitcher, Tony J & Alida Bundy

An Analysis of the Species Changes in Lake Victoria

Renewable Resources Assessment Group (RRAG), Imperial College, London, UK

Significant species changes have occurred in Lake Victoria since the introduction of Nile perch (*Lates niloticus*) and exotic tilapias in the late 1950s. Many of the endemic species have been reduced to insignificant numbers and the fishery is now largely comprised of 2 introduced demersal species, *Lates niloticus* and *Oreochromis niloticus* (Nile tilapia) and the native zooplanktivorous pelagic cyprinid *Rastrineobola argentea*.

The introduction of Nile perch has been blamed for this great reduction in species diversity. But should the finger really be pointed at Nile perch alone or has it simply been used as a convenient scape goat for other underlying developments in the lake and its fisheries? And is it really such a disaster as conservation-minded scientists would lead us to believe?

In this paper we have attempted to answer these questions by re-examining the fisheries data from Lake Victoria. The data, mostly commercial catch data and some effort data has inherent problems, not least the uncertainty of its accuracy. With this knowledge we have made a variety of different assumptions and subjected the data sets to time-series and multivariate analysis.

Even before the Nile perch swam in the waters of Lake Victoria, species abundance had been reduced due to excess fishing pressure; subsequent environmental changes and predatory pressure from Nile perch only exacerbated this trend. Furthermore we suggest that in economic terms, the Nile perch and the Nile tilapia have been a great success: the Lake now has a thriving fishery which needs only positive management to ensure its continuing success. Reports of its demise appear to be premature.

Reynolds, J Eric, D F Greboval & P Mannini

Thirty Years On: Observations on the development of the Nile Perch Fishery in Lake Victoria

UNDP/FAO Regional Project for Inland Fisheries Planning (IFIP), BP 1250, Bujumbura, Burundi

A broad assessment of the socio-economic impact of species changes in Lake Victoria is presented, together with observations on possible future trends. The evolution of the Nile perch fishery is traced with respect to catch, effort, and prices lakewide and for each of the riparian countries. A review is given of basic economic performances/indicators for both the pre- and post- Nile perch fisheries regimes. Estimates are made of the net benefits accruing to society (producers and consumers) as a result of the Nile perch introduction. Projections of future (medium and long term) accumulations of benefits are also calculated based on differing assumptions about the continued productivity of the Lake.

Ribbink, A J

Conservation in the Lake Malawi National Park: A World Heritage Site

JLB Smith Institute of Ichthyology, Private Bag 1015, Grahamstown 6140, South Africa

There is probably no other park in the world which offers protection to as many endemic vertebrates as does the Lake Malawi National Park. Some of the endemics appear to be threatened by translocated species. A programme to develop management procedures to minimise this threat has been initiated by the Department of National Parks and Wildlife. The problems, the goals and the research initiatives will be discussed.

Sanyanga, Rudo Angela

Changes in the Abundance of *Synodontis zambezensis* Peters 1954 in Lake Kariba

Lake Kariba Fisheries Research Institute, PO Box 75, Kariba, Zimbabwe

Synodontis zambezensis was found to be the most abundant species in Lake Kariba in a gill-net survey done in 1991 using Lundigren multi-mesh monofilament gill-net. In 12 of the 15 stations sampled *S. zambezensis* made up more than 50% of the total catches in fresh weight. Its index of relative importance (IRI) was 54%, followed by *Brycinus lateralis* with 20% then *Barbus marequensis* with 8% and other inshore species contributed less than 18%.

It is argued that the *S. zambezensis* has increased in abundance since the establishment of Lake Kariba and may still be increasing. There is need to develop a fishery which harvests the *S. zambezensis* without harming the cichlid stocks.

Ssentongo, G W

Life-history Patterns and Resilience of Tilapiine Species in the African Great Lakes

UNDP/FAO Regional Project for Inland Fisheries Planning (IFIP), Bujumbura, Burundi

This paper deals with the factors influencing life-history patterns and resilience of tilapiine species. The persistence of tilapias in African lakes is facilitated by progenesis, diversity of niches, vicariance, ecological succession and predictability of environment, particularly for the Great Lakes. Besides, the tilapiines are endowed with both k-selected and r- selected attributes.

Life history patterns involve growth, reproduction and maintenance. Any tilapia could have limited food resource at its disposal over its life-span. The energy from food has to be allocated to the three competing life processes. The main life history features of tilapiine cichlids are: the brood size, age and size of first maturity, shifting energy from growth to reproduction, fecundity, parental care and survival of the young.

The populations of tilapiines are delimited in two ways:

(a) by other tilapias and fish species with which a tilapiine competes in the same locality; and
(b) by other species with which it has mutually exclusive geographical ranges.

Tilapiine species which grow to a large size require more energy for growth and maintenance than the species which grow to a smaller maximum size and matures at an early age. A delicate balance exists between growth and reproduction and this determines the reproductive potential of these species at any size or age. Spawning periods appear to be influenced by photoperiod, temperature, salinity, rainfall, social factors, ontogenic factors and physiological factors.

Vicariance (the development of natural biogeographical barriers) has split some tilapias into species and subspecies groups with a common ancestor. Vicariance within tilapiines is evident in Lakes Victoria, Tanganyika, Rukwa, Malawi, Mweru and Bangweulu.

Sympatric speciation (the differentiation and attainment of reproductive isolation of groups of species occupying the same area) has also enabled tilapias to co-exist.

Stauffer, Jay R, Jr.

The Impact of Intra-lacustrine Introductions on the Endemic Faunas of Lake Malawi

Pennsylvania State University, 101 Ferguson Building, University Park, Pennsylvania 16802, USA

The rock-dwelling cichlids (mbuna) inhabit the rocky shores and rock outcroppings of Lake Malawi and comprise a major portion of the haplochromine species flock that is endemic to the lake. These fishes are known for their explosive radiation, and many of the species are endemic to only one particular island within the lake or are geographically restricted to one part of the rocky shore along the lake. Distributional surveys document that at least 12 species were introduced to Thumbi West Island (Cape Maclear) from other parts of the lake approximately 20 years ago; no documentation is available, however, concerning when or where introductions took place, or which fishes were involved.

Presumably, these introductions were made by persons in the aquarium trade, in order to reduce the time and expense required to travel to more remote portions of the lake. As a consequence of these introductions, the island now has high species richness (greater than 40 species). Stauffer and Hert (in prep.) discussed the morphological divergence of two introduced forms, *Pseudotropheus aurora* and an undescribed form known as the cobalt zebra in the aquarium trade. Surveys conducted in 1991 yielded a putative intergeneric hybrid, *Cynotilapia afra* x *Pseudotropheus zebra*, based on morphological characteristics. A plot of the first sheared principal component (morphometric data) versus the first factor score (meristic data) indicated that the supposed hybrid was intermediate to the two presumed parental forms. The presence of conical teeth on the lower jaw and bicuspid teeth on the upper jaw gave further evidence of hybridization. A total of 11 *P. zebra*, 11 *C. afra* and 6 putative hybrids were screened using starch gel electrophoresis for 14 enzymes. Two polymorphic loci (Aconitase and Esterase-3) were found. Slight differences in allelic frequencies were detected, but the sample size was too small to determine if these differences were significant ($P<0.05$).

Turner, G F, D Tweddle & R D Makwinja

Species Composition Changes of Demersal Cichlid Communities as a Result of Trawling in Southern Lake Malawi

Fisheries Research Station, PO Box 27, Monkey Bay, Malawi

Since the introduction of commercial trawling on Lake Malawi in 1968, the fishery has undergone steady expansion and now yields some 6-7000 tonnes per annum, about 15% of the total fish production of the lake and adjoining water bodies. Biomass estimates and maximum sustainable yields for each of the seven fishing areas in the southern portion of the lake were calculated by FAO from the results of experimental trawls from 1971-5. In all areas, except south of Boadzulu Island (Area A), effort levels have remained below those recommended and yields have consequently been low.

For the last 15 years , in area A, levels of effort and yield have been near to or above those recommended, but catches have remained fairly stable. Between 1971 and 1974, experimental trawls revealed substantial decreases in the populations of larger haplochromine cichlids in this area, following which the minimum cod-end mesh size was increased from 25 to 38 mm. From experimental trawling, biomass estimates have been made in 1990-91 and the species composition of the catch was investigated in 1991.

The results are compared with those of the earlier study to determine if the populations of these larger species, a number of which are endemic to the south-eastern arm of Lake Malawi, have recovered or continued to decline.

Turner, G F, M B D Seisay and N P van Zalinge

Management and Conservation of Fish Stocks of Lakes Malawi and Malombe

FAO Chambo Fisheries Research Project, PO Box 27, Monkey Bay, Malawi

The status of the major exploited fish stocks in Lakes Malawi and Malombe is reviewed. Attention is focused on the South East arm of Lake Malawi, Lake Malombe and the connecting Upper Shire River, which together yield more than 50% of the total catch of around 48,000 tonnes from the Lake Malawi area. More than 200 fish species are commercially exploited by at least 14 fishing methods. Species composition analysis and other biological information are used to investigate the interactions between gears and between fisheries in different water bodies. Traditional and commercial fisheries for tilapiine cichlids (chambo) exhibit substantial overlap in species caught and cannot be considered separately. Evidence is provided for movement of some of the tilapiine stocks between Lakes Malombe and Malawi. Interactions between tilapiine and haplochromine fisheries are discussed, and investigations into some of the haplochromine fisheries made.

Tweddle, D, G F Turner and M. Seisay

Changes in Species composition and abundance as a consequence of Fishing Pressure in Lake Malombe, Malawi

FAO Chambo Fisheries Research Project, PO Box 27, Monkey Bay, Malawi

In the 1970s, catches in Lake Malombe were dominated by Chambo, *Oreochromis* spp, large high-value fish which comprised about 90% of the 6,000 tonne annual yield. Towards the end of the decade, a new fishing method, nkacha, developed to exploit the small cichlid species, Kambuzi, which were abundant in the lake. Catches overall doubled but Chambo went into decline. Kambuzi catches now also appear to be in decline with a big increase in the use of very fine mesh nets. The current situation is that twice as many fishermen are taking the same total annual yield as in the 1970s, but the catch now consists of 90% small, low- value Kambuzi. A major extension and enforcement campaign is to be launched to attempt to restore the fishery.

Twongo, T

The Impact of Fish Species introductions on the tilapias of Lakes Victoria and Kyoga

Uganda Freshwater Fisheries Research Organisation, PO Box 343 Jinja, Uganda

The indigenous tilapias *Oreochromis esculentus* and *O. variabilis* in lakes Victoria and Kyoga have steadily declined over the last five decades to the point of virtual disappearance from both lakes. On the other hand, introduced tilapias notably the Nile tilapia, together with non-indigenous Nile perch have over the past twenty or so years become firmly established in those environments most favourable to the indigenous tilapias. This paper discusses the impact introduced fish species have had on the tilapias of lakes Victoria and Kyoga under past uncontrolled fishing regimes.

