The Relationship Between Catch and Effort and its Effect on Predicted Yields of Sardine Fisheries in Lake Kariba

B.E. MARSHALL

Abstract

There is an unusual relationship between catch per unit effort and effort in the Lake Kariba sardine fishery. This is apparently a result of ecological changes in the lake following the decline of the *Salvinia* mats that existed there until 1973. Predictive models based on the entire data set (1974-89) are of limited value because they are influenced by the rapid decline in catch per unit effort that took place from 1974 to 1978. A model based on the 1980-89 data indicates that the current catch could be increased substantially. Some empirical models and features of the sardine's biology suggest that it is a realistic model.

Introduction

The relationships between fish catches and the effort needed to achieve them are of fundamental importance in the management of fisheries. These data are of special significance because they constitute the history of fished species and, ultimately, provide the best index of what has happened to it.

It seems, however, that there is a decreasing interest in studying catch-and-effort data in fisheries research for most developing countries. One reason is that these data are difficult and expensive to collect, especially if a fisheries site has many widely scattered fishers using a variety of gears which means that estimates of effort cannot be standardized. Also, advances in computer software have made it relatively easy to investigate growth and mortality and use these data in fisheries management. This is borne out by a rough analysis of the papers in the first seven volumes of *Fishbyte*, articles on aspects of growth and mortality are about 3.5 times more frequent than those on catch and effort.

Lake Kariba is a large reservoir (5,400 km^2), and has a large outflow (50-65 $km^3 \cdot year^{-1}$) relative to its volume (160 km^3). This is important because it means that significant amounts of nutrients are lost each year. Consequently, the quantity of nutrients brought in by the Zambesi and other inflowing rivers during the rainy season (November-April) determines the productivity of the lake in the following year. This is most clearly illustrated by the variations in sardine abundance in relation to river flow (Marshall 1982, 1988a, 1988b).

Fishing for the sardine *Limnothrissa miodon* in Lake Kariba began in 1974 and is well documented because catch-and-effort statistics have been collected from the beginning. In addition, ecological work has been done on the lake since it was created in 1958 (Marshall 1984) and the view that catch-and-effort statistics backed up by ecological data can play a major role in fisheries management is examined in this paper.

Catch and Effort in the Kariba Sardine Fisheries

The relationship between effort and catch per unit effort in this fishery is an extraordinary one (Fig. 1). Catch per unit effort (C/f) fell rapidly from 1.56 t/night in 1974 to 0.42 t/night in 1979, while effort rose from 313 to 11,511 nights per year.This sharp decline suggested that fishing was having a major effect on the stocks, and models based on the catch-and-effort data then available led early workers to predict that the maximum sustainable

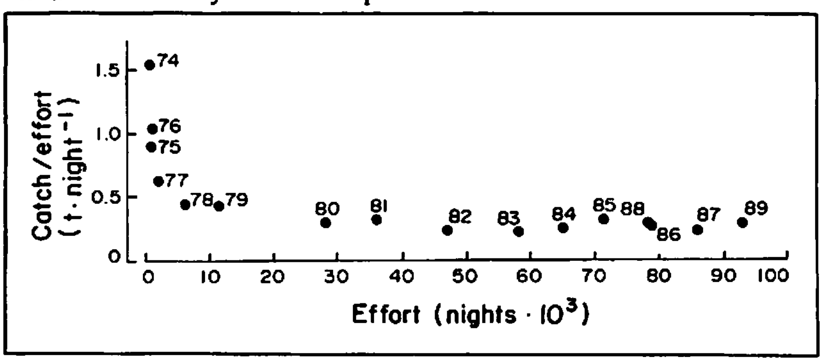

Fig. 1. *The relationship between fishing effort (f) and catch per unit effort (C/f) in the Lake Kariba sardine fishery, 1974-78 (Zimbabwean and Zambian data combined). Based on Zimbabwean data in Marshall (1987a) and Sanyanga et al. (1990) Zambian data; Zambia Fisheries Department and Scholz and Mweetwa (1990). Estimates of effort were not available for the Zambian fisheries in 1988 and 1989 so this was estimated by assuming that C/f for those years was equal to the mean for the two preceding years (1986-87).*

