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Feature article

FISHERIES MANAGEMENT — A REVIEW OF THE CURRENT STATUS AND RESEARCH NEEDS IN ETHIOPIA

Dirk Reyntjens[1] and Tesfaye Wudneh[2]

[1] Lake Fisheries Development Project, Ministry of Agriculture,
PO Box 8576, Addis Ababa, Ethiopia

[2] Animal and Fisheries Development Team, Ministry of Agriculture
Addis Ababa, Ethiopia

ABSTRACT: The last few years have seen huge increases in fishing effort and production on the major water bodies of the country. Already some stocks show signs of overfishing raising the issue of proper management of this natural renewable resource. This paper reviews some concepts used in fisheries biology and stock assessment and compares these with the current knowledge on the major stocks. A list of possible small research projects which would make a direct contribution to the rational management of the fisheries on these stocks is discussed.

Key words/phrases: Ethiopia, fisheries management, research needs

INTRODUCTION

The importance of the fisheries sector in Ethiopia is relatively difficult to evaluate. Much happens unrecorded at the local level, often in remote places. The figures used in this presentation refer to the lakes and reservoirs covered by the Lake Fisheries Development Project - Phase II. They are the lakes Abaya, Awassa, Chamo, Langano, Tana, and Ziway and Koka reservoir as well as some minor lakes in South-Wollo. From September 1996 to August 1997 over 3000 fishermen landed an estimated 10,400 tons from these water bodies (Table 1). This corresponds to a total value at the landing site of over 13 million Birr (LFDP, 1997a). However, the real importance of the fisheries sector even on these water bodies is much bigger than these figures suggest. Other activities such as net-making or filleting need to be considered. Also, most activities are small-scale in places where alternative employment opportunities are rare.

Table 1. The major water bodies covered by the Lake Fisheries Development Program.

	Abaya	Awassa	Chamo	Koka	Langano	Tana	Ziway
Altitude (m)*	1285	1708	1282	1590	1585	1829	1848
Area (km^2)*	1070	97	551	255	225	3500	434
Max. length (km)*	60	17	36	20	23	80	32
Max. width (km)*	20	11	23	15	16	64	20
Volume (km^3)*	7.5	1.0	2.1	2.3	2.7	28	1.1
Mean depth (m)*	7	11	6	9	12	8	2.5
Shore line (km)*	225	52	118		77.5	385	102
Conductivity [$\mu s(cm)^{-1}$] **	1021–1030	819	1506–1586	195–205	1575	105–212	334–394
Landings in 1996/97 (tons) **	124	573	3464	739	491	1470	3180
Potential production (tons/year)***	?	1100	3100	1500	1900	13200	3500
Estimated safe levels (tons/year)**	390	520	3340	840	210	1460	2200

Sources: *, Vanden Bossche and Bernacesk (1991); **, LFDP (1997a); ***, LFDP (1994b) - (Empirical models).

A few species contribute to most landings. Nile tilapia [*Oreochromis niloticus* (Linnaeus, 1757)] accounts for nearly 60% of all landings (6,080 tons). The next most important species is *Labeo horie* (Heckel, 1846-49) (2,010 tons), African catfish [*Clarias gariepinus* (Burchell, 1815)] 1200 tons and Nile perch [*Lates niloticus* (Linnaeus, 1758)] with 230 tons (LFDP, 1997a). A group of closely related *Barbus* spp. account for over 600 tons on Lake Tana.

The last few years have seen huge increases in fishing effort and production (LFDP, 1995ab; 1996ab; 1997a), the most dramatic being a ten-fold increase in landings from Lake Chamo in just four years. Between September 1992 and

August 1997, total production increased by 220% (from 3,250 to 10,400 tons). Part of the increase in production is only apparent as production data until the end of 1993 represent landings recorded by fisheries officers. For instance, the actual landings in the Southern part of Lake Tana alone were estimated at around 700 tons per year in 1992 (Tesfaye Wudneh, pers. comm.) against an official production of 460 tons for the whole lake. Similarly, the official figures for the landings from Lake Awassa in 1992 and 1993 were 300 and 415 tons while a "back-of-the-envelope-calculation" based on records of catch per fishermen and number of fishermen give estimates of 940 and 860 tons instead (LFDP, 1994c and 1995a). Effort figures give a better picture of the expansion of the fisheries sector as they are based on surveys. According to the data available, the number of fishermen increased by 25% and the number of gill nets by 55% (LFDP, 1993, 1994a, 1996c). Nevertheless, these figures underestimate the real increase in effort as new gears are more efficient than older ones.

Several stocks already show signs of overfishing (LFDP, 1996b; 1997b). For instance, the landings of Nile perch from Lake Chamo have dropped from an all time high of 190 tons in October 1994 to less than 20 tons per month in 1995/96. At the same time the contribution of Nile perch to the total landings has dropped from around 70% in 1993/94 to less than 10% in 1995/96. The landings from Lake Awassa averaged 910 tons per year during 1991-1996, but only 500 tons in 1995 and 1996 or a drop of nearly 50% (LFDP, 1995ab; 1996ac). The landings recovered somewhat in 1996/97 (LFDP, 1997a).

CONCEPTS IN STOCK ASSESSMENT

The stock

A stock is a well defined group of fish which show no or little mixing with other groups. These fish necessarily belong to the same species or even sub-species and inhabit the same geographical area. One essential feature of a stock is that its basic or vital (growth and mortality) parameters are the same over the whole area occupied. For reviews of the concept of stocks refer to Booke (1981), Ihssen *et al.* (1981) and McLean and Evans (1981).

Stocks are the basic units which are studied by fisheries scientists. Stock assessment is, at first, carried out for each stock separately. It is not always necessary to know the exact or absolute size of a stock, be it in numbers or in weight. For many purposes the changes in stock size over time are more important than the actual amount at any one moment. One relative measure of stock size is the catch per unit effort (CpUE). It is a reasonable assumption that the catch per unit effort is directly proportional to the stock size if the effort is properly defined. If there are twice as many fish in a particular water body, it can be expected that, for instance one gill net will catch twice as much, all other conditions remaining constant.

(Catch per Unit Effort) = (Catchability coefficient) x (Stock Size)

The proportionality coefficient is called the catchability coefficient. It is conventionally designated by the letter q and is normally assumed to be a constant for a given gear and environment.

It is not always easy to properly define a stock. The identification of the species or sub-species considered is a first step. In most cases in Ethiopia, this is relatively straightforward. There are few species in the commercial landings and they are easy to distinguish one from the other. The difference between a common carp and an African catfish is evident to all. However, in the case of the big barbs of Lake Tana proper identification is a major problem. Banister (1973) in his revision of the large barbs of East Africa lumped all species described for the lake into one very variable *Barbus intermedius* Rüppel, 1836. Nagelkerke (1997) divides these same fish into fourteen species, seven of them new to science. The differences between them are not always clear. This greatly complicates data collection.