Witte, F and T Goldschmidt

Dynamics of the Haplochromine Cichlid Fauna and Ecological Changes in the Mwanza Gulf of Lake Victoria

Haplochromis Ecology Survey Team, PO Box 903, Mwanza Tanzania

Lake Victoria, the largest tropical lake in the world, was until recently a typical cichlid lake. Eighty per cent of the demersal fish biomass of this lake consisted of haplochromine cichlids. The more than 300 haplochromine species, of which 99% were endemic, exploited virtually all food sources in the lake. Since the explosive increase of the Nile perch in the early 1980s the catches of haplochromines, which were the dominant prey of Nile perch, decreased.

From 1978 till 1991 stations on a transect across the Mwanza Gulf and along neighbouring rocky shores were sampled by the Haplochromis Ecology Survey Team (HEST). Of the 123+ haplochromine species originally caught at these stations more than 80 had disappeared from the catches after 1986. The rate and sequence of the decline of the haplochromine species in the Mwanza Gulf was determined by their abundance, their adult size and the habitat overlap with Nile perch. Pelagic species and the species of the shallow littoral habitats were least affected.

Since 1988, when haplochromine catches were extremely low, a slight increase of haplochromines has been observed in the Mwanza Gulf. However, according to the preliminary data collected at the transect, it concerns an increase in the number of individuals of only a few species. Indications of ecological and morphological changes have been found for some of the surviving species.

Beside haplochromines many other fish species declined as well. On the contrary the catches of the endemic pelagic cyprinid *Rastrineobola argentea* and the introduced *Oreochromis niloticus* increased.

With the disappearance of the haplochromines and the decline of other fish species, the food web in the sub-littoral and off-shore areas of the lake changed considerably. The original fish fauna included many primary and secondary consumers. Currently, secondary and tertiary consumers dominate. The diet of top predators (birds and otters) has also changed. There are indications of an increase in phytoplankton, macrophytes and benthic organisms. Blooms of blue green algae have been associated with deoxygenation of the hypolimnion and mass fish kills.

It is of great importance for a proper management of the lake's fisheries to continue a close monitoring of the current changes in this ecosystem. From a scientific point of view it is also necessary to describe the impact of the introduction of the Nile perch. This introduction can be regarded as a large scale experiment which potentially can yield a wealth of data for a diverse array of biological subjects such as: extinction dynamics, food web dynamics, changes in life histories, phenotypic plasticity and speciation.

ANNEX 4
Discussion of Symposium Papers: Rapporteurs Reports

Friday 27 March 1992 Lake Victoria

Rapporteur H Masundire

0900-0930 J Ogari: Faunal Changes Resulting from Nile Perch Introduction in Lake Victoria (Kenya Sector)

Ogutu-Owayo: In considering causes of changes in species composition, have you considered the impact of introduced tilapias and hybridisation?

A: Could be a factor with reference to *Oreochromis esculentas.*

Pitcher: What caused the lake level rises?

A: Very high 'uhuru' rainfalls in the early sixties (1961-64).

0930-1000 D B R Chitamwebwa: The Impact of Exotic Fish Introduction and Environmental Changes on Fish Species in Lake Victoria

D.Tweddle: Have there been any measurements of biomass of *Caradina* in Lake Victoria?

A: No, but we have noted increased in *Caradina* as by-catch in trawl nets.

Mannini: Is the increase in *R. argentea* due to increase in fishing pressures?

A: Not known.

Masundire: What is Ndagaa? How does one distinguish between Ndagaa as *R. argentea* or as L. Tanganyika ndagaa.

A: In Lake Victoria, Ndagaa refers to *R. argentea.*

Q: How do you assess Ndagaa as the second most important economically species?

A: It is difficult to assess.

Beverton: Is Nile perch showing any oscillations?

A: It is an opportunistic feeder. It is therefore not easy to notice food induced oscillations as it (*Lates*) can switch in diet.

1000-1030 A W Khundongania: The Impact of Exploitation, Competition and Predation on the Changing Stocks of Lake Victoria

D Tweddle: Is there still high CPUE in the north of Lake Victoria?

A: No CPUE has obviously gone down (no figures were given).

Q: In spite of heavy fishing there are still haplochromines in Lake Malawi - why is this?

A: No comment on this question.

P Chifamba: Even if a species contributes little in the diet, the impact of predation may be significant.

A: Nile perch changed its diet once haplochromines had been eliminated.

Witte: Which species disappeared with the haplochromines?

A: Anadromous species.

Rapporteur R Sanyanga

1100-1130 P B Ochumba: Limnological Changes in Lake Victoria since the Nile Perch introduction

B Marshall: Do you have any data on any nutrient loading from factories, since the changes may be more due to eutrophication than to Nile Perch.

A: The open lake does not seem to be influenced by the catchment area. The nutrient source for the open lake is mainly from the atmosphere.

Masundire: What is the impact of the Nile Perch on the algal bloom?

A: Nile perch destroyed the ecosystem by disturbing food chain. Haplochromines which fed on algal bloom were wiped out.

1130-1200 G Mbahinzireki: Benthic Communities of Northern Lake Victoria, Uganda

J Moreau: Do you have any values for benthic biomass?

A: No.

F Witte: How can you compare values of clupeids with those of MacDonald since there was that much variation? What about seasonal variation?

A: Shall be looking at seasonal variation.

B Marshall: Isn't the clupeid *Rastrineobola argentea* eating *Caradina*?

A: It's possible.

1200-1230 T Twongo: Impact of Fish Species Introduction on the tilapia Fisheries of Lakes Victoria and Kyoga

Harris: Can you compare the fishing methods between the two lakes that produce differences in the abundance of *Lates*?

A: The causes are due to depth and seining. Seining is very effective in harvesting Nile perch.

R MacConnell: What is the effect of water hyacinth on the tilapias?

A: The water hyacinth will influence feeding and spawning grounds.

1230-1300 F Witte: Dynamics of the Haplochromine Cichlid Fauna and Ecological Changes in the Mwanza Gulf of Lake Victoria

Masundire: Is the cause of algal blooms due to shift in diet of *Rastrineobola argenta*?

A: It could be a possibility. But 40% feed on bottom debris.

MacConnell: Does *Rastrineobola* have vertical migrations like zooplankton?

A: They are now found in deeper areas. Could be due to absence of haplochromines. The distribution and migration only known after switch in species.

Pitcher: Did your survey measure DO?

A: We did, but the results are not as striking as those in the Kenya area. The Nile perch seems to follow haplochromines.

Ben Tuvia: To what extent is the diet explained by stomach studies?

A: There is no correlation between haplochromines in the habitat and those in the stomachs.

Rapporteur J Ogari

15.30-1600 E Reynolds, D Greboval & Maninni: Thirty Years On: Observations On The Development Of The Nileperch Fishery Inlake Victoria

and

1600-1630 C Harris: Socioeconomics.

Masundire: Looking at table of monetary values for 1989, the figures appear more or less equal for Kenya, Tanzania and Uganda and yet Kenya has a smaller portion of the catch.

A: The waters in Nyanza Gulf exceedingly productive. There is a lot of cross border transport of fish into Kenya. All of those industrial processing plants have created a situation of over-capacity. They are deriving an unknown percentage of their supplies from the Eastern sector of Uganda and from the Southern part of Tanzania. There is a lot of smuggling.

A Bundy: I wonder if you know how much of this increased revenue actually filters down to the fishermen?

A: We reckon that there is a substantial transfer of benefits; you have some spin-off effects coming into the picture and people are not simply taking all that extra money out and drinking it, but there is substantial transfer of money back and reinvestment into other areas, e.g. housing, business, etc.

Tweddle: What does Hong Kong do with a hundred tons of dry swim-bladders?

A: They eat them. Swim bladders also contain substances which are used in the brewing industry.

Tweddle: Secondly, what will you do when a species of fish becomes extinct? There is no mention of that.

A. I don't know the answer to Tweddle's question. The only observation I would make is that we do not yet have a good idea of what has become extinct and what hasn't. There are suggestions from researchers that in certain parts of the lake populations of haplochromines are reappearing. What has happened is that with more fishing pressure on Nile Perch you create conditions conducive to the re-emergence of haplochromine stocks - which haplochromines, I don't know.

Ochumba: The loss of species diversity is very alarming for the average graduate student from Kenya, Uganda and Tanzania who would like to work on haplochromine fish. You have to come to a European or a North American aquarium, or to the British Museum of Natural History. That is where the species are now preserved.

A: I quite appreciate that. I and can only repeat an anecdote about how the loss of haplochromines has been perceived locally. I talked to a fisherman in Speke Gulf in Tanzania. I asked him about these haplochromines they've lost now because of the Nile Perch. He looked at me and said - well that's a problem for the haplochromines!

Tarbit: In defence of the introduction and the socio-economic information that we're hearing here, sometime ago we did a calculation in ODA which showed that in the countries of Central and Eastern Africa, not only around Lake Victoria but throughout the great lakes region, the population almost doubled since 1972-3. in 1972-3 people used to eat approximately 14 kilos of fish per person per year. As a result of the introduction of Nile perch, and of Kapenta into other lakes, they are still eating 14 kilos of fish per person per year despite the fact that the population has doubled. Now I would like to point out to people that there is drought this year in Eastern and Southern Central Africa and that livestock production is likely to go down as a result of this drought over the next few years. You might well be very grateful that Nile perch and other species are being introduced into various lakes as they may be needed to maintain supplies of food.

MacKaye: I want to make a comment on Tweddle's question. How do you price the value of a fish species. You've done a superlative job here as a lawyer for the defence, and also given us a good rationalisation for putting these fish in, but we're dealing with politics here, we're dealing with big major international grants and justification projects. The question I've got, and it's one I have to deal with in Nicaragua with the introduced African tilapia, is what are we managing for. Are we managing for the short term, 30 year maximum gain? Are we managing to maintain biodiversity while at the same time trying to cope with these introduced fishes? How do we manage to maintain the economic gain you yourself so eloquently presented and at the same time bring back the haplochromis? Or is the only consideration a short-term dollar sign, which in my view will collapse once *Lates* feeds on itself and is over-fished, as almost every fishery in the world now is. Then we will have nothing and the Africans will have nothing left of their national heritage. They may not have Notre Dame, but they certainly do have some incredibly important biological regimes. That has to be addressed in terms of aesthetics. What value do you put on aesthetics?

A: I share these concerns.