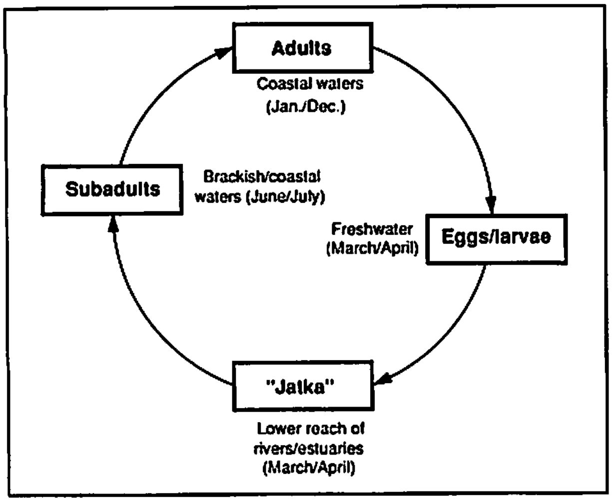

Fig. 1. ***Framework used to structure the available information on the life history of hilsa in Bangladesh, illustrated by ways of the "main stock" (adapted from Fig. 1 in Bakun et al. 1982).***

with ELEFAN. These suggested for a value of TL_∞ = 60 cm, a range of K = 0.8-1.0/year for hilsa in Bangladesh as a whole. Also, gill net selection curves were applied to the available length-frequency samples and catch curves were then constructed. These confirmed that the mortality experienced by hilsa in Bangladesh is extremely high. On the other hand, stock identifications, as mentioned before, remain an open issue and morphometric and electrophoretic studies are still required to resolve this. The results may change the stock definitions presented in Fig. 2, but will not affect the usefulness of the matrix approach we adopted.

The major research gap that was identified for all stocks and stages (except eggs/larvae) is the need to obtain and analyze catch-and-effort data. These, analyzed by stock, and using a length-based version of virtual population analysis, will tell us which of the gears used to exploit hilsa has the most deleterious effects for the fishery as a whole, and what mix of gears would maximize yields.

We expect to obtain these results in 1993. They will be presented, along with the supportive evidence, in a publication on the freshwater resources of Bangladesh.

In the meantime, we conclude this with the suggestion of four measures which, if implemented, would already lead to higher overall catches:

i) reduce effort on "jatka" in nursery grounds, especially in March/April;
ii) reduce effort on spawning grounds during the peak spawning season (September/October);
iii) ban "gara jal" (bamboo fencing) entirely blocking rivers; and
iv) reduce catch of hilsa below 35 cm by restricting the use of small-meshed nets.