Another possible complication is that different stocks may be made up of fish from the same species. It is clear that the Nile tilapia from Lake Ziway and from Lake Chamo belong to different stocks, since they can not possibly be in contact. In the case of large water bodies, it is conceivable that fish from let us say the south may never meet and mate with fish from the north. There could therefore be two different stocks. In practice, Ethiopian water bodies are relatively small and stocks can be safely equated with a species for each lake, such as the Nile tilapia stock of Lake Awassa or the African catfish stock of Lake Tana. Table 2 lists the major stocks on the lakes and reservoir covered by the LFDP and gives the landings in the period from September 1996 to August

1997 (LFDP, 1997a). Current estimates of safe production levels based on stock assessment studies are also given in Table 2 (LFDP, 1997b).

Table 2. Current and estimated safe production levels (in tons) for the major stocks (LFDP, 1997ab).

Lake	Species	Sept. 1996 - Aug. 1997	Safe production level[1]	Growth	Maturity vs size	Spawning
Chamo[2]	Labeo	1980	1500	Preliminary	No	No
Ziway	Tilapia	1960	2000	Satisfactory	Yes	Yes
Chamo	Tilapia	1320	1700	Preliminary	Yes	Yes
Tana	Large Barbs	620	460[3]	Good?	Yes?	Yes?
Awassa	Tilapia	460	440	Good	Yes	Yes
Koka	Tilapia	420	500	Satisfactory	No	No
Tana	Tilapia	400	460	Good	Yes	Yes
Tana	Catfish	363	520[4]	Satisfactory	Yes	Yes
Langano	Tilapia	220	170[5]	Satisfactory	No	No
Chamo	Nile Perch	170	190	Good	Yes	Yes
Koka	Common carp	110	?	Preliminary	No	No
Abaya	Nile Perch	100	200	Preliminary	No	No
Abaya	Bagrus	70	140	Preliminary	No	No

[1] These figures have to be considered long term averages. The fact that in a single given year, production exceeds the "estimated safe level" does not yet mean over-exploitation.

[2] The latest data available for Lake Chamo are from 1995/96.

[3] The results of the stock assessment studies done were inconclusive. There are three possible reasons: 1) All the big barbs are treated as one single big 'super' species. This was necessary as the catch and effort data available does not distinguish between species; 2) the big fish (species) could be moving out of the fishing grounds to deeper waters, the data used would then not be representative of the full stock; and 3) it is possible that the recruitment of the Barbus on Lake Tana is already affected by the seasonal fishing on the migrating spawners in the rivers.

[4] This level is defined not by the stock itself but because of the necessity for not to over-exploit the more valuable tilapia and barbs. The introduction of a new gear specific for catfish would mean that the estimated safe level could be reviewed upwards.

[5] All stock assessment models used give very low estimates for the potential production from Lake Langano compared with much higher estimates obtained by the empirical models. These results are thought to reflect a very low primary productivity of the lake. They also could be due to the fact that the fishery would exploit only one small stock while there are others left undisturbed till now. However, this is thought to be unlikely.

Of course, other stocks exist even on these same water bodies. Some of these such as some *Mormyridae* or *Characidae* in the lakes Chamo and Abaya might become important in the future.

Reproduction and recruitment

The fish belonging to one stock, born roughly at the same time form a cohort. One special moment in the life cycle of an exploited fish stock, is when the young move into the areas where fishing is actually carried out. From that moment onward, they can be captured if an appropriate gear is used. This is called the age or time of recruitment. The size of the recruitment is the number of fish reaching that particular stage. Since it is not possible to catch a fish which did not first recruit to the fishery, recruitment is a very important aspect which directly influences total possible production.

The number of young fish recruiting every year in a given water body is a function of the number of eggs spawned. This is, in turn, directly related to the biomass or total weight of sexually mature fish present. The relationship is however, little understood. Many other factors, such as water level fluctuations (De Silva, 1985), play a role. Only one point of the Recruitment/Biomass curve is sure. If there are no breeding fish, there can not be any recruitment. Initially, as the spawning stock biomass increases, the size of the recruitment will increase also. From a certain stage onwards, the recruitment has either to remain constant or to decrease (Fig. 1).

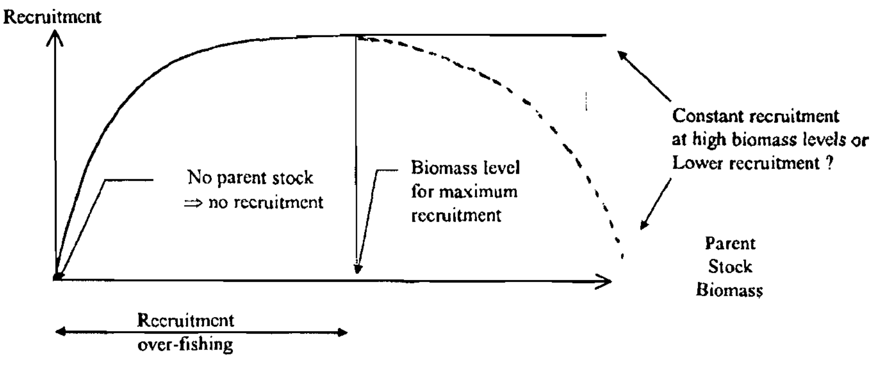

Fig. 1. The relationship between recruitment and stock biomass.

Any fishing results in a reduction of the fish biomass present in a water body. If this biomass drops below a certain level, recruitment will start to decrease. This in turn results in lower biomass and yield. This is a situation which fisheries management absolutely needs to avoid. It is called recruitment overfishing. For a discussion of recruitment refer to Beyer (1989).

One way to avoid or limit the risk of recruitment overfishing is not to catch immature fish. Not all fish mature at the same age or size. A theoretical relationship between length and per cent mature fish is shown in Fig. 2. One important parameter here is the L50 or the size at which 50% of the fish are mature. Normally one would try to avoid catching fish smaller than L50.

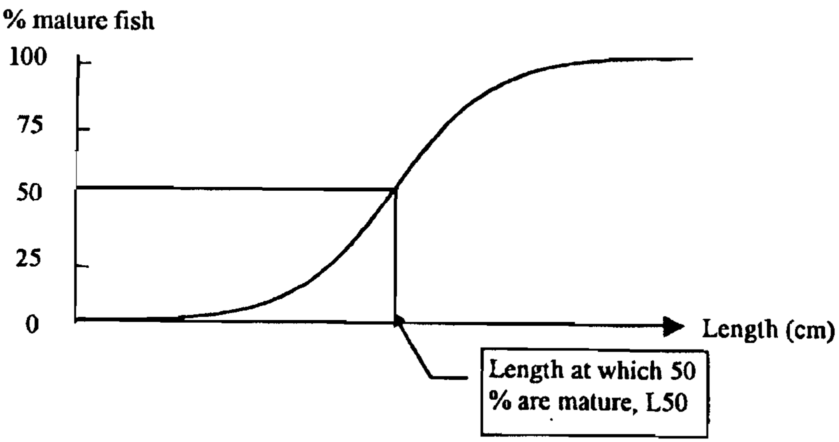

Fig. 2. Relationship between % mature fish and fish length.