Bundy: How does one quantify all this?

A: Quality of life. Job safety/job security.

Twongo: How can you get good comparative information pre-Nile perch and post perch?

A: In working with the situation in Lake Victoria, try we try to get as much as possible from Fisheries Department.

Pitcher: In Lake Victoria, and generally in Africa, there is a great deal of change taking place even without Nile perch or its fishery. How do you partition changes among these different causes?

A: We are looking at isolated lake-side communities where changes may be attributed to fishing.

Saturday 28 March 1992

0900-0930 George Ssentongo: Life History Patterns and the Resilience of Tilapine Species in the African Lakes

P. Chifamba: You indicated that the effect of introduced species is different to that of exploitation, but man can be seen as a predator. Why is it different?

A: The difference is that introduced species compete with the indigenous fish for shelter and food which adds to the effects of predation Indigenous species in Lake Malawi couldn't compete with *O. niloticus*. Tilapia spawn in sheltered areas which protects their young. *O variabilis* spawns in sandy beaches and is thus vulnerable to predation by Nile perch.

R Ogutu-Owayo: Nile tilapia was introduced into Lake Kyoga where it out-competes the native tilapines. Why?

A: *O. niloticus* is the stronger competitor for food.

T Twongo: The *Tilapia zillii* population in Lake Kyoga is shrinking. Apparently it has problems competing with *O. leucostictus*. Why?

A: *T. zillii* is found widely area in Africa. It is one of the oldest tilapias, but it is better as a riverine species. In lacustrine habitats it has problems with reproduction. It is not a mouth brooder, which do better in this habitat. It occurs in swamps but it has problems with egg survival there.

0930-1000 K McKaye: African tilapia in the Great Lakes of Latin America: Economic Opportunity or Ecological Catastrophe?

D Tweddle: What is the difference between management for three to four years and management for 100 years?

A: Management for 3 to 4 years means that people investing want their money back within a short time.

T Twongo: What caused the fish kill in California on your slide?

J Stauffer: There was a citric acid spill which killed everything.

T Twongo: Were the indigenous fish equally affected?

J Stauffer: The fish were all exotic, and the fish kill killed all the fish in the lake.

Lowe-McConnell: Your talk was very interesting. Tilapia is also used in Brazil, in the Amazon. However, there they have to control the predators to get the tilapia going. I also saw lots of tilapias in mangrove swamps on Trinidad.

1000-1030 P J B Hart: The Feeding Ecology of tilapia in Relation to Ecological Changes in Lake Naivasha, Kenya

G Carvalho: I was confused by one of the tables which showed a date of introduction for an indigenous species.

A: This was the date when it was last reported.

P Hickley: There were changes in the MSY. It does not matter that MSY is probably overestimated; it is just to demonstrate that the lake is under-exploited. Yesterday we heard that the Nile perch was not that bad in Lake Victoria. Large-mouth bass in Lake Naivasha feeds mainly on invertebrates. Should the Nile perch be introduced to Lake Naivasha?

A: No! A lot of people depend on the tilapia fishery. If Nile perch was introduced, the yield would go up for a few years and then probably crash.

P Hickley: I agree. I wouldn't like to see that either.

D Tweddle: What caused the massive crash in the number of canoes?

A: No: the numbers just levelled off.

P Hickley: As the catches decreased the number of canoes went down. Perhaps they all went back to Lake Victoria. (Laughter).

28 March 1992, LAKE MALAWI

Rapporteur M Mtsambiwa

1400 - 1430 D. Tweddle: Changes in Species Composition and Abundance as a Consequence of Fishing Pressure in Lake Malombe

Tarbit: Is the decrease in the average value of the catch regarded as a tragedy? Is more conservation required or is the fishery self-managing? Would the allocation of use rights be a valid management strategy?

A: UN aid and UNDP are planning to help and there is collaboration between the current FAO project and GTZ, who are looking at a similar situation in Lake Chiuta. If the fishery can be sustained, we are reluctant to do anything. But there are years of lower catches and there is a difference in catches between east and west shores. Don't think decreasing mesh size is sustainable. We hope to keep fishery with nets, it can be sustainable if mesh size is increased.

Twongo: Has there been a change in stocks due to the Kambuzi seine fishery?

A: We suspect there has, but no evidence. We have considerable problems with recognition of species.

Harris: Curious about figure with two different catch recording systems?

A: The newer recording system appears to be better as it is more sensitive, but the old system gives better total catch.

Harris: The old system seems to generate fluctuations which are not apparent in the new.

A: It is sensitive to sampling with relation to the gill nets. The nets are long and catch high numbers. If the nets are included in the survey, good estimates are expected, bad if they are not included. Better quality data is obtained using gear survey data. However this is difficult to estimate because in poor conditions gear and boats are packed away in the fisherman's houses.

Blake: Could the decrease in the Chambo fishery be seen as beneficial? More fish are available to the poor, due to low prices.

A: True, but it is not a stable situation.

Q: Linking into the question of less valuable fish meaning more food for the poor, what about a commercial approach to the fishery? Has an alternative form of income been identified for people selling chambo? What direction will the fishery take?

A: You can ask! All inland agricultural areas have been taken. The area also prone to flooding. There is industrial development at Mangochi. Effort reduction is not necessarily due to a reduction in the resource. but rather to outside factors such as fuel costs.

1430-1500 R Makwinja and G F Turner: Species Composition Changes of Demersal Cichlid Communities as a Result of Trawling in Southern Lake Malawi

Harris: Differences in CPUE and effort could be due to a fluctuating fishery. A bad year could induce a higher effort and result in the same catch. In a good year, marginal effort could apply - older boats could be brought out thereby affecting the estimate of effort and therefore reduce CPUE.

A: Not to a great extent. There is a limited amount of vessels: 5 pair trawlers. There is little poaching. A fluctuating CPUE could depend on the state of the boat.

Beverton: Would you support the evidence published by Tweddle and Magasa in 1989? Was the estimate of surplus production accurate?

A: The MSY might be right, but it has not yet been reached. However, fopt has been exceeded with no effect on CPUE, except in the first three years of exploitation.

Beverton: The '89 estimate was not too bad?

A: With the exclusion of recent data, no correlation has been found as in the '89 paper.

Tweddle: In defence of the '89 paper, the intention was not to set fopt or MSY, but to discuss changes in the fishery, such as changes in efficiency and the effect of an increased mesh size on catches. It also examined cycles and a strong year class of Utaka.

A: The primary point is that haplochromines show a high degree of resilience in terms of CPUE as a result of species composition changes. However, there has been a devastating effect on the species composition. We should propose a closed area as refuge.

1500-1530 G F Turner: Management and Conservation of Fish Stocks of Lake Malawi and Lake Malombe

Beverton: Was the VPA length-based?

A: Yes. We are trying an age-based analysis.

Beverton: Estimates of production provided unexpected results.

A: All work done on species composition was based on one year's study. Looking at the 35mm trawl for Utaka, few were found in the catch which was composed mainly of *Diplotaxodon*, a species rare in the catches of 1970.

Tarbit: Why has *Diplotaxodon* taken over?

A: It is not known. Utaka are an inshore group. The SADACC pelagic project at Senga Bay showed that there are not many in open water. Could have been a decrease due to seining. Utaka breed in shallow water and are common in pair trawls. They are susceptible to fishing. *Diplotaxdon* have lower fecundity and should not withstand fishing so well, but they don't breed inshore.

McKaye: Agree that Utaka fishing occurs on the breeding grounds. Anything known about the breeding biology of *Diplotaxodon*

A: Males are never caught on the breeding grounds. Five to six eggs are produced and they breed all year round. They are a midwater species. There could be some benthic species.

Bundy: Have you identified certain areas for reserves? What hope is there of these being established?

A: World Bank has set aside money for demersal stock assessment. There might be ODA funding? There is also a possible project by Global Environment Fund to sort out species composition.

Carvalho: With the confusion over taxonomy, have any attempts using biochemical genetics been made? What are the problems?

A: There are two different approaches to taxonomy of these haplochromines. One used by Ribbink is to grade by colour, feeding habits, distribution and to give an English name. Alternatively, a long time is spent over species, using morphology and involving type specimens - these few could be named leaving another 150 species without a name. There is too much concentration on this. I advocate the first technique.

Q: Do the chambo hybridize?

A: They are difficult to tell apart!

Q: The overlap could be between hybrids.

A: It may be asked how they may diverge in the first place.

Rapporteur M Pearce

1600-1630 A J L Ribbink: Conservation in the Lake Malawi National Park: A World Heritage Site

E Reynolds: How important is the export aquaria trade to the Malawian economy? And how many exporters are there? .

A: Exports are worth 1.2 million kwacha a year (about £300,000). There is now one exporter although there used to be several. One is better, no competition, no over-fishing on small stocks.

Q: Is there any fishery management within the park?

A: No fishing within 100 metres of the shore except from traditional beaches.

Tweddle: Large amount of invisible earnings - e.g. tourists from the park and aquaria trade.

Q: How many species are endemic to the island of Thumbi West?

A: 53 species (75%) endemic in the area, but Thumbi West very close to the mainland and other islands and species move.

K McKaye: Since there has been data from Thumbi West since 1970, what evidence is there that any species is diminishing?

A: No evidence.

Q: How long can the culling/protecting programme be continued?

A: Indefinitely, as people are being trained who will see it through into the far future.

Twongo: How does endemicity occur, what barriers are there to establishing endemicity?

A: Fish are sedentary, linked to substrata, there is no gene flow over large distances,

Q: If fish come from outside which are not endemic why should it pose a problem?

A; It is possible for ecological equivalents to evolve at different locations around the lake.

Hartnell: Will there be a time when culling will no longer be necessary?

A: if there is any observed economic or other benefit from the introduction, then there will be no need for culling.

16.30 - 1700 J R Stauffer Jnr: The Impact of Intralacustrine Introductions on Endemic Faunas of Lake Malawi

Ribbink: What is the importance of dumping of unwanted fish by aquaria collectors in causing dispersion as compared to natural dispersion?

A: It's very important. There have been reports from Lake Tanganyika of some problems.

Pearce: In Zambian waters the problem was there. Now collectors kill unwanted fish.

McKaye: Speciation due to hybridisation occurring amongst African cichlids was released into the wild in Florida by aquarists. Parasitic bivalves originating from Lake Malawi can be found in Florida.

Carvalho: The principal component analysis was used to infer introgression had occurred. What other evidence is available?

A: Also done other work to look at allozymes. From 34 allozymes only 4 were polymorphic. We have looked at other techniques such as minisatellite DNA analysis. Yes, the possibility for introgression exists.