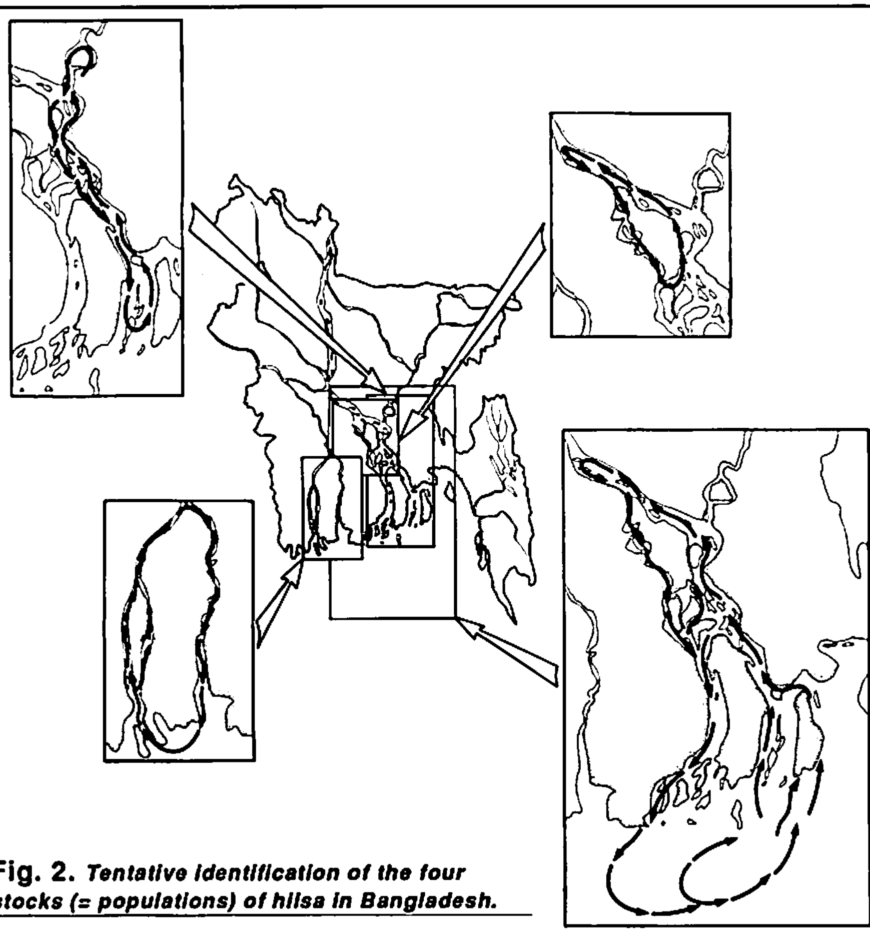

Fig. 2. ***Tentative identification of the four stocks (= populations) of hilsa in Bangladesh.***

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Further Reading

Bakun, A., J. Beyer, D. Pauly, J.G. Pope and G.V. Sharp. 1982. Ocean science in relation to living resources. Can. J. Fish. Aquat. Sci. 39(7):1059-1070.)

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yield and optimum effort would be about 7,000 t and 25,000 nights, respectively (e.g., Marshall et al. 1982). These predictions proved to be incorrect and the catch and effort rose to around 25,000 t and 90,000 nights, respectively. Despite a huge increase in fishing effort there was no significant change in C/f between 1980 and 1989. Minor variations are attributed to changes in river flow following droughts (Marshall 1988a).

What then is the explanation for this unusual relationship? The decline in C/f during the first years of the fisheries is clearly unrelated to the level of fishing effort. If this were not so, the decline would have continued into the 1980s but it did not. The answer seems to be that this is a consequence of ecological changes in the lake during the early 1970s.

During the first half of its existence, Lake Kariba was dominated by extensive mats of the floating fern *Salvinia molesta*. This plant reached its greatest extent in 1962 when it covered about 1,000 km^2 or 22% of the lake's surface. Coverage then decreased to 5% in 1973, 1% in 1978 and is now of negligible importance to the ecology of the lake. It is not clear why this sudden decline took place. Mitchell and Rose (1979) suggest that the weed might have been controlled by a neotropical grasshopper *Paulinia acuminata* which was introduced for this purpose. On the other hand, Marshall and Junor (1981) suggest that the weed lost in a competition for nutrients.

Whatever the explanation, the decline of *S. molesta* seems to have had a major effect on fish populations (Fig. 2). This plant had played a significant role in retaining nutrients (Mitchell 1973) and its decline evidently released large quantities of nutrients which enabled fish populations to increase. This increase was shortlived because of the loss of nutrients through the outflow and all stocks began to decline after 1974. This, of course, applies to the sardine stocks as well and the trend in tigerfish abundance (see Marshall 1987b). The situation appears to have stabilized in 1980 when fish populations stopped decreasing and some increased slightly in subsequent years.

Predictive Models Using Catch-and-Effort Data

The exponential model of Fox (1970) fits the entire data set (1974-89) rather well (Table 1) and predicts that the maximum sustainable yield is about 25,000 t while the optimum effort would be about 110,000 nights (Fig. 3). This is close to the current yield. This model behaves exactly like earlier ones, with shorter time series, which also suggested that the current levels of effort were optimal (Table 2). A model based on the entire data set seems, therefore, to be of little practical value.

The model based on the 1980-89 data alone was strikingly different (Table 1). The very small correlation coefficienty shows that C/f did not change as effort increased during this period. Accordingly, it seems that increases in yield and effort are still possible (Fig. 3).