Growth

Growth can be defined as the increase of a body measure over time. Usually some measure of length is used. How fish grow is important as it is directly related to the potential sustainable yield. Fish are generally assumed to continue growing their whole life-time. Their rate of growth, however, decreases as they grow older and bigger. Very old and big fish grow very slowly. Young and small fish grow rapidly. As is the case for all living organisms, every single fish grows in a different way. However, it is not practical to account for all fish making up a stock. The growth which is normally discussed, is therefore, that of an "average" fish or the growth of the average of a cohort. A cohort is a group of fish born at approximately the same time in the same environment. For a review of growth models refer to Pauly and Morgan (1987).

The mathematical expression most commonly used to describe the growth of fish is the von Bertalanffy Growth Formula or VBGF (Bertalanffy, 1934). It is often written in one of the following two forms:

$$\frac{\Delta L}{\Delta t} = K \cdot (L_\infty - L_t) \qquad \text{or} \qquad L_t = L_\infty \cdot \left(1 - e^{-k \cdot (t - t_0)}\right)$$

In these expressions, ΔL is a change in the average length (L) of a cohort over a period of time equal to Δt; K is called the instantaneous rate of growth, L_∞ is the mean length of the very old fish and L_t is the average length of fish aged t, t_0 is the theoretical age at which the length of the fish is zero. Figure 3 shows the general aspect of such a growth curve.

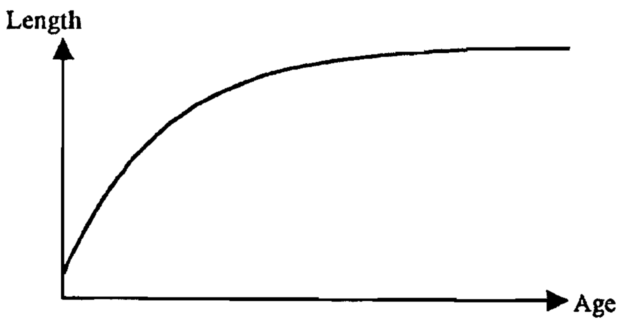

Fig. 3. General aspect of the von Bertalanffy Growth Curve.

Actually the von Bertalanffy growth formula does not describe properly the growth of fish over a whole life time. Particularly very young fish do not seem to follow this pattern. However, it has proved a very useful tool for the size or age ranges normally caught by fisheries. It is one of the basic formulae in stock assessment.

Very often we are not so much interested in the length of a fish but in its weight. Length and weight are related. The relationship is: $W = a \cdot L^b$. In this equation, a and b are parameters which can be estimated for each stock from length and weight data by regression analysis. The parameter b averages 3 and is usually between 2.5 and 3.5.

Mortality and catch equation

The number of fish in a cohort declines over time because of mortality. The rate at which fish die is obviously proportional to the number of fish alive. The coefficient of proportionality is called the instantaneous rate of total mortality, conventionally designated by Z. Fish die either due to the fisheries on them or due to any other cause such as disease or capture by a predator. It is therefore convenient to divide the instantaneous rate of total mortality into a component due to the fishery, conventionally indicated as F, and a component due to all other causes, conventionally designated as M. The mathematical expression of the above is:

$$\frac{\Delta N}{\Delta t} = -Z \cdot N_t = -(F+M) \cdot N_t$$

If Z remains constant, the expression above is mathematically equivalent to the following one:

$$N_t = N_0 \cdot e^{-z \cdot (t - t_0)}$$

In these expressions, ΔN is the change in numbers in a small time interval Δt, N_t is the number of fish of a single cohort surviving to the age t, N_0 is the number of fish of a single cohort at age t_0.

Together with the von Bertalanffy Growth Formula, this last equation which is also called the exponential decay model, is a corner stone in the theory of exploited fish stocks (Beverton and Holt, 1957).

Figure 4 illustrates what happens to a cohort if it is submitted to different levels of mortality. It is evident that $Z=2$ y^{-1} represents a high rate of total instantaneous mortality. A cohort exposed to such a high mortality rate is virtually exterminated in two years time.

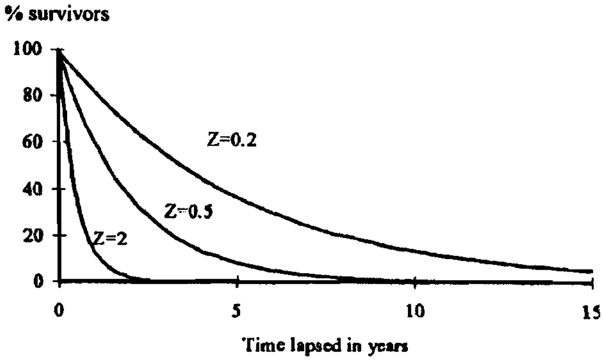

Fig. 4. Per cent survivors as a function of years at different levels of total mortality.

Fish die either because they are caught by a fisherman or due to any other reason. The number of fish caught by the fishery is therefore the total number dying times the ratio of the instantaneous rates of fishing mortality to total mortality or:

$$C_{t_1;t_2} = \frac{F}{Z} \cdot \left(N_{t_1} - N_{t_2}\right)$$

This expression is called the catch equation.

A mathematically equivalent form is:

$$C = F \cdot \bar{N} \cdot \Delta t$$

In this expression, $\bar{N}$ is the mean number of fish present over the considered time interval Δt. C is the total catch and F the instantaneous rate of fishing mortality during that interval.

Models

The first question which is usually asked to a fisheries scientist is: How much can we catch without endangering the resource? There are several tools, called models, which can be used. Models are a simplified mathematical description of processes happening in a water body. There are three basic groups of models each having specific requirements in terms of data and ability to perform calculations. Each model has also its own assumptions. Checking whether the assumptions are reasonably met is a very important consideration.

Empirical models

Strictly speaking empirical models are not stock assessment tools since they will not yield any information on stocks. They are mentioned here only for the sake of completeness. Empirical models make a link between some easily measured characteristic of a water body, such as its area, the conductivity of the water or the mean primary production and an expected yield. This link needs first to have been established empirically for a group of water bodies for which both the yield and the considered characteristic are known. Basically when an empirical model is applied, a given water body is being compared with the original group. For a review of empirical models applied to African inland waters refer to Crul (1992).

Empirical models have several draw backs. The water body studied should not to be too different from the ones in the original data base. If not, the empirical model is not applicable. They do not give any insight into what is actually happening in the fishery or with the stocks. The estimates of the potential production are not much better than educated guesses. They do not tell anything about the relation between fishing effort and landings. Nevertheless, these empirical models are useful when little is known and an idea of the possible levels of production is necessary. They have been used for the major lakes and reservoir covered by LFDP (1994b) (Table 1).