Monday 30 March

Rapporteur: Chitamwebwa

0900-0930 R Lowe-McConnell: African Lakes Revisited

Professor Tuvia: Since *Oreochromis niloticus* is the most used fish in aquaculture, isn't there the threat of accidental introductions into more lakes?

Answer: Only Lake Malawi has no *Oreochromis niloticus* at present.

Q: Is *O. niloticus* able to eat and digest blue-green algae?

A: The fish is able to eat and digest blue-green algae by changing the pH of its stomach contents.

G Turner: *Oreochromis karongae* in Lake Malawi is also able to eat and digest blue-green algae.

9300-1000 B Marshall: Why is *Limnothrissa miodon* such a successful introduced species and is there anywhere else we should put it?

D Tweddle: Was the disappearance of *Salvinia* on Lake Kariba linked with the upsurge of kapenta?

A: They introduced a grasshopper to eat up the weed. The weed declined before the upsurge of kapenta, but the kapenta increase could be linked to release of nutrients caused by the weeds collapse. I have also speculated that kapenta may have reduced the nutrients available to the weed and helped to bring about the collapse.

D Tweddle: Is the water hyacinth also present in Lake Kariba?

A: The weed has not yet invaded the lake, though it is reported in the Zambezi system.

Mtsambiwa: What evidence is there to show that *L. miodon* spawns in shallow waters?

A: No eggs have ever been sampled from the lake, but the larvae and juveniles are always seen in inshore waters.

Professor Beverton: Is there any evidence of competition between *Oreochromis* and *L. miodon*?

A: There is no obvious competition. *O. mortimeri* continues to flourish in the lake in the presence of *L. miodon*.

G Mbahinzireki: Could kapenta be introduced into Lake Victoria to supplement *Rastrineobola argentea*?

A: No - from the lesson already learnt with the Nile perch, no fish should be introduced into the lake and other natural lakes.

D Tweddle: Cladoceran copepods in Lake Victoria could possibly account for the increase in biomass of *R. argentea*. Are copepods present in Lake Kariba?

A: I don't know. I haven't come across them in literature.

1000-1030 H H de Iongh: Impact of Kapenta Introductions in Lake Kivu

M Pearce: I have found literature where they mention the presence of shrimp in Lake Kivu, but you have not mentioned them as food for kapenta in your talk.

A: The kapenta does not only eat shrimps but a wide range of organisms such as insect larvae, adult insects, chironomids, etc. It is a somewhat opportunistic feeder. But pelagic plankton accounts for most of its food.

J Ogari: Is there a difference in size of the fish caught?

A: Inshore catches comprise small juvenile fish but off-shore catches are made up of big adult fish. There is no obvious change in biomass.

B. Marshall: Juvenile kapenta are always found in shallow waters.

M Z Mtsambiwa: Do you know where kapenta in Lake Kivu spawns?

A: As the previous speaker has said, it is almost impossible to trace the eggs of kapenta, but the larvae and especially juveniles are always found in shallow waters. However there is no proof that they spawn in shallow waters.

F Witte: Is it true that Lake Kivu lacked a species occupying the pelagic zone? In Lake Victoria it was taken for granted that no haplochromines fed on zooplankton, but later some species were discovered to be occupying this niche.

A: No pelagic species other than kapenta has ever been caught in the pelagic waters even with gill nets. I have never heard of a species which existed in the pelagic zone before the introduction of kapenta.

P Mannini: Did you carry out total mortality estimates?

A: Total mortality was very high, in the region of 5.

P Chifamba: What are reasons for the observed decline in catch per unit effort?

A: Probably some fish were sold elsewhere before being landed such that the actual values were not recorded.

M Z Mtsambiwa: Have any growth parameters of the fish been determined?

A: Samples of growth parameters were taken but have not yet been analysed.

R Beverton: Are there any predators of kapenta on the lake?

A: There is no pelagic predator except *Clarias* in shallow waters.

1030-1100 H Masundire: Seasonality of Zooplankton Abundance and its Relevance to Kapenta Yields

B Marshall: Did kapenta removal increase the biomass of zooplankton?

A: Harvesting of kapenta releases pressure on planktonic food allowing it to grow fast and big.

D Tweddle: Is there a relationship between nutrients and kapenta yields, besides that of zooplankton and kapenta yields?

A: Yes, the nutrients are related to kapenta yields as well.

J Tarbit: Could not the density of zooplankton induce aggregation of kapenta and therefore influence catchability?

A: Possibly, but there is no evidence so far.

T J Pitcher: Improvement of fishing methods could result in increased catches without real increase in number of boats.

J Kolding: Schooling of kapenta in Lake Kariba was not detected with echo-sounder.

Rapporteur Dr T Twongo

1130-1200 H Kawanabe: Unique Ecological Diversity of Littoral Fishes in Lake Tanganyika

Ribbink: Why do you consider Lake Tanganyika to be the evolutionary cradle of cichlid fish fauna of other African Lakes like Malawi and Victoria?

A: The evolutionary lineage of the cichlid fauna of other African lakes is available in Lake Tanganyika.

Tweddle: Your evolutionary data on the cichlid fishes of Lake Malawi go back to only about one million years. However, data from other sources shows Lake Malawi may be 20 - 25 million years. What is your comment on this?

A: Not in a position to comment.

Ribbink: Are scale-eating fishes specialised to eat only scales?

A: While young they eat plankton. Adults are observed to take mainly scales, plus mucus from scaleless fishes. Inclusion of zooplankton has not been ruled out.

Masundire: Did you suggest lack of haplochromines in Lake Tanganyika?

A: No. Haplochromines are certainly present in the Lake.

Lowe-McConnell: Could you supply references for your source of data to enable follow-up reading?

A: Yes references will be provided.

Masundire: African lakes have very low zooplankton biodiversity when compared to that of temperate lakes. On the other hand African lakes tend to have a diverse fish fauna. Do you think there is a cause effect relationship between the two in the case of the African lakes.

A: I can't attempt the linkage but the biodiversity of other invertebrate organisms such as molluscs is similarly high in African lakes with a diverse fish fauna.

Chifamba: Have any studies been made to show the effectiveness of fish reserves as promotion of fish biodiversity?

A: Studies are still underway.

Ogutu-Owayo: Why is there a high fish species diversity in Lake Tanganyika in the presence of the native Lates species and relatively low diversity in other lakes like Turkana and Albert where the Nile perch is present?

A: This could be attributed to subtle adaptions on the part of Lake Tanganyika cichlids to reduce predation pressure.

Chitamwebwa and MacConnell: The great diversity in lake shore and lake bottom morphometry in Lake Tanganyika provided cover for the cichlids and facilitated evolutions of diversity.

Roest: How were the catch figures extrapolated to total catches.

A: The lake was zoned and estimates made per zone. Missing data was calculated and total catch assumed 750 fishing units with 150.

Kolding: Why is there no correlation between the predator (mukeke) and the prey (*Stolothrissa*)?

A: Prey adapts very rapidly - e.g. spawning in *Stolothrissa* occurs when catch is lowest - the fish quickly moves inshore. Note that other predators correlate well with the prey.

Rapporteur: G Mbahinzireki

1400-1430 M Pearce: Some Effects of Exploitation on the Structure of the Pelagic Community in the South East Arm of Lake Tanganyika

Marshall: Are there were more planktivorous fish species in the community?

A: Not quite certain.

Masundire: When do fish mature in fished waters?

A: Size at first maturity is estimated at 7cm which could be an under-estimate. Normally fish in fished waters grow faster.

Twongo: Why are fish in industrially fished areas bigger?

A: I do not know.

Tweddle: Stress due to fishing sometimes reduces competition and creates favourable conditions for growing to a large size.

Tarbit: What is the effect of seining on the fishery?

A: Juvenile fish mortality was high.

Q: What recommendations would you make for the fishery on the lake?

A: Fishermen should be encouraged to fish in the off-shore waters to give juveniles a chance to grow. They should fish out more of the predatory species which would otherwise prey on the clupeids.

Kolding: What is the fishing mortality of that part of the lake?

A: Not sure, but it is high, about 3 - 5 per year.

1430-1500 I Cowx: Changes in Fish populations of Lake Itezhi-tezhi following inundation

Kolding: Following the inundation and filling up of the Kariba dam, there was a significant drop in the species numbers and diversity. Has this observation been seen in the Itezhi-tezhi?

A: Riverine fish species tolerate fast flowing waters and tend to die off compared to slow moving species that easily colonize and thrive in newly filled dams. Riverine cyprinids have almost disappeared from Itezhi-tezhi, while cichlids and clariids now dominate.

Tweddle: What sampling methods were used in the fishery?

A: Significant fish catches were made with gill nets during dam level rise. Seines did not show any catch. As the dam level rose, some species of fish may have invaded the dam from the catchment area.

Marshall: Drought and low rainfall in the region are likely to lead to the largest draw-down in history. As the littoral areas used for spawning by some species contract, it is likely that the pelagic species like the sardines will dominate in the introductions in reservoirs.

Lowe-McConnell: Do you have any information on whether *Limnothrissa* could have found its way into the Kafue river system?

A: There are positive indications that *Limnothrissa* is a recent introduction in the area.

Mtsambiwa: The origin of *Limnothrissa* introduction into Lake Itezhi-tezhi was from Lake Tanganyika.

de Iongh: Was there any other pelagic clupeid species in the lake before the introduction.

A: Only *Alestes* was present.

Rapporteur P Ochumba

1530-1600 M Z Mtsambiwa: Feeding Behavioural Changes in Tigerfish *Hydrocynus vittatus* following the introduction of Kapenta *Limnothrissa miodon* in Lake Kariba

Marshall: The big purse seiners caught the tigerfish in large numbers, while the present small purse seiners and gill nets may not efficiently catch them because population is low. This could bias the data.

Chifamba: The relationship between the abundance of tiger-fish and the sardine in Lake Kariba.

Mbahinzireki: Have any studies on the seasonal fluctuations of kapenta catches been related to zooplankton studies.

A: A zooplankton bloom normally occurs in Kariba between June and July before an expected increase in kapenta catches. No specific correlations were made. Definitely a time lag exists between zooplankton and kapenta blooms.

Ogari: If you consider the tigerfish to be an opportunistic feeder, then how would you explain its catch to drop following drop in the kapenta catches?

A: Smaller tigerfish are found inshore while larger ones are off-shore - what smaller tigerfish was not determined in the study. It's probable that more tigerfish should be associated with large kapenta populations in a typical predator-prey fashion.

Tarbitt: Could the decline in the tigerfish catches be related to low flow, agricultural wastes and the use of pesticides in the catchment area in controlling tsetse flies?

A: No date was available in this study.

Marshall: There was probably a recruitment failure due to drought between 1987-88, and this could have resulted in low tigerfish catches.