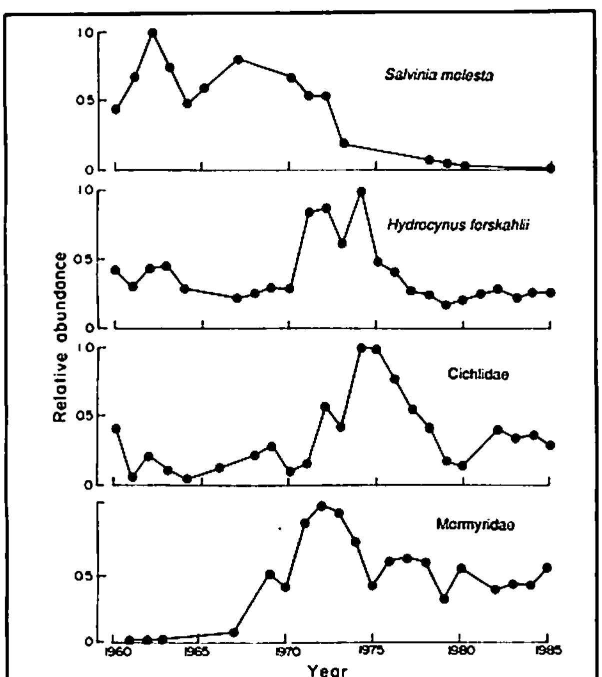

Fig. 2. ***Relative abundance of important organisms in the eastern basin of Lake Kariba, 1960-85. Data from Marshall and Junor (1981), Marshall (1984), Machena (1990) and Lake Kariba Fisheries Research Institute (unpublished data).***

Table 1. Models for predicting catch per unit effort (t/night) in the Kariba sardine fishery, based on catch and effort data. Methods according to Fox (1970).

Period	Type	Equation	Correlation
1974-89	Exponential	$\log_e(C/f) = 0.57 \exp(-8.42 \times 10^{-6} f)$	-0.50
1980-89	Linear	$C/f = 0.28 - (2.50 \times 10^{9} f)$	-0.002

Table 2. Relationship between predicted and current maximum sustainable yield and optimum levels of effort, based on the entire data set available at various times, in the Lake Kariba sardine fishery. Note that "current" values refer to those in the last year of the period under consideration. Both the linear and exponential relationships were used.

	Yield		Effort		
Period	Current	Predicted	Current	Predicted	Source
1974-80	7,988	7,000	27,723	25-30,000	Marshall et al. (1982)
1974-84	16,602	14-16,000	64,868	86-129,000	Marshall (1985)
1974-89	28,451	25,000	92,855	110,000	this paper

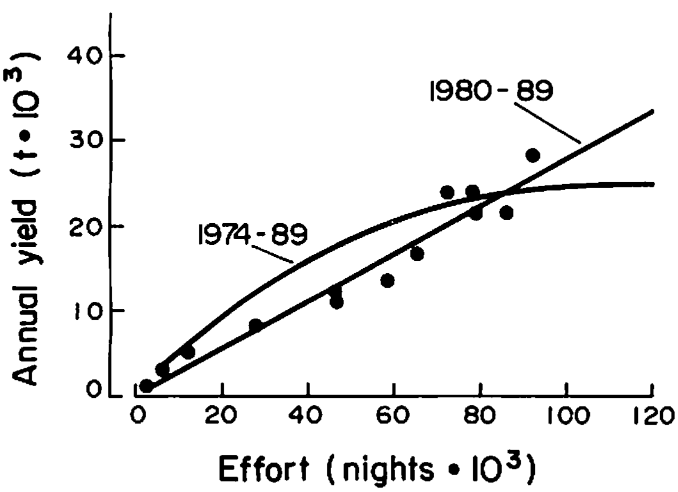

Fig. 3. ***Predicted yield of the Kariba sardine fisheries based on the models in Table 1. The points show the existing relationships between effort and yield (data points for 1974-76 have been left out for clarity).***

Discussion

It is clear that there are two periods in the fisheries: a) prior to 1980 when the effects of the *S. molesta* decline were still being felt; and b) post-1980 when the lake had stabilized and was no longer being influenced by nutrients released from the weed. Data from the first period exert a strong influence on the data from the second and they should be left out because they are a consequence of conditions that no longer exist in the lake. The post-1980 data are probably a more realistic representation of what has happened in the fisheries recently but the predictions are so different that few fisheries managers are likely to accept it uncritically.