Surplus production models

Surplus production models need data on average catch per unit effort and effort for several years. Also, fishing effort needs to have undergone substantial changes over the years covered. These models are based on theories describing how much a stock will produce at different levels of biomass but they do not take into account factors such as growth or recruitment. The amount produced would then correspond to the "surplus" which can be removed safely to bring back the stock to its original status. The application of these models consists in fitting a mathematical model to data by a procedure known as regression analysis. As well as checking on the assumptions inherent to each model, it is necessary to test statistically the significance of the results.

A review of the surplus production models can be found in Gulland (1983) and in most stock assessment textbooks. The most commonly used surplus production models are probably the Schaefer (1954) and Fox (1970) models. According to the Schaefer model, the catch per unit effort (CpUE) is a decreasing linear function of effort. The total catch is, of course, the product of CpUE times the effort and is described by a parabola (Fig. 5).

One of the interesting properties of the Schaefer model is that it predicts that the production is maximum when the catch per unit effort is half what is at very low levels of fishing effort. This provides a first guideline for fisheries management. In the absence of indications to the contrary, Catch per Unit Effort should not be left to drop to less than half what it was at very low levels of fishing effort.

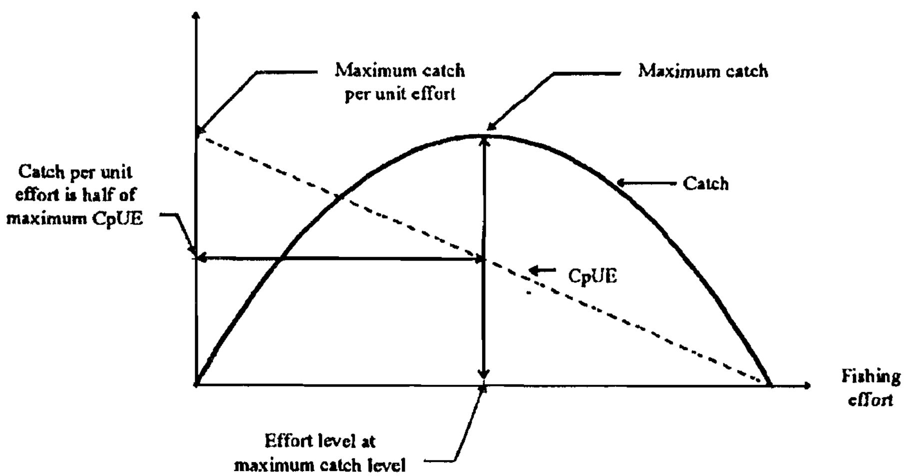

Fig. 5. The Schaefer surplus production model.

Analytical models

Analytical models are the most demanding of all. Figure 6 illustrates the concepts behind analytical models by considering what happens to a cohort from the time of birth until it has died out.

1. The number of survivors declines exponentially over time:
   $N_t = N_0 \cdot e^{-z \cdot (t - t_0)}$
2. The average length of the fish of the cohort grows according to the von Bertalanffy growth formula: $L_t = L_\infty \cdot \left(1 - e^{-k \cdot (t - t_0)}\right)$.
3. The average weight of the fish of the cohort is given by the length - weight relationship: $W = a \cdot L^b$.
4. The biomass of a cohort is the product of the number of fish times their weight.

The biomass of a cohort changes over time as the fish die, grow in length and in weight. It is maximum at a given age. Ideally this would be the age at which the fish are caught as it would guarantee the maximum possible yield. If the fish are caught before that age, there is growth overfishing. Analytical models do not usually involve any statistical procedures and therefore can not give confidence limits. Some idea of the reliability of the results is obtained by letting the input parameters vary and see the impact of the output.

The flow chart (Fig. 7) illustrates, in a simplified manner, the three major strategies in stock assessment as they are applicable to the Ethiopian fisheries. It is not the purpose here to describe these different methods. For this one can refer to a manual such as the one by Sparre and Venema (1992) or King (1995) or to original publications. Estimates of growth parameters are inputs in stock assessment studies. There are essentially two different strategies to obtain these estimates. Either fish are aged by marks on some hard structure such as ear bones or vertebra, or length frequency data is analyzed to detect growth patterns. Ideally several methods are used to corroborate the results. Length frequency analysis is now done mostly with the help of computers and specific software such as FiSAT (Gayanilo *et al.*, 1995), or LFDA (MRAG-ODA, 1992). When it can be done, the determination of growth based on linking the size of many individual fish with estimates of their actual age is thought to be more reliable. Both the Addis Ababa University and the Awassa Agricultural College have good experience in these ageing techniques (Demeke Admassu, 1989; Yosef T-Giorgis, 1990; Yosef T-Giorgis and Casselman, 1995).

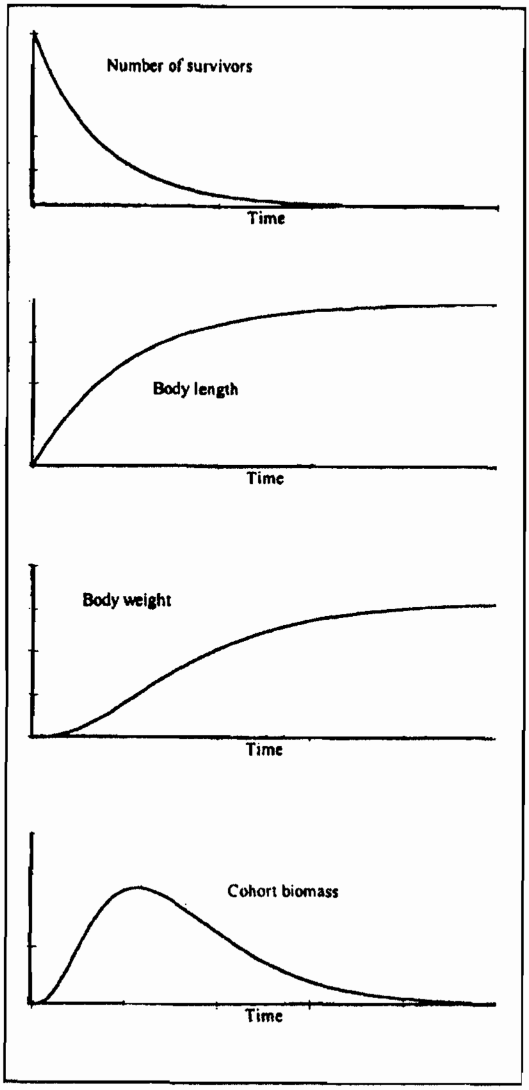

Fig. 6. Principles of analytical models.