Mtsambiwa: The catches could also be attributed to off-shore fishermen that fail to report the catches to fisheries officers.

Tweddle: Abundance of tigerfish from the Kariba Anglers Association and the Tigerfish Tournament data show a gradual decline with time.

1600-1630 R A Sanyanga: Changes in Abundance of *Synodontis zambezensis* (Brown Squeaker) in Lake Kariba, Zimbabwe.

Chitamwebwa: Is it possible that the gill net mesh size of 4.5 inches used could have missed large individuals in the fishery?

A: Gear used in the experimental studies were targeted at large specimens. *Clarias macrocephalus* was missing in the catches. Smaller gill nets caught cichlids present in the fishery.

Marshall: A species of *Barbus macroghensis* could be used to indicate changes in fishery of the lake.

Masundire: *Synodontis* have been reported at 60m depth in the lake. Is there any scope for its commercial exploitation as a source of nutrition?

A: The fish is eaten but not a high priority in the diet. Some people use it as a fishmeal. It is likely to be more popular in the fishery as the catches continue to grow.

Tarbitt: The Malawi *Synodontis* feeds on molluscs. What is the benthic fauna in Kariba?

A: More studies are proposed. Ten specimens examined during the study showed that their gut had molluscs.

Tweddle: *Synodontis* are abundant in the open lake and are caught by gill netters. Some may feed on *Microcystis* algae and probably many more other things.

A: Records from the 70s show a progressive increase in catches in the fishery. This could probably be explained by the low predation, under-exploitation and dislike by fishermen as it fouls their nets.

Chifamba: Where is the highest abundance of the fish by depth?

A: In terms of CPUE, the highest catches were realised at the 12m depth contour.

Twongo: Does the fishery trend observed in the study correlate with the environment and new development strategies in the catchment?

A: During the impoundment, cichlids dominated the fishery, when the dam stabilised their breeding sites were lost. The lake turned from eutrophic to an oligotrophic one and kapenta fishery now dominates.

1630-1700 M M Gashagaza: Current Research on *Limnothrissa miodon* of Lakes Tanganyika and Kivu

Roest: I should warn about using date such as that from Burundi. It is not reliable and so one has to be careful when looking at such data.

Mtsambiwa: What is the effect of small sized fish on the fishery?

A: No idea.

Bundy: Did you separate the two species in the catch?

A: No. They were mixed. However, currently the species are being separated and data is being analysed.

Ogari: Where are the fingerlings of other fish species when Ndagaa is preyed upon?

A: I concentrated on ndagaa only.

1700-1730 M N'Sibula: Fishery Biology of the clupeids, *Stolothrissa tanganicae* and *Limnothrissa miodon* in the North-Western end of Lake Tanganyika

Roest: Why do you find fish larvae in shallow waters in Lake Kivu?

A: No idea.

Masundire: Is the vertical migration of fish larvae during day time associated with avoidance of predation?

A: He promised to find an answer in future.

H H de Iongh: While working on Lake Kivu he found that fish would feed early in the morning and digesrion would follow during day time.

Moreau: Confirmed that this was common among fish.

ANNEX 5: Reports of Round Table Discussions: Rapporteur's Reports

Lake Malawi

Rapporteur Dennis Tweddle

Ssentongo's paper

Harris: In relation to success or failure of a tilapia introduction, how can one assess factors likely to affect outcome.

Turner: Can get pointers from life history studies but can never be certain. In the past they have been done on a hope for the best basis. *Oreochromis lidole* seems to be a desirable species but there are questions on whether it would succeed in for example the Aswan Dam. Nile perch predation etc. cannot easily be predicted in advance.

Ribbink: Stressed one should only consider introductions to artificial impoundments, not to old lakes with established faunas.

Ssentongo: Mentioned that many similar looking lakes in Uganda were stocked with Nile tilapia with variable success. In one *O. niloticus* did very well but in another they failed.

Lowe-McConnell: Discussed Rwandan lakes - *O. macrochir* hybridises there with *O. niloticus*.

Pitcher: Raised questions. Why consider introductions only to artificial impoundments? Are detailed ecological studies necessary to predict success of failure? Can one predict changes in life histories after introductions?

Ribbink: Suggested one can anticipate life history changes in many cases, provided one looks at possible niche shifts and carefully studies ecology beforehand.

Harris: What is a successful introduction?

Ogutu-Owayo: Same as a successful agricultural crop.

A discussion on sport fishing then developed. McKaye is pushing eco-tourism in Nicaragua. Promoting sport fishing for predators allows exploitation of tilapia for food - an optimal management scheme. Sport fishing is developing at least in Kenyan waters of Lake Victoria.

Bundy and Pitcher: After an introduction, how does one manage optimally?

Pitcher: Aid donors often carry out crazy schemes - reasons for Nile Perch introduction were colonial angling, secondary reason, perhaps an excuse, to feed on inedible haplochromines.

Turner: In the long term would demand have risen to make haplochromines desirable?

Tweddle: Never get the chance to find out, haplochromines were popular on lakeshore at Entebbe in 1971-2, but not at that time inland in Uganda.

Marshall: The haplochromines may well come back in the long term. I think that *O. nilitocus* is the biggest threat in Africa.

Tweddle: We certainly don't want it in Lake Malawi and no exotica of any sort are allowed in the Lake Malawi catchment area.

McKaye: Talked about Somoza in Nicaragua and rainforest destruction in Brazil supplying beef to US. Should manage for biodiversity. Analogy of rivets all holding an aeroplane together.

Turner: Who do we want to feed? The elite with big perch fillets? Or the rest of population with small cheap fish.

Reynolds: Only 20% of the Nile perch is exported, lakeshore people are still eating the rest.

Harris: Many Victoria fishermen cannot afford to upgrade to perch gear and are losing out.

Lake Naivasha

Pitcher: Do we treat it as an experimental lake and try other introductions?

Tweddle: Tigerfish!

Cowx: Worth considering, Black Bass are eating crustacea, not much fish. Room for predator, also pelagics - *Limnothrissa*?

Marshall: *Mormyrus longirostris* is spectacularly successful in Lake Kyle.

Ogari: Naivasha may dry up.

Other delegates: More reason to feel free to experiment

A general discussion followed, including Pearce, Marshall, Ssentongo, Tweddle on susceptibility of lakes to perturbations caused by introductions. Those most vulnerable are those with diverse specialised faunas. Lakes with only a few generalised species can cope with added species.

Moreau Ecopath Paper

Pitcher: How do we use ecopath? Can we use it for prediction of future?

Moreau: Ecosystem has to be in equilibrium, the main sensitivity is to the feeding regime of the fish. Ecopath cannot really predict changes.

Pitcher: Can you massage a model given data on changes to be made?

Jeppe: Ecopath is pure conjecture. Tried on two Lake Turkana scenarios. The model showed that predation had gone up by 200%. Thus, whatever Ecopath says, you still have to follow up with detailed studies.

Lake Turkana

The pelagic food chain collapsed with the fall in lake level, no new nutrients being washed in during low rainfall years.

Marshall: Stressed that in any studies - on fish or anything else - one must be aware of the possibility of environmental changes triggering changes in the ecology, fish yields, etc.

Lake Malawi

Pitcher: Nile perch yields far more fish and economic benefits than haplochromines ever could have done in Lake Victoria. Why not put it in Lake Malawi?

Tweddle: Lake Malawi is nowhere near as eutrophic as Lake Victoria. One should compare Victoria with Lake Malombe instead, where the current yield of 10,000 tonnes per year is as high per unit area as Lake Victoria production. One should also remember that Victoria could have produced similar yields to the present, but based on a properly managed haplochromine trawl fishery.

A general discussion on the aquarium fish trade followed. The popularity of Malawi cichlids abroad has many benefits to the country. The actual monetary value of the fish themselves is about K1 million. This is perhaps much less important than the tourism which is generated. Numerous aquarists are attracted to the country to see the fish in their natural environments. Lake Malawi National Park generates more tourism revenue than all the other national parks in the country put together. The publicity generated by the sale of fish abroad is of great value to the country.

Limnothrissa; Lake Kariba; Lake Tanganyika

Rapporteur Brian Marshall

The discussion began with a consideration of the biology of *Limnothrissa miodon*. In Lake Tanganyika it was generally believed that its larvae could not be separated from those of *Stolothrissa tanganicae*, but recent work in Zaire suggests that it can be done. The separation is based on a microscopic examination of their mouths and melanophores and it was possible to separate them when they were only 2mm long. Larval *Stolothrissa* (5mm long) had been recorded in deep water whilst larvae *Limnothrissa* were in shallow areas. This would confirm earlier ideas about breeding separation in these species. The fecundity of *Limnothrissa* was very high and may have contributed to its success. However, estimates of fecundity should be treated with some caution as there was not always a close correlation between egg numbers and subsequent recruitment. This was because it is now known that most teleosts seem to be batch spawners, laying a few eggs at a time.

The most important factor was the number of fry that survive. The Lake Malawi cichlid *Diplotaxodon* species was a good example of this because it only lays 6 - 10 eggs but, because it is a mouth brooder, there is no larval stage and the fry do not become free- living until they are about 10mm long.

Fry survival is obviously an important factor in determining the size of a cohort but the overall determinants of cohort size in these pelagic fish were still poorly understood. Although there was no evidence of cohort failure in Limnothrissa it may have occurred in the Lake Malawi Usipa (*Engraulicypris sardella*) whose population fluctuates considerably.

Part of the problem was that cohorts could not be separated by conventional length- frequency analysis, especially when samples were taken form commercial catches. it might be possible to use this method in specially designed programmes but their analysis of daily rings on otoliths might be more useful.

This method could fail in the largest fish and it would be desirable to have an independent method. However. this problem is likely to be minimised by the fact that few large fish occur and the most important problems relate to the early life history of these fish.

The life history variation in Limnothrissa may have contributed to its success but this characteristic can be found in other fish species. Marshall's idea that *Limnothrissa's* success can be measured by comparing its biomass, expressed in terms of volume, was discussed but there was no agreement on its usefulness. It was generally felt that the conventional measure of biomass, i.e. in terms of area, was adequate.

The relationship between zooplankton and *Limnothrissa* was an important aspect. It was clear that the fish has had a major impact on the composition of the zooplankton but it was not clear if some generalised measure of predation could be attained. The notion that the cladoceran/copepod ration indicated the level of predation was a beginning, although the fact that this ratio had recently changed in Lake Kariba suggested that it might not be entirely valid.

The idea of predicting *Limnothrissa* yields from the abundance of zooplankton could be a useful technique. However, the exact relationships were still unclear and the reasons for zooplankton/sardine correlations warrant further investigation. In Lake Kariba, where much of this work has been done, there was a strong seasonal pattern dictated by the limnological nature of the Lake. Both species might therefore be responding to this seasonal pattern.