Is it realistic to suppose that efforts and yield could be substantially increased? Some aspects of the sardine's biology suggest that this is possible. In 1981-83 the mean biomass of the sardines was about 25,000 t but it is likely to be rather higher than this at other times because 1982 and 1983 were years of poor rainfall and the sardine biomass was considerably reduced (Marshall 1988c).

Limnothrissa is a small, short-lived species with a very high turnover as reflected in its high mortality rate of 4-6/year (see Kolding et al., p. 39). This means, therefore, that annual biological production might be in the order of 125,000 t/year, of which a large fraction might be harvestable.

Another way of testing this idea is to see what potential yields (Py) are predicted by some of the empirical models that are available for this purpose. One is Pauly's (1982) equation, in which

$$Py = 2.3\ \overline{W}^{-0.26}\ \overline{B}$$

$\overline{W}$ = mean weight of individual fish (here about 1.0 g) and $\overline{B}$ = mean biomass (25,000 t). The result is a predicted yield of 57,500 t/year.

The second empirical model is Cadima's modification of Gulland's equation (Sparre et al. 1989) in which

$$Py = 0.5\ Z \cdot \overline{B}$$

with all symbols as defined above. With $Z < 5$/year, the result is a predicted yield of 62,500 t/year.

Thus, biological data and the performance of the fisheries itself support the view that the fisheries in Kariba is capable of further expansion. Obviously, this expansion could not go on indefinitely and some safeguards would be needed; for example, it might become necessary to close the fisheries during part of the breeding season, from September to April. Catches are, in any case, lowest from November to February (Marshall 1988a) so this might not be difficult to enforce.

The Lake Kariba fisheries were allowed to expand relatively slowly at first because no one knew what the sustainable yield would be (Marshall et al. 1982). Although it was agreed that there was evidence of overfishing at this stage (Machena and Mabaye 1987) this cautious approach has been continued and the expansion of fishing effort has been slow in recent years. Perhaps fishing effort could be allowed to increase progressively, provided of course that accurate catch-and-effort statistics continue to be kept.

References

Fox, W.W. 1970. An exponential surplus yield model for optimizing exploited fish populations. Trans.Am. Fish. Soc. 99:80-88.

Machena, C. 1990. Ecology of the hydrolittoral macrophyte communities in Lake Kariba, Zimbabwe. Uppsala University, Uppsala, Sweden. Ph.D. thesis.

Machena, C. and A.B.E. Mabaye. 1987. Some management aspects and constraints in the Lake Kariba fishery. Naga, ICLARM Q. 10(4):10-12.

Marshall, B.E. 1982. The influence of river flow on pelagic sardine catches in Lake Kariba. J. Fish Biol. 20:465-470.

Marshall, B.E. 1984. Lake Kariba (Zimbabwe/Zambia). *In* J.M. Kapetsky and T. Petr (eds.) Status of African reservoir fisheries. CIFA Tech. Pap. 10:105-153. FAO, Rome.

Marshall, B.E. 1985. A study of the population dynamics, production and potential yield of the sardine *Limnothrissa miodon* (Boulenger) in Lake Kariba. Rhodes University, Grahamstown, South Africa. Ph.D. thesis.

Marshall, B.E. 1987a. Catch and effort in the Lake Kariba sardine fishery. J. Limnol. Soc. South Afr. 13:20-22.

Marshall, B.E. 1987b. On the relationship between tigerfish and sardines in Lake Kariba. J. Limnol. Soc. South Afr. 13:78-79.