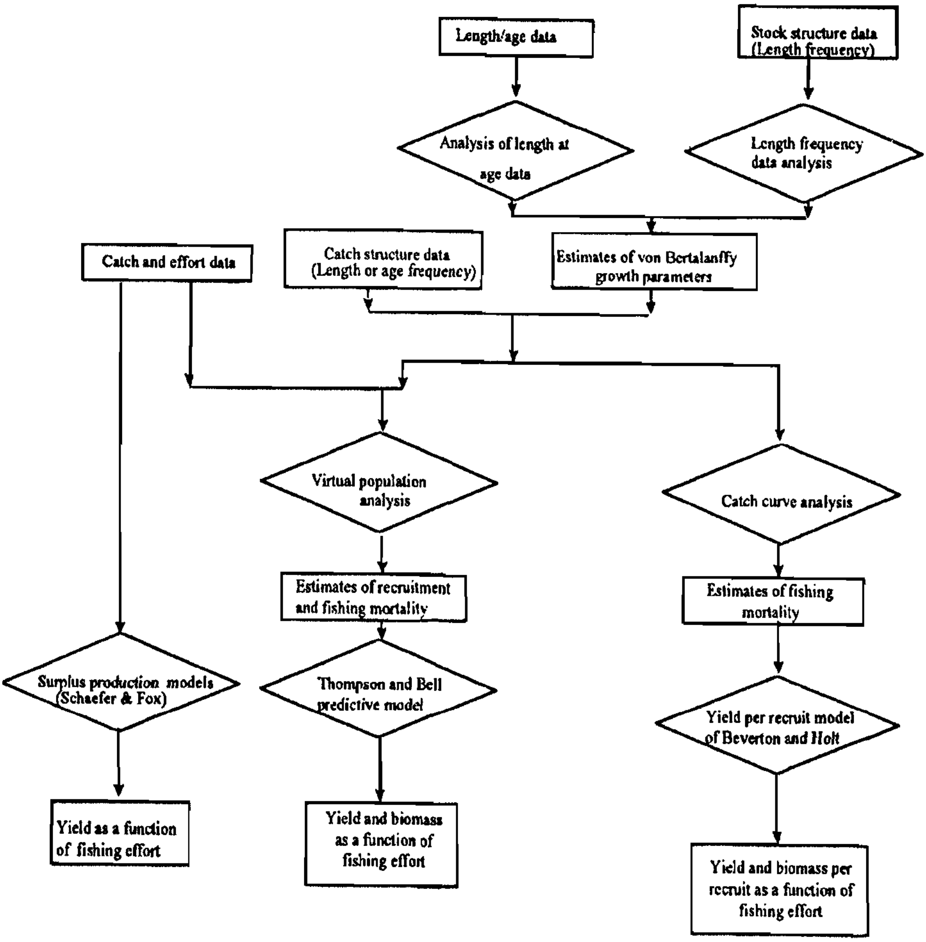

Fig. 7. Stock assessment strategies.

Only catch and effort data are needed to apply Surplus Production Models. The second and third strategies refer to analytical models which, as can be seen, are much more demanding of data. All have as output a predicted relationship between fishing effort and "sustainable" production levels. The maximum of the predicted curve is called the Maximum Sustainable Yield. However, the analytical models allow for much more refinement in the predictions about the stock behaviour.

Catch Curve Analysis in its most applied version or "Linearized Length Converted Catch Curve", assumes constant fishing mortality over the whole size range of fish exploited by the fishery (Pauly, 1983; 1984ab). This is generally not the case in Ethiopia because the gears used, mostly gill nets, are selective. For gill nets there is obviously a size of fish which has a greater probability of being retained. Fish who are smaller could swim through the net while bigger fish will simply bump into the net and then swim out. A comprehensive review of gear selectivity can be found in McLennan (1992).

The same limitation does not apply to Virtual Population Analysis (VPA). The virtual population is the population which can explain the total catch in numbers and by size or age. VPA can be either length based or age based. The length based methods, such as the Jones Length Based Cohort Analysis are the most applicable to tropical fisheries. For a review of these methods refer to Jones (1984).

Both the Beverton and Holt yield per recruit (Beverton and Holt, 1957; Gulland, 1961) and the Thompson and Bell (1934) models allow predictions to be made about the yield and the stock biomass under different levels of fishing effort. However, the Beverton and Holt model will assume constant fishing mortality over the whole size range of fish exploited by the fishery. This greatly reduces its applicability to the Ethiopian fisheries.

ELABORATION OF MANAGEMENT PLANS

There are four major points which have to be taken into account when formulating fisheries management recommendations:

- The objectives: What is it that the management of the fisheries has to achieve?

- The reference points: Once objectives have been defined it is necessary to be able to translate them into reference points which are either targets to be achieved or limits to be avoided.

- The management tools: The tools to be used have to be efficient from the fisheries biology point of view and should be related to the stated objectives. They also have to be socially and politically acceptable to the parties involved.

- The control: Sustainable implementation of any type of fisheries regulation presupposes the existence of an effective control mechanism. However, this falls outside of the purpose of the present paper and will not be further discussed.

Objectives of fisheries management

It is possible to list several very different objectives:

- *The least administrative and political trouble*

No management system is likely to be sustainable if it causes lasting political and administrative troubles. Historically, the least administrative and political trouble has often been the most important factor in starting any fisheries management scheme.

- *Fish production*

Maximising the fish production is often the stated objective of fisheries management. This is particularly appealing in situations of high quality protein shortages.

- *Economic considerations*

Aiming at a production level situated at Maximum Sustainable Yield (MSY) generally means that the return to the society (the resource rent) is lower than it could be. It is also possible to aim at guaranteeing a certain income level for the fishermen or a return on investment made.

- *Social considerations*

Should be important factors in defining the objectives of fisheries management. Particularly important are the expected effects on income distribution and employment from the fisheries sector in areas that often lack alternative income generating activities. One problem with these social considerations is that they often prove even more difficult to quantify than the economic ones and therefore to define clearly.

Reference points

A reference point is a quantified expression of the chosen management objective. It is a value derived from technical analysis which represents a state of the fishery or of the resource and which is believed to be useful for the management of the stock. To be useful Reference Points need to have a means of verification and an objectively verifiable indicator. Two basic types of reference points may be identified:

- A Target Reference Point (TRP) indicates a state of the fishery or of the resource which is considered desirable and at which management should aim. Target reference points require constant monitoring and readjustment of management measures;
- A Limit Reference Point (LRP) indicates a state of the fishery or of the resource which is deemed undesirable and which management action should avoid. When a LRP is reached, it should trigger automatic corrective measures.

Some of the most commonly used reference points are briefly discussed below. A review is given in Caddy and Mahon (1995).

Maximum sustainable yield criteria

The Maximum Sustainable Yield (MSY) and the corresponding levels of fishing effort (f_{MSY}) or fishing mortality (F_{MSY}) are probably the oldest reference points used in fisheries management. This is because the concept is clear and simple. It is therefore easily accepted by the responsible bodies and the public. However, experience shows that MSY is not a safe target and that it might be better to consider it as a limit to avoid.