Work by Gliwicz in Cahora Bassa had shown that *Limnothrissa* was an extremely effective predator on zooplankton. This had produced a distinct monthly cycle, with their numbers dropping at Full Moon when they could get no protection from the turbidity of the water.

The natural mortality of the sardines was very high and its causes were unclear as was the fate of the fish that died. Large numbers of fish evidently die during the year, possibly because they reduce the zooplankton. If they move into shallow water to seek more food they would be more vulnerable to predation from the inshore species.

Limnothrissa is known to be cannibalistic in Lake Kivu but, as yet, there is no evidence of cannibalism from Lake Kariba. However, the addition of 2% mortality in the ECOPATH model applied to Kariba data brought about a high level of mortality. However it was possible for fish populations to withstand high levels of cannibalism. Examples include the Hake which has up to 40% cannibalism and the Pike from 5 - 20%.

There is some evidence that *Limnothrissa* may feed on smaller fish under the influence of light attraction and there was a need to investigate this phenomenon in more detail. It was pointed out that in Lake Kivu cannibalism was most common in large female *Limnothrissa* and there was some speculation that they used this as a food resource prior to spawning.

The fish fauna of Lake Tanganyika has strong links with the Congo fauna and the suggestion that it was the cichlids in the Rift Valley lakes was discussed. The numerous haplochromis lineages in the lake may reflect its great age although they may not have originated in the lake.

Different genera do not, of course, indicate different lineages. Lake Malawi has more genera and more species than Lake Tanganyika but there is probably only one lineage. It is not clear why there should be more species in Lakes Malawi and Victoria. There is a possibility of convergence between cichlids in Malawi and Victoria and non-cichlids in Lake Tanganyika. Another possibility is the greater deoxygenated layer in Lake Tanganyika has restricted speciation in that lake.

It would be dangerous to assume that all lineages speciate at the same rate but further work needs to be done on this aspect. It is now known that there are morphologically similar but genetically distinct and it is possible that the lineages in Lake Tanganyika are now more stable than in the other lakes.

The role of predation was also considered because Lake Tanganyika is distinguished by the presence of various predators species. This idea was first expressed by Worthington who suggested that the presence of *Lates* might explain there are no haplochromine species flocks in Lakes Albert or Turkana. A lack of cover in these lakes as well as their much younger age might also contribute to this.

There was an interesting disparity between the diversity of plankton communities in temperate and tropical waters. Most temperate lakes have more plankton species than tropical ones but it was not clear why this should be so. Speculation centred around the roles of glaciation and predation; it was also pointed out that mobile, widespread species will not speciate. There were some endemic species in Lake tanganyika but most tropical planktonic species were widespread.

The question of setting up aquatic parks was also considered. The problem of how big such parks should be was related to the number of species one wanted to conserve. In general, the larger the area the more species will be conserved, but small areas might be suitable. This is because small areas in these lakes may hold diverse habitats, and because of because the high degree of endemicity amongst the cichlids. Small areas were, of course, more difficult to manage.

It would be possible to set up similar parks in Lake Victoria because some haplochromines still survive in rocky areas. These areas are under pressure because many people now fish for *Oreochromis niloticus* and catch haplochromines as well. The haplochromines are also caught for use as bait for Nile Perch.

The possibility of setting up reserves in Kenya, Tanzania or Uganda was considered but nothing has been done because no-one knew which species had survived and where they were. However, it was known that they could survive in rocky areas where they were less vulnerable to the Nile Perch.

All three countries were serious about conservation in Lake Victoria but felt that more data were needed. In Tanzania, there was one island National Park and another which was a Nature Reserve. Fishing was prohibited on both islands and haplochromines seemed to be more abundant in their waters. Oreochromis variabilis can also be seen there. In Kenya, a small facility was being set up to rear Labeo victorianus and Oreochromis esculentus with a view to restocking the lake.

It was important that conservation measures should involve the local people who should be able to see its benefits. This would be difficult in Lake Victoria because, in contrast to Lake Malawi, the visibility in the water is low and the fish cannot be seen readily. Nevertheless, this approach should be considered as a rescue operation.

The idea of establishing artificial reefs was also considered but there were unlikely to have much effect in Lake Victoria. At present the fish that live in these habitats are reasonably safe whilst those that do not have gone. However, it was pointed out that anglers are able to catch large Nile perch from the rocks and were they there because there were more haplochromines.

Lake Victoria

Rapporteur: Rosemary Lowe-McConnell

Of the 14 issues suggested by Tony Pitcher for discussion (answers needed) the following were chosen by him:-

What is happening and why?

1. Nile Perch (a) numbers stocked? (b) when first seen? (c) why the 10 year delay in explosion?

(a) Numbers stocked by Uganda Fisheries Department (Witte) Entebbe 35 in May 1962 [16-43a], 339 in September 1963 (Lake Albert stock) making a total of 374. Numbers stocked by Kenya Fisheries Department were 8 at Kisumu late 1963 (Lake Turkana stock). Lake Kyoga was stocked in 1955 and 56 and Lake Kyoga fish spread 80 miles in 7 years (Gee in EAFRO Anne Rept 1962/63, p.14)

(b) First sightings were, according to Chitamwebwa, near Mwenza in 1968 (around 20 caught in 2 net) and from 1972 occasionally saw small ones. (Fishermen wondered what they were.) In Uganda 1972 Tweddle saw huge one (circa 200 lbs) near Entebbe and half a dozen smaller ones in a shoal. NB two found in Lake Victoria (May 1960, November 1960) prior to stocking (R. Lowe-McConnell) - whether this was due to Owen Falls escapes, anglers or dams and ponds flooding the lake.

Witte: In the Mwanza area, the fact that from the early 1980s sub-adult and adults were found (no juveniles until the 1985 boom) suggests there were migrants to the area. We could not have missed seeing them earlier.

(c) Why the 10-15 year delay? There were big fish present for angling but no explosion. Hypotheses suggested: Richard Oguto Owayo, quoting Jackson, thought that haplochromines were kept low by other predatory fish c 1971-79, and then increased because of an increase in the food supply of Nile perch, allowing Nile perch to increase and move to other areas.

Turner thought that larger haplochromines were eating juvenile Nile perch until the larger haplochromines were removed by bigger Nile perch, i.e. the haplochromines were controlling Nile perch.

Reynolds - lack of capability to catch Nile perch at this time so dont know how many there really were?

Witte: HEST trawled over large areas and would have found them if they were there. HEST saw a sudden increase, but in 1969-70 not throughout the lake.

Cowx thought that fishermen were not reporting unusual species, quite usual. Pearce agreed that fishermen knew of them before they were officially recorded and Tweddle maintained that fishermen knew of them in the early 1970s.

Conclusion: Delay in exploding population was real, not simply an artifact. Reason why a mystery still.

2. Caradina

Witte: Increased in the early 80s - only numerous 1984-5 in Mwanza area. It was first recorded in 1979 as strange; then colleagues caught large numbers, i.e. after the Nile perch increase and the haplochromine decrease.

Witte could not imagine that detritus food common to the haplochromines and the shrimp would be limiting.

Chitamwebwa: Observed *Caradina* clumps last year for first time in shallow water, clinging to rocks and dying en masse.

Ochumba: Must not forget anoxic factor. What can *Caradina* withstand? They might have to move to shallower or impure water although they are still present in deep water. Report of R Lowe McConnell's observations of *Caradina* and stunted haplochromines in Kisumu area at deoxygenated depth.

Reynolds asked about the possibility of harvesting *Caradina*. Only as by-catch used as animal food.

Pitcher spoke on the need for knowing production rates as well as biomass for *Caradina*. Also contacting people with experience of quantitative sampling of such animals, which was difficult.

Witte: How to sample them? They clog trawls.

A discussion on lift nets followed.

3. Anoxia and what causes it.

Brian Marshall: Lake Victoria is the most vulnerable of African lakes to eutrophication.

If Lake Victoria mean depth is 40 metres the retention time is 100 years. If Lake Tanganyika mean depth is 500 metres the retention time is 1000 years. If Lake Kariba mean depth is 30 metres retention time is 3 years. Then twice P loading 2/t = 0.4 for Victoria, 0.5 for Tanganyika, and 10 for Kariba. Thus twice the load pushes Victoria into eutrophication very much more easily than for Tanganyika or Kariba.

Marshall: Ochumba's graph of papermills, brewery wastes, sugar discharging into Mwanza Gulf bottom waters means serious pollution. Victoria has 100 year retention time. c.f. Kariba 3 years retention time. Urgent need to find nutrient loading of the lake. Nile perch may blind us to considering a more serious problem of eutrophication.

Asked why fish kills? Why don't fish move away? Marshall explains re Seiches (cf bathwater) of anoxic water leading to fish kills.

Hybridisation Discussion

Would tilapia hybrids be fertile or sterile? Cyprinid hybrids are sterile and hybridisation is used for sterile tilapia for fish culture.

Many tilapia crosses produce fertile hybrids. O. variabilis x O niloticus (Lake Victoria) resembles O. niloticus x O. macrochea in Ruwanda. Also in Madagascar, Moreau).

Hybrids in *Lates* from Lake Albert, Lake Albert and Lake Turkana. Status of stocks and or hybrids unknown.?

5. Economic Issues

Cowx: If reduce fishing by half to treble catch after a few years - what would happen in transition period? How to overcome problem of getting fishermen to reduce fishing effort (cf difficulties in Asia). Fishermen will not accept it.

Reynolds: This is a very serious issue.

Craig: Beach seining is an important way of getting fish to local population who cannot afford high prices of the Nile perch and Nile tilapia that are exported.

Discussion on Co-Management of resources. (Including local fishermen in the management).

Pitcher: Talked about minimising the effect of Nile perch. Can Nile perch stand present fishing?
Assumption of rapid recruitment, but is this true?
If not fishing could collapse.

Kolding: Spoke about recruiting models which assume no cannibalism - might however, get increased cannibalism.

Witte and others reported five factories built for the haplochromine trawl fishery that are now unused. There are already 60 processing plants on the lake. One should beware of over-capitalisation. The fish meal factory at Mwanza now stands idle.