Marshall, B.E. 1988a. Seasonal and annual variations in the abundance of pelagic sardines in Lake Kariba, with special reference to the

effects of drought. Archiv. Hydrobiol. 112:399-409.
Marshall, B.E. 1988b. Why are the sardines in Kariba so small? Zimbabwe Sci. News 22:31-35.
Marshall, B.E. 1988c. A preliminary assessment of the biomass of the pelagic sardine *Limnothrissa miodon* in Lake Kariba. J. Fish Biol. 32:515-424.
Marshall, B.E. and F.J.R. Junor. 1981. The decline of *Salvinia molesta* on Lake Kariba. Hydrobiologia 83:477-484.
Marshall, B.E., F.J.R. Junor and J.D. Langerman. 1982. Fisheries and fish production on the Zimbabwean side of Lake Kariba. Kariba Studies 10:175-231.
Mitchell, D.S. 1973. Supply of plant nutrient chemicals in Lake Kariba. *In* W.C. Ackermann, G.E. White and E.B. Worthington (eds.) Man-made lakes: their problems and environmental effects. Geophysical monograph series 17:166. American Geophysical Union, Washington.
Mitchell, D.S. and D.J.W. Rose. 1979. Factors affecting fluctuations in extent of *Salvinia molesta* on Lake Kariba. PANS 25:171-177.
Pauly, D. 1982. Studying single-species dynamics in a multi-species context, p. 33-70. *In* D. Pauly and G.I. Murphy (eds.) Theory and management of tropical fisheries. ICLARM Conf. Proc. 9, 360 p.
Sanyanga, R., P. Jokonya and R. Chimanga. 1990. 1989 Fisheries statistics, Lake Kariba-Zimbabwe side. Project Report 68. Lake Kariba Fisheries Research Institute, Zimbabwe.
Scholz, U. and E. Mweetwa. 1990. Data on Lake Kariba fisheries. Gwembe Integrated District Development Programme, Gwembe. 18 p. (Unpublished)
Sparre, P., E. Ursin and S.C. Venema. 1989. Introduction to tropical fish stock assessment: Part 1. Manual FAO Fish Tech. Pap. 306(1).

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Growth, Mortality, Maturity and Length-Weight Parameters of Fishes in Lake Kariba, Africa

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Abstract

This preliminary compilation presents vital parameters for 22 species of freshwater fish from Lake Kariba. The majority of the growth parameters are derived from tables in Balon and Coche's "Lake Kariba: a man-made tropical ecosystem in central Africa". The rest of the parameters are compiled from more recent sources and unpublished data.

Introduction

Lake Kariba (277 km long; 5,300 km^2; 29 m mean depth and 120 m max. depth) was dammed in 1958 and filled in 1963. It is shared almost equally by the two riparian countries, Zambia and Zimbabwe, and the fisheries yields some 35,000 t/year. Despite the rather extensive present literature on various aspects of the lake ecosystem (e.g., Marshall 1984; Machena 1988), only few and scattered estimates of von Bertalanffy growth parameters, length-weight coefficients and size of maturity of the fish species have been published. This contribution is an attempt to assemble an array of important parameters of fishes from Lake Kariba.

About 40 species of fish occur in the lake (Bell-Cross and Minshull 1988; also see Torres, p. 42). Vital parameters from 22 of the most important and common species are presented here, although four species of the commercially exploited genera *Distichodus* and *Labeo* are missing due to lack of data. The remaining species not included are mainly small cyprinids and cichlids, not important to the fisheries.

Materials and Methods

Nonlinear methods were used to fit the length-at-age data in Balon and Coche (1974). The programs used were the VONBER algorithm implemented in the LFSA package (Sparre 1987) and the simplex algorithm in the SYSTAT (1990) statistical package (both programs provided identical results). Because back calculated length-at-age of fish from fish at different age classes were derived from unequal sample sizes (Balon and Coche 1974), the data were weighed by the sample size of each age group. However, for some species (*Brycinus lateralis, Serranochromis codringtonii, Clarias gariepinus, Heterobranchus longifilis, Labeo altivelis, Malapeterus electricus, Synodontis nebulosus* and *S. zambezensis*) the programs did not reach convergence indicating that the data did not follow the von Bertalanffy growth function (VBGF). Graphical plots of these data showed nearly linear growth. In such cases, tentative

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