The reasons for the poor performance of MSY criteria are several. Most important is that MSY estimates are generally not very reliable. An accuracy better than ± 20% on the level of effort yielding the MSY is rare. Also natural production does fluctuate quite a lot from year to year, particularly for the faster growing and shorter lived species. The fluctuations from year to year will also be bigger as the production levels come nearer to the estimated MSY. In a bad year, if the effort applied is the estimated f_{MSY}, the stock will in effect be over-exploited. The consequences of this accidental over-exploitation will be felt for a long time. It is to avoid such an accidental overfishing that the TRP of *2/3* f_{MSY} is sometimes proposed (Doubleday, 1976). It allows a large fraction of the MSY to be harvested (about 80%) but reduces very much the risk of accidental over-exploitation and stock collapse. Figure 8 illustrates these points. The curve shown is the predicted yield/effort relationship for *Bagrus docmak* from Lake Abaya (LFDP, 1996d; 1997a).

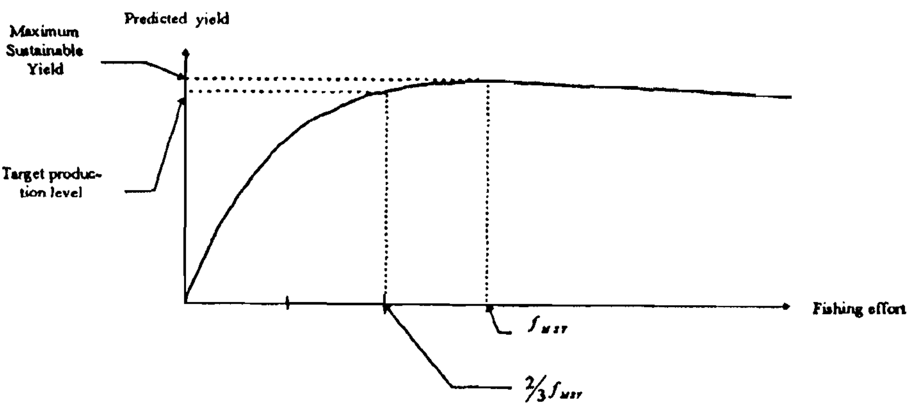

Fig. 8. **MSY criteria to define a TRP.**

Effort criteria

One of the outputs of the Thompson and Bell length based predictive model is a curve linking an estimated or predicted (equilibrium) yield with effort. However, for many species there is no clear maximum to this curve. Also, the calculations assume constant recruitment. This is an assumption unlikely to be met at high levels of effort and consequently low levels of spawning stock biomass. Because of this $f_{0.1}$ (f nought point one) has been proposed by Gulland and Boerema (1973) as a TRP. The $f_{0.1}$ is the level of fishing effort at which the marginal yield is one tenth what it is at very low levels of fishing effort. For an example of the application of this criteria on an African inland fishery see FAO (1993). Figure 9 illustrates these points on the predicted yield/effort relationship for *Bagrus docmak* from Lake Abaya (LFDP, 1996d; 1997a).

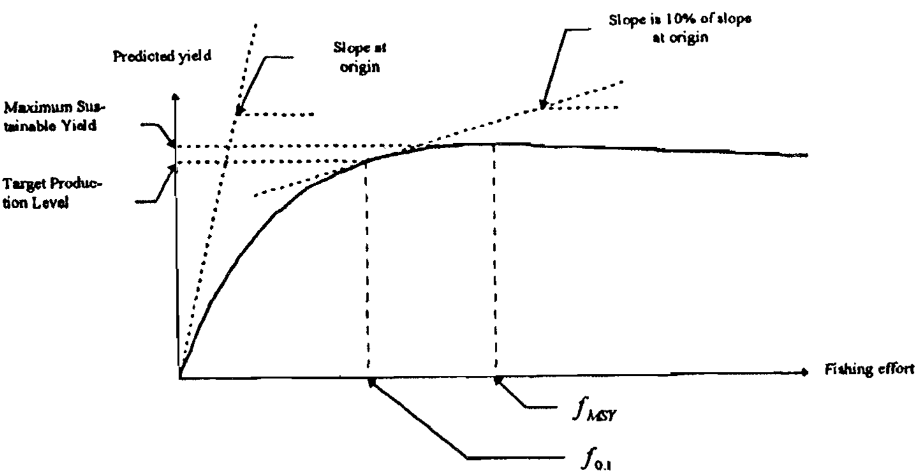

Fig. 9. The $F_{0.1}$ criteria to define a TRP.

Size of fish criteria

The mean size of the fish caught can be used in conjunction with other data, in particular size at maturity data. The rationale is to make sure that enough individuals have a chance of reproducing before capture and minimise the risks for recruitment overfishing. However, one should notice that this introduces a selection pressure towards small early maturing fish (individuals and/or species).

Spawning stock biomass criteria

The Thompson and Bell length based predictive model can also be used to predict the mean length of the fish caught and the corresponding size structure of the stock. In conjunction with sex ratio and size at maturity data, this makes it possible to predict the Spawning Stock Biomass under different levels of fishing effort. When the relation between Spawning Stock Biomass (SS) and Recruitment (R) is not known it is generally advisable to aim for at least 30% of the virgin (un-fished) stock (Clarke, 1991).

Ecosystem criteria

The need for multi-species or ecosystem approaches has frequently been raised. It is, however, very difficult to identify clear reference points which may be useful in this context. Also there is only a limited experience with them. One possibility is to set LRP in terms of minimum or maximum proportion of certain species in the catch. Another approach involves the use of biomass size spectrum of living organisms as an indicator of exploitation.

Economic criteria

The fishing effort (or mortality) corresponding to the Maximum Economic Yield is often given as a TRP. However, it is at least as difficult to quantify exactly as the MSY. Also any economic criteria reference point is responsive to changes in the economic environment such as the prices of inputs and of fish, the level of subsidies and so on.

Tools available

A legal consultancy provided by FAO, showed that there are at present (early 1998) no legally enforceable fisheries regulations or rules in Ethiopia. A number of directives regulating the fisheries have been issued in the past. They are no longer in force as the primary legislation under which they were issued have been repealed. In particular, members of fisheries co-operatives do not enjoy any specific legal advantage as far as fishing rights are concerned. This situation will change soon as a draft national fisheries proclamation has been elaborated. Also, lake management plans have now been drafted for the major lakes and reservoirs of the country (LFDP, 1996d). The draft fisheries proclamation provides for the identification of Fisheries Management Areas to be declared and administered by the Regions. The Regions could then concentrate their management efforts (and the means available) on their most valuable resources.

The major management tools which might be considered by the Regions are briefly discussed below:

- *Catch quotas*

Catch quotas are an appealing concept but the drawbacks are many. Such a system requires the collection and processing of catch data in real time. In addition, the control system must be able to take action very fast. It has been shown that under conditions of environmental perturbations and recruitment variations, a constant effort strategy ultimately results in higher catch rates than a constant catch strategy. This is the case even when the two strategies correspond to the same theoretical reference point in terms of production (Hanneson, 1993).