ANNEX 6
Reports of Field Visits

Field Visit to East Africa - Dr Tony Pitcher, Jan-Feb 1992

Objectives of Field Visit

1. *To discuss with key participants and other key scientists how the workshop sessions may best be shaped to address the themes of the project. Inevitably, many of the topics which were offered as verbal presentations did not do this very explicitly, and so to ensure the quality and focus of the roundtable discussions, preliminary rehearsal of the major issues in the main field sites was considered valuable. Visits to Institutions in Central Africa enabled me to take account of the views and knowledge of a wider range of scientists in this respect than could attend the London workshop.*

2. *To further appraise the quality and extent of data that will be forthcoming. Most participants for the data workshop gave few details of the nature and extent of data they would be bringing with them, so the field visit aimed to enable us to appraise some of the most important data and make some preliminary analyses in advance of the London workshop. In at least one case, we hoped to be able to gain access to important data on changes in species composition which is not going to be brought to the workshop.*

3. *To attend a meeting of the FAO Sub-Committee for the Development and Management of the Fisheries of Lake Victoria, 10-14th February at Jinja, Uganda, as official UK observer from ODA.*

In addition, given that the main trip was organised under the direct auspices of this project, there were a number of secondary objectives, as set out in the 1992/3 report relating to relevant project themes in Kariba and Malawi.

Itinery

Dr Tony Pitcher and Ms Alida Bundy travelled to Zimbabwe, Malawi, Zambia, Uganda and Kenya during January and February 1992. The detailed itinery was as follows:

Zimbabwe:	11 Jan - 29 Jan
Harare	11 Jan - 16 Jan
Kariba	17 Jan - 20 Jan
Zambia:	20 Jan
Bumi	21 Jan - 26 Jan
Kariba	27 Jan - 28 Jan
Harare	28 Jan - 29 Jan
Malawi:	29 Jan - 7 Feb
MonkeyBay	29 Jan - 2 Feb
Salima	3 Feb - 4 Feb
Monkey Bay	5 Feb - 6 Feb
Lilongwe	6 Feb - 7 Feb
Uganda:	7 Feb - 15 Feb
Jinja	7 Feb - 14 Feb
Entebbe	14 Feb - 15 Feb

(TJP traveled back to UK via Nairobi 15-20 Feb, paid for by University of York)
Kenya (Shimoni & Mombasa):20 Feb - 29 Feb

Finance

Tourist class air tickets to cover the entire trip were obtained very cheaply from the same source as for the London workshop. In several cases savings were made in accommodation and local transport arranged through friends and colleagues who were to attend the London workshop, or through associated projects. The air fare to Zimbabwe was paid for by NORAD, and the cheque paid into the Workshop account. The Kenyan leg was at no extra cost to the project, as the flights would have routed through Nairobi in any case.

Furthermore, considerable savings to the project budget accrued on the return air tickets purchased in London and delivered personally to sponsored workshop participants in Africa. This personal delivery was important for two reasons: first, of the two air tickets sent by insured post, one went astray; secondly, tickets of this type are not regarded favourably by all governments.

Activities during the field visit

A. ZIMBABWE

1. We took part in a one-week research cruise sampling for larval sardines on Lake Kariba with Morris Mtsambiwa at LKFRI, an Imperial College research student. Light trap nets were employed at three sites transecting three depths out from the shoreline, and an acoustic survey carried out over each transect with a portable 120 KHz Simrad machine.

2. We gave a one-day training course on the latest update to LFDA for Zambians and Zimbabweans at LKFRI.

3. I held discussions with Dr Digby Lewis about possible PhD sponsorship from NORAD for Portia Chifamba, who carried out her Masters project work at RRAG in 1991, for work on fishing effort and production models for the Lake Kariba kapenta fishery.

4. I assessed the logistics of sampling kapenta for the newly approved project on biochemical genetics of kapenta introduced to African Lakes, held jointly with Dr Gary Carvalho of the Fish Genetics Group at Swansea University. The brief visit to Zambia was in connection with this project. A report was made to

the Swansea team on return to the UK and this intelligence later proved invaluable in circumenting the inordinate delays in obtaining research permission for the project in Zimbabwe.

5. We paid a courtesy visit to Professor Chris Magadza and Hilary Masundire at the University Lake Kariba Research Station. Later, Masundire attended the London workshop sponsored by UZ.

6. We held extensive discussions with Dr Brian Marshall, who we sponsored to attended the London workshop, at UZ Harare, about freshwater sardine ecology and fisheries. Marshall has a number of new and controversial ideas bearing on the comparative aspects of fisheries for successfully introduced sardines in the African lakes. These will be discussed and appraised in the final report.

7. In addition to the above, we held useful discussions about the Lake Kariba sardine fishery with Jeppe Kolding (NORAD, Kariba), who attended and produced a paper for the London workshop and book; Gordon Mudenda (Zambia, visiting Kariba and since promoted to deputy Director of Fisheries in Zambia); Rudo Sanyanga (LKFRI, Zimbabwe) and Andrew Palfreman (an economist from the Fisheries Institute, University of Hull).

8. We held unfruitful discussions about access to the Lake Kariba gill netting data with Jeppe Kolding (NORAD, Bergen, Norway) and Cecil Machena (Head of LKFRI, Parks Dept, Zimbabwe). The only way forward is indicated above in the contracts section.

B. MALAWI

1. At Monkey Bay, we visited Dennis Tweddle for discussion of future possibilities concerning the assessment of Lake Malawi fisheries. We discussed the undesirable consequences of trained Malawians leaving the government lab soon after they returned. At present Dennis Tweddle represents the only hope for any continuity or quality in research on Malawian fisheries. Fortunately, he was confirmed in his post as Acting Director while we were there.

2. At Monkey Bay and Mangochi, I had meetings with George Turner and Mohammed Seisay (both ex-Bangor) from the FAO 'chambo' project, about assessment of the artisanal and commercial cichlid fisheries in Lake Malawi and Lake Malombe, the latter in dire condition since the introduction of fine mesh seines.

3. I paid a courtesy visit to Maldeco commercial fisheries where Jim Magasa, another ex-Bangor student and ex-head of the Monkey Bay laboratory, is in charge of biological work.

4. At Lilongwe, I had a meeting with Tom Barrett and Martin Tainsh at BDDSA about the publication of the two volumes of *Collected papers on fisheries research in Malawi* and the possibility of a further similar arrangement with Martin Pearce's work for ODA in Zambia. Pearce attended RRAG for a week's training in August 91 and was sponsored by us to attend the London workshop. BDDSA indicated that there would be limited support for Pearce publications if he could be persuaded to get as far as writing them but there would be no further extensions to his contract. We discussed the agenda for a meeting with Martin Pearce and Dick Beales after the London workshop. Also discussed the new World Bank Biodiversity project in Malawi, which curiously was said to be sponsoring new jetties for the fishermen as well as a visitors centre.

5. We visited the ODA-SADACC pelagic fisheries project at Salima, including tours of the unconventional new research vessel and the well-equipped and organised laboratories in the research compound. Discussions were mainly with Andy Mentz, Tim Allison, who received a weeks training at RRAG in March 1981, and with Ben Ngutunga from Tanzania, an ex-Bangor MSc, employed on the SADACC project. Productive work on this project was only just beginning, although some interesting results from the first acoustic cruise suggested higher densities of pelagic organisms than had been anticipated.

6. I held a meeting with Rosanna Robinson at Monkey Bay about behaviour in cichlids in the wild. (ex Bangor MSc: currently PhD student of Tony Ribbink, Grahamstown, South Africa, a sponsored participant at workshop).

C. UGANDA - CIFA MEETING AT UFFRO, JINJA

1. FAO Rome gave me permission to attend as an observer the 6th session of the Committe for the Inland Fisheries of Africa (CIFA): Sub-committee for the Development and Management of the Fisheries of Lake Victoria. The meeting took place from 10th to 14th February at Jinja, Uganda.

The most valuable part of the Uganda visit was the opportunity of meeting and holding discussions with a number of experts on Lake Victoria who had come to attend the CIFA meeting, especially members of the FAO-IFIP team based in Bujumbura Burundi, staff of the UFFRO laboratory at Jinja, Kenyans from KMFRI and visitors from the USA. It was at this meeting that our own perspective on the fisheries of Lake Victoria was formed.

The CIFA meeting itself was well-attended but rather poorly organised, for example the scientific delegates had no visual aids with which to present their papers and resorted to holding up prepared overhead sheets in the hope that the audience could see them. Even allowing for these problems, and the large amount of support work put in by a couple of CIFA-FAO staff, the scientific quality of the majority of papers was regrettably low and are hardly worth summarising here. The draft report from the meeting is submitted as an appendix to this report.

Nevertheless, the political impact of the meeting was considerable and there was a groundswell of agreement which apparantly was a new and welcome departure. The basis was laid for the re-formation of a lake-wide management body that I understand was formally constituted later in 1992 at an American-sponsored symposium in Uganda.

It was recognised that considerable changes to the lake environment were under way. The lake ecosystem was much simpler now, and the pelagic component dominant, based on a previously rare shrimp, *Caradina* and the pelagic zooplanktivorous cyprinid, *Rastrineobola* (ndagaa). Neither of these species appear to be studied effectively: for example staff working on a Canadian-sponsored *Caradina* project in Jinja failed to appreciate that they should be measuring shrimp production as well as standing biomass. Fisheries for both shrimp and ndagaa are undocumented. It was evident that the water hycacinth presented a new and under-estimated threat to inshore fisheries, and this threat was not being taken seriously enough despite an excellent FAO consultancy report and semi-popular video from an expert in Florida.

I have to report that in Uganda there was evidence of a number of heavily-financed aid projects that I assess ill-considered. The local scientists are not stupid and most have been well-trained in the west, but such projects not only create aura of scientific aid-dependency, but also a tendancy to shape future aid requests in the expectation that this type of scheme is the one likely to receive support. In Uganda I have no hestitation in identifing two such projects on Lake Victoria whose impact I consider to be undesirable.

- An American-sponsored project re-visiting the loss of the haplochromines, focussed on saving some species of haplochromines in US aquaria. Whist in itself unexceptionable, the project diverts US aid from more valuable fishery-oriented work. This project continues in the unhelpful tradition of branding the Nile perch as the perpetrator of the loss of species in the lake while ignoring the benefits of the fishery. Articles in the US press arising from a well-publicised conference associated with this project continue to rehearse this theme, thus encouraging the spending of public money on the project, which would more appropriately be privately sponsored by the aquarium trade.
- An almost derelict Nile perch processing factory, fitted out with ceramic tiles and much high-tech hardware sponsored by Italian aid. The failure of this expensive factory is ironic given a thriving Ugandan Asian owned factory only 1 km away.

At best such projects divert attention and resources from the issues of importance to the local human population. At worst they exacerbate the lack of focus on assessing and understanding the ecology of the actual fisheries which are being so heavily prosecuted by the commercial and artisanal sectors. Moreover, many African scientists in government fishery laboratories often work on pure science or limnology projects in association with overseas universities, whereas this manpower would in my opinion be more profitably employed on topics directly relevant to the fisheries themselves. The well-populated strata of politicians and scientist-politicians seem to be aware of this problem, but do little to alter the emphasis because almost all of the scientific work carried out depends upon the forex brought in by donors.