- *Closed area*

A closed area is a fixed and known part of the water body that remains off limits for the fishery year round. There are different reasons a closed area may be desirable. The first is to protect certain life history stages. For instance, the nursery grounds of some fish species with protracted or year round spawning seasons could be protected as closed areas. Alternatively, closed areas can be extremely useful to insure a minimum escape of the spawning fish. The second reason is that the part of a fish stock present in such a closed area constitutes a buffer or reservoir protecting the fishery against fluctuations in yield.

- *Closed seasons*

We speak of a closed season when a part or the whole of a water body is closed for fishing during a specific time period each year. Seasonal closures are usually implemented to protect particularly vulnerable stages in the life cycle of a stock. Classical examples are migrating or spawning stocks and juvenile fish on the nursery grounds. To be effective such a tool requires that the specific moment and place a stock is vulnerable be clearly identified.

• *Mesh size regulations*

In their most common form mesh size regulations aim at allowing immature fish to escape capture by gill nets. However, mesh size regulations may be required for other gears such as beach seines, or may have the aim to allow the bigger spawning fish to escape capture. Mesh size regulations should be based upon knowledge of the reproductive biology of the stock and the selectivity of the gear considered.

• *Gear restrictions*

Certain types of gears or fishing practices may need to be forbidden altogether. This is so when they are so particularly effective in killing fish that even at low levels of application they may irreversibly damage the stocks. Very often these are gears or practices that target particularly vulnerable stages in the life cycle of a stock.

• *Licensing*

Open access to the fishery is generally assumed to be the major problem in Ethiopia. To overcome it would require either a licensing system or some private or community rights. The major problems associated with a licensing system are the definition of the number of licences, their kind and who is eligible for them. The number and exact kind of licences would probably have to be decided lake by lake. Ideally, a licence would authorise its bearer to fish with clearly specified types and numbers of crafts and of gears.

• *Auction of property rights*

Under this system the ownership of a particular stock or stocks would be given to the highest bidder. Equity is the major problem here, as by giving the property rights to one individual or institution they are automatically denied to others.

• *Community rights*

Attributing community rights to the fishery is only second to the auctioning of property rights as the easiest way for the authorities to get rid of the problem of management altogether. The communities would get the responsibility of the management and have to bear the consequences. Such communities might still be given technical advice but would otherwise do as they like.

- *Taxes on effort or catch*

Any form of taxation, be it on the effort (such as the number of nets) or on the catch, would make fisheries less attractive. If the taxes are reasonably well collected this would drive the less efficient fishermen out of the business and reduce overall effort. Implementation is however, a problem. One way out would be to couple this taxation to the issuance of a licence.

- *Control of traders*

The fishermen we have been considering are not producing for own consumption but for cash. They have to sell their production and to buy some inputs. In most cases they have to address a middleman, a trader, who will bring the product to the consumer and/or supply them with what they want. This necessary link can be used to exert a certain amount of control on the fishery.

All these tools aim to be means for the regulation of fishing effort, or, stating it otherwise, of fishing mortality. Fishing mortality is the rate at which the fishery is removing fish from the lake. It is important to stress that it is indeed the rate at which the fish die and not how that is of relevance to our discussion. Limiting a certain gear or forbidding it altogether is useless if other fishing practices can compensate for it. For instance closed seasons can be even counterproductive if they lead to increased fishing effort before or after the closure.

DISCUSSION OF RESEARCH NEEDS AND PRIORITIES

The data or information directly used in stock assessment models are, for each stock separately:

1. Data on the amount of fish caught and the effort extended to achieve that production;

2. Data on the catch structure (length or age frequency);

3. Information on the growth (Von Bertalanffy Growth Formula parameters);

4. Information on the reproductive biology (essentially the relationship between size and maturity).

It is evident that for a fully rational management more information is desirable, in particular about the ecosystem in which the stocks exit and about the stocks themselves, especially the spawning grounds and seasons. In addition, it should be stressed that the stock assessment models mentioned use data from a commercial fishery. They do not apply if there is no commercial fishery at all.

Table 2 presents on overview of the current documented knowledge on growth and reproductive biology of the most important stocks. One peculiarity of fisheries research, is that the collection of data and information even on the above mentioned areas, is a never-ending process. All fisheries are continuously changing. Each year is different from the previous for man made (such as new gears) or natural causes (such as an exceptionally abundant rainfall). Particularly, data on catch and effort and on catch structure need to represent uninterrupted time series to be most useful. The growth and reproductive biology will also undergo changes though less marked. Any such study therefore needs to be updated from time to time and can anyway only be used for stock assessment if the data on the fishery are already available. If the fishery reduces the biomass of a given species, the remaining individuals may be expected to grow better as they have more food and space. Some species, such as Tilapia, are able to adjust their size/age at maturity to compensate for increased fishing pressure. For instance, on Lake Ziway, the average size at first maturity of female *O. niloticus* has gone down from 18–19 cm a few years ago (Woldemichael Getaneh and Maria Getaneh, 1979) to less than 16 cm (Yared Tigabu and Abee Mamo, 1996).

In principle, the data collection and analysis systems set-up by the Ministry of Agriculture with the Regional Bureaux and local offices with the support of the EU funded Lake Fisheries Development Project - Phase II, are to cover continuously the four types of data needed for stock assessment. In practice, this has proven over-ambitious and the priority is given to data on the fishery itself or on the first two as it is only the Ministry of Agriculture with the Regional

Bureaux which can provide the necessary continuity. These data are now being routinely collected for the stocks presented in Table 2.

While there are quite a few papers published on the limnology of different Ethiopian lakes (see for instance Amha Belay and Wood, 1982; Kassahun Wodajo and Amha Belay, 1984; Wood and Talling, 1988; Tudorancea *et al.*, 1989; Seyoum Mengistou and Fernando, 1991ab; Elizabeth Kebebe and Amha Belay, 1992; Elizabeth Kebebe *et al.*, 1992; Zinabu G/Mariam, 1994, not to mention several MSc theses), we are aware of only one paper aiming specifically at stock assessment and fisheries management (Schroeder, 1984). Two more papers by Nagelkerke *et al.* (1994; 1995b) address the issue of management in the context of the preservation of biodiversity of a unique *Barbus* spp flock in Lake Tana.

The barbs, generally of Lake Tana, have received a lot of attention mostly from the point of view of their taxonomy (Golubtsov and Krysanov, 1993; Mina *et al.*, 1993; 1996; Sibbing *et al.*, 1994; Nagelkerke *et al.*, 1994; 1995ab; Nagelkerke and Sibbing, 1996; Nagelkerke, 1997; Demeke Admassu and Elias Dadebo, 1997).