I understand from Rosemary Lowe McConnell that the need for a greater emphasis on the fisheries themselves was forcefully expressed during the recent American-sponsored symposium in Jinja. I hope that ODA can do something to reinforce this attitude. It is to be regretted that in the present circumstances there is no longer any direct ODA presence concerned with Lake Victoria fisheries in these three East African countries. My recommendation is that this should be re-considered as a priority: a British fisheries-oriented input would be welcomed and would have a more beneficial influence than than the US, Scandinavian, Dutch, Italian, Canadian and Japanese aid donors, all of whom have little experience in fisheries. The only currently sensible input comes from FAO, who are under-financed, primarily Francophone, and remotely based in Bujumbura.

2. By chance in Jinja we met Craig Harris, a socio-economist from Michigan State University. Harris has developed research that attempts to identify the true beneficiaries and the fate of the considerable wealth created by Nile perch. While in Uganda, we successfully encouraged Harris to attend the London workshop in return for sponsored acommodation. His paper, contributed to the book, provides a perspective on the overall socio-economic analysis by the FAO economists.

3. In Uganda, sponsored airtickets for the London workshop were handed to J. Ogari and Peter Ochumba (KMFRI, Kisumu, Kenya); Arthur Kudhongania (Director of UFFRO), Richard Oguto-Owayo, Timothy Twongo (UFFRO, Jinja, Uganda); George Ssentongo (from FAO, Burundi). Mr Nsibula's (Uvira, Zaire) ticket was given to FAO Bujumbura staff to take back to Bujumbura where they expected to meet him in the near future. Discussions were also held with other workshop participants such as Fritz Roest (Wageningen, Netherlands), and F. Mbahizireki (UFFRO, sponsored to London by British Council).

4. We also had useful discussions with Dominique Grêboval (FAO, Burundi), F.Orach-Meza (Deputy Commissioner for Fisheries, Entebbe, Uganda), W.Bugenyi (Asst. Director, UFFR, Jinja), W.Sichone (Director of Fisheries, Dar es Salaam, Tanzania), Anton Kiyuku (Director of fisheries, Bujumbura, Burundi), J. Kapetsky (FAO, Rome) and Ian Dunn (FAO consultant).

D. KENYA

This visit was to Simon Hemphill, Pemba Channel Fishing Club, Shimoni, in order to read and comment on the final draft of his PhD thesis covering the assessment of Indian Ocean yellowfin tuna stocks using 25 years of data from a sport fishery. We discussed arrangements for a possible short visit to RRAG to complete writing up. This visit was at no extra cost to the project.

e. Report of A. Bundy (RRAG)

As a part of the ODA research project 'Impact of Species Changes in African Lakes', I participated in a 7-week field trip to Africa as assistant to Dr T Pitcher in January and February 1992. Countries visited were Zimbabwe, Malawi, Uganda and Kenya. The following aims were identified for my visit in the 1991/92 annual report:

1. Assist in the analysis and appraisal of data on site using the project's portable laptop PC. Software packages (LFDA, CEDA) developed by RRAG under the ODA programme are being taken out along with statistical packages such as SYSTAT which will be used during the London workshop. It will be valuable for participants to be introduced to this software and have the opportunity to use methods in advance of the London workshop.

2. develop closer liaison with sponsored participants at the workshop in:

- assessment of abilities and interests;
- discussion of the shaping of the symposium roundtable sessions;
- selection of data sets for the data workshop;
- attendance at the FAO meeting in Uganda as an observer.

3. To work on data on species changes held at the LKFRI laboratory Kariba, where previous considerable difficulties have been experienced in gaining access to the data. A direct visit to the site was probably our last hope of finding a way of looking at this interesting set of regular gill net survey data, which has been gathered in a standard way for the past 26 years.

1. APPRAISAL OF DATA AND SOFTWARE

I met Dr Dominic Gréboval, representing IFIP/FAO, Bujumbura in Lake Kariba. Dr Gréboval has extensive experience of African Lakes and he gave a very useful summary of the nature of the data originating from Lake Victoria, specifically the nature of its unreliability and the way that catch statistics are gathered in the riparian states around the lake. He also donated copies of recent IFIP reports with the latest catch figures from Lake Victoria. This was invaluable for subsequent analysis of species changes in Lake Victoria and a stock assessment of Nile perch. This data analysis was carried out throughout the trip, incorporating extra information as it was acquired.

The software mentioned was brought to Africa and the RRAG packages distributed to workshop participants in Zimbabwe, Malawi and Uganda. The methods in the packages were discussed and explained to participants. Very few were familiar with SYSTAT so note was made that the use of this package should be considered at the London data workshop.

It transpired from discussions with Ugandan and Kenyan participants that levels of computing ability were highly variable. In fact some had hardly used a computer and so I planned a parallel remedial course for the London data workshop for those unfamiliar with computers.

Dr Pitcher gave a short course for NORAD on the use of LFDA and CEDA to personnel from Zimbabwe and Zambia at LKFRI. I acted as demonstrator.

2. LIAISON WITH SPONSORED WORKSHOP PARTICIPANTS

Essentially a major aim of this visit was to meet those attending the workshop and to discuss differing interests and needs. We met more people than anticipated, both in Lake Kariba and at the FAO meeting in Uganda, which proved very useful.

In Zimbabwe, we were able to meet and discuss the issues in Lake Kariba with Dr Brian Marshall (University of Zimbabwe, Harare) and Mr Morris Mtsambiwa, Ms Portia Chifamba, Ms Rudo Sanyanga LKFRI, Lake Kariba and Mr Jeppe Kolding, University of Bergen, Norway all of whom were registered participants of the workshop. In Malawi we met Dr D Tweddle and Dr G Turner and Mr M Seisay. In Uganda we met the following sponsored participants: Dr AW Khudhongania (Director of UFFRO), Dr R Ogutu-Ohwayo, Dr T Twongo from Uganda also of UFFRO and Mr J Ogari and Mr P Ochumba from KMFRI, Kenya and Mr G Ssentongo (FAO, Burundi). In addition the following registered participants were there: Mr F Roest (Wagenin, The Netherlands), Dr E Reynolds (IFIP/FAO, Burundi). Also met Dr Craig Harris, socio-economist from Michigan State University who was very interested in the London workshop and agreed to try attend and present a paper at the London workshop (he did).

I discussed the type of data that would be brought to the data workshop with all the participants. It became apparent that the nature of the data would be quite diverse and not all of it suitable for the types of methods we intended to employ on the course. Where problems were likely, these were discussed.

With regard to the discussion and shaping of roundtable sessions, Dr Pitcher made most of these arrangements, inviting various participants to chair sessions.

My main interest in regard to the themes of the project, ie., 'Impact of Species Changes in African Lakes' is Lake Victoria and perhaps the most useful and rewarding part of the field visit was the time spent in Uganda at the FAO meeting, the 6th of CIFA Sub-Committee for the Development and Management of the Fisheries of Lake Victoria. The meeting itself highlighted the issues and problems in managing the fisheries of Lake Victoria, not least the problems of 3 countries trying to manage one resource. Unfortunately the scientific side of the meeting left a little to be desired but the forum provided an opportunity for the 3 riparian states to work together and discuss further possibilities for the proposed Lake Victoria Fisheries Commission, a body to manage Lake Victoria.

3. KARIBA GILLNET DATA

It had been hoped to obtain a set of gillnet data held at LKFRI, Lake Kariba. However, I was informed by Dr Cecil Machena, deputy director, that this data is being analysed by Mr L Karenge of LKFRI as part of his MSc at the University of Bergen, Norway. He is sponsored by NORAD and works with Mr Jeppe Kolding. As a consequence of discussions held, Mr Kolding and Mr Karenge will submit a contract report on the results of this work (see above).

A subsidiary aim of the field visit was to allow me to assess candidate localities and data in Zimbabwe/Zambia, Malawi, Uganda and Kenya for my SSERC PhD project on biological, technical and economic interactions between artisan and commercial fisheries, in particular the formulation of general strategies and models for the resolution of conflicts. As a result of this visit, I identified Lake Malawi as a very promising case study, modelling the interaction between the large and small scale sectors in the chambo *(Oreochromis)* fishery. Lake Tanganyika was also discussed at length with Dr Grêboval, Dr Roest and also Mr Kanyike, director of the Burundi Fisheries Department. In this fishery, kapenta are prosecuted by large and small scale sectors in the North and South of the lake. I plan to include this fishery in my PhD, but not as a major case study. I decided that since the large and small scale fisheries in Lake Kariba exploit different species, that this would not constitute a suitable case study.

Field Visit to Uganda - Dr John Craig - May 1991

Terms of reference

1. Determine the nature, format and extent of pertinent data available in Uganda.

2. Assess how this data may be used in furthering the aims of the project.

3. In cooperation with Ugandan colleagues, gather as much as possible of the data and return to the UK on disk.

4. Comments and information on any other data kown to exist in Kenya or Tanganyika.

5. In cooperation with Ugandan colleagues, identify scientists who might be sponsored to attend the forthcoming March 1992 London workshop in 1992.

Results and Appraisal

John Craig spent from 1st to 12th May in Entebbe and Jinja, Uganda. His own 31-page report, along with extensive data tables and data on disc, was delivered in June 1991. The report includes 12 tables of data on Lake Victoria, Lake Kyoga and Lake Albert fish catches.

A further batch of data from Tanzania was sent via R. Oguto-Oweyo after the main report.

1. Fish catches in Uganda 52-88
2. Fish catches in Lake Albert 52-89
3. Fish catches from Lake George 63-88
4. Fish catches from Lake Kyoga 37-53
5. Lake Victoria - Kenya waters 58-85
6. Lake Victoria - Tanzanian waters 58-85
7. Lake Victoria - Ugandan waters 65-89
8. Biomass of major fish species in Lake Victoria 68-71
9. Fish catches at Jinja
10. Average wt of fish landed at Masese, Uganda
11. Catch rate from research trawl, Uganda 71-85

The Craig visit to Uganda was successful and cost-effective in achieving its aims, although the limited scope and the patchiness of the data available was rather dissapointing.

Most of the data consists of commercially landed catches with a small amount of research trawl information. Nothing was found that could have shed light on the changes in the ecology of the lake or the reasons for the Nile perch explosion. Understandably, most data did not cover the years of civil unrest in Uganda, and unfortunately for the attempts at Nile perch assessment, recent years are absent from research trawl data while the laboratory at Jinja is awaiting refurbishment after the destruction wrought.

Nevertheless, the data given Craigs appendices includes some very useful material gathered on the visit, that would have not been available until much later in the project.

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