Quite some studies have been conducted on Nile tilapia from Lake Ziway (Woldemichael Getaneh and Maria Getaneh, 1979; Getachew Teferra, 1987b; Zenebe Tadesse, 1988; Eyualem Abebe and Getachew Teferra, 1992) or Lake Awassa (Getachew Teferra, 1987ab; Tudorancea *et al.*, 1988; Getachew Teferra and Fernando, 1989; Demeke Admassu, 1989; 1990; 1994; 1996; Yosef T-Giorgis, 1990). Only two papers and two MSc theses refer to Nile tilapia from other lakes: Lake Chamo (Getachew Teferra, 1993; Yirgaw Teferri, 1997), Lake Haiq (Kebede Alemu, 1995) and Lake Tana (Zenebe Tadesse, 1997). Seifu Seyoum and Kornfield (1992) argue that the tilapia of Lake Tana should be considered an endemic sub-species *Oreochromis niloticus tana*. Two more MSc Theses look at the African catfish, *Clarias gariepinus* from Lake Awassa (Elias Dadebo, 1988) and *Bagrus dokmac* (Forskall 1775) from Lake Chamo (Hailu Anja, 1996).

Moreover, there are several ongoing studies and PhD or MSc research projects on the fisheries in the Southern part of Lake Tana, the Nile perch of Lakes

Abaya and Chamo, the tilapia from the lakes Chamo, Langano and Ziway and the catfish of lakes Awassa and Chamo. Some of these should be nearing publication. Also LFDP has collected and analyzed data for all the most important stocks of the country but this is reported in 'grey' (not peer reviewed) literature only (LFDP, 1993, 1994ab, 1995ab, 1996abcd, 1997ab).

Von Bertalanffy Growth Parameters

Strictly speaking only a good estimate of L_∞ is necessary to be able to carry out the length based stock assessment methods. Preliminary estimates of L_∞ are available for all stocks. For some of the stocks, good estimates of both parameters (K and L_∞) are available and were obtained by length frequency data analysis and age determination. For other stocks, particularly the tilapia stocks, estimates of both parameters (K and L_∞) are available but were obtained only by length frequency data analysis. They are marked as satisfactory.

Relationship maturity/size

This relationship allows for the modelling of spawning stock biomass levels as a function of fishing effort. It can also be used to elaborate recommendations on allowed gear characteristics such as minimum gill net mesh sizes. This relationship is available only for the tilapia stocks of Awassa, Tana and Ziway and for the intermedius morphotype (*Barbus tsanensis* spec.nov) and *Clarias gariepinus* of Lake Tana. The fact that this mathematical expression is not available does not imply a complete lack of knowledge or any management problem. For instance the relationship has only recently been described for the tilapia from Lake Chamo (Yirgaw Teferri, 1997) but because all fish caught by the commercial fishery are very big and mature this did not mean there was any problem. Although there are differences between water bodies, a lot of information can be obtained from literature.

Spawning seasons/grounds

The knowledge of spawning seasons can be used to mark closed seasons for fishing if the spawning areas are known. A "No" in the table means that published or "grey" literature" referring to a specific technical or scientific study on that subject for that particular stock is not available. Again, this does not imply a total absence of knowledge on the topic or any management problem. The fishermen and the fisheries officers are usually very well aware of the spawning periods and grounds. Literature about the same species in other water bodies is also valuable. For instance, there is no reason to suspect that the Nile perch from Lake Abaya would behave differently from Nile perch in other lakes inclusive nearby Lake Chamo.

The current situation is therefore one in which even small but well focused research projects on the growth and reproductive biology of the major stocks can contribute directly to the rational management of the fisheries. Such projects are well suited to academic institutions as good results can be obtained based on data covering a single full annual cycle. However, a good communication between the academic institutions and the Ministry of Agriculture together with the Regional Bureaux of Agriculture is necessary if this "applicable research" is to make the contribution it can. This condition is for the time being not being fulfilled for several reasons. These are probably mostly related to different priorities. Research institutions need to have their results published. They may be reluctant to share their data and information until actual publication. Unfortunately, this is a process which may take years by which time the data have lost most of their usefulness for stock assessment and resource management. The way to overcome these problems is to meet more and to get to know each other better. We hope that the publishing of a "fisheries statistical bulletin" which aims to make the data collected on the fisheries available to all contributes to this goal.

The question remains then on how to identify these small but well focused research projects? To select one, we could use some criteria such as:

1. The current production level;
2. The estimated production potential;
3. The amount of knowledge already gained.

Even based on these criteria, it is evidently not possible or even desirable to give a kind of hit-parade list. Nevertheless certain priorities should be apparent.

- The growth and reproductive biology of *Labeo* on Lake Chamo. This species is the major prey for the Nile perch which is now overfished. Nevertheless relatively little is known about this species. Good estimates of the growth parameters would be particularly useful.

- The growth, reproductive biology and spatial distribution of *Clarias* on all lakes. Though there are a lot of published and consistent data on *C. gariepinus* from other African lakes or even under aquaculture situations, relatively little is specific to Ethiopian water bodies.

- The growth and reproductive biology of *Bagrus docmak* from Lake Abaya would certainly also be useful. The results could be compared with those of a study recently conducted but not published about the same species in Lake Chamo (Hailu Anja, 1996).

  The difference between the potential production levels as guessed by empirical models and the safe production levels determined by stock assessment methods may be very big (Table 1). This is due to several factors. The models might simply not be applicable because of some specific parameters. For instance the lakes Abaya and Langano have extremely turbid water. This must result in lower than expected productivity. The "safe levels" for a given lake is the sum of the safe levels obtained for individual stocks. Empirical models do not make this distinction. If some stocks are not exploited the total "safe level" for a lake will be underestimated. Lake Tana, in particular, will never fulfil its promise of being the single biggest source of fish, unless a pelagic fishery can be developed. One candidate species for such a fishery is *Barbus trispilopleura* (Boulenger, 1902) about which very little is actually known.

- The study of the growth, reproductive biology and spatial distribution of the small pelagic *Barbus* of Lake Tana should therefore also receive high priority.

Up to this point the word ecosystem has been used only once and feeding not at all. This is not an oversight. Ecosystem information such as feeding biology or composition and biomass of benthos or plankton, is interesting and useful. No fish is an island. Such information does give us a better understanding of what we see, but, for the time being, it can not be easily translated into management advice. The paucity of benthos in some lakes may explain why there are few bottom feeders. However, it will not in any way help one to find out how much of these few existing bottom feeders can safely be harvested. Nevertheless, it certainly would be very interesting if a comparison was made of productivity indices such as primary productivity or plankton/benthos biomass for the major lakes and reservoirs with the actual or estimated save production levels. This would, for instance, help to corroborate (or to reject) the disappointing results obtained by stock assessment techniques for the lakes Abaya and Langano. It could also provide a quick tool for a preliminary assessment of the potential yields from not yet exploited water bodies, mostly reservoirs. This would be a locally developed empirical model. For the most studied lakes, there should already be enough information to build ecosystem models of the kind made possible with ECOPATH 3.0, a specific software developed by ICLARM. Finally as time series of catch and effort data become available, it would be interesting and potentially very useful to try to develop single lake models incorporating environmental parameters such as water level fluctuations, and effort to make yield predictions.

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