juveniles. Thus in the long run, the fish populations are reduced to low levels - or will tend to avoid such areas and restrict themselves to areas where such disturbances are minimal or absent (R.H. Lowe-McConnell, pers. comm.).

Table 4 gives among other things, the average catch per haul and the average percentage composition of catch by weight for cichlids, noncichlids and *Limnotilapia dardennei* south of Kigoma, where confined bays yielded higher catches (average 11.7 kg/haul) than north of Kigoma (average 7.6 kg/haul).

The inshore waters of Lake Tanganyika require special attention to safeguard both the environment and the resources. All processes harming the environment and the resource base therein must be carefully evaluated/stopped. Disposal of dangerous chemicals/pesticides, insecticides and oils or sewage disposal that may pollute the inshore water should be avoided.

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Estimating the Maximum Sustainable Yield of Bonito (*Sarda chiliensis*, Scombridae) off Northern Chile from Monthly Catch Data

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Abstract

Monthly catch data of bonito *Sarda chiliensis* from northern Chile, from 1976 to 1989, were used to obtain a series of estimates of the "Z-G" parameter (i.e., total mortality rate minus the growth coefficient in weight). This series was then used to estimate a maximum sustainable yield of 4,500 t/year through a modified version of the surplus production model of J. Csirke and J. Caddy. The status of the fishery is discussed.

Introduction

In Chile, the resource of bonito (*Sarda chiliensis* Fam. Scombridae) is mostly exploited in the north (18°20'S-24°00'S) by small-scale fishers, especially during spring and summer when the bonito migrates toward the coastal zone. The products of the bonito fishery are fresh, frozen and canned bonitos. However, the catches have remained low especially when compared with those in Peru (Pauly et al. 1987).

This contribution is an attempt to estimate the maximum sustainable yield (MSY) of bonito off northern Chile, using a "catch curve method" modified to estimate the Z-G parameter, i.e., total mortality minus the growth coefficient in weight, from monthly catch data. Subsequently, the estimates of Z-G are used to estimate MSY by applying a modified version of the surplus yield model of Csirke and Caddy (1983), i.e., through a parabolic plot of total catch on Z-G.

Materials and Methods

The monthly catch data analyzed here, from 1976 to 1989, were obtained from "Statistical Fisheries Annual Reports" published by the National Fisheries Service of Chile (SERNAP).

The catch data were then grouped into seasons lasting from August of a given year to July of the following year because maximum catches of bonito tend to occur in (southern) spring and summer. Subsequently, these data were regrouped in bimonthly sets (i.e., August-

September, October-November, etc.) to reduce the impact of the abrupt changes that occur between some months (Table 1).

It was assumed that maximum catches are obtained in the months when the nearshore biomass of bonito is highest and that a fraction of this biomass remains in the coastal zone, to be reduced by fishing until the next season.

Table 1. Bimonthly catch (t) and Z-G (from equation 4) of *Sarda chiliensis* off northern Chile.

Season	Aug/Sep	Oct/Nov	Dec/Jan	Feb/Mar	Apr/May	Jun/Jul	Z-G
76/77	42.3	139.1	166.0	813.8	280.0	337.1	0.441
77/78	34.0	567.2	1010.2	791.1	278.3	2.2	1.942
78/79	15.6	702.9	897.0	1416.9	500.3	115.7	1.253
79/80	22.5	558.5	1342.1	1337.0	107.0	159.0	0.892
80/81	111.0	127.0	465.0	492.0	351.0	72.0	0.961
81/82	140.0	718.0	1038.0	199.0	378.0	72.0	0.736
82/83	174.0	1109.0	3446.0	272.0	71.0	134.0	1.108
83/84	611.0	2670.0	2022.0	625.0	511.0	103.0	0.789
84/85	946.0	1821.0	3406.0	194.0	85.0	121.0	1.084
85/86	192.0	2328.0	746.0	530.0	24.0	23.0	1.267
86/87	47.0	542.0	584.0	63.0	50.0	35.0	0.867
87/88	22.0	661.0	231.0	132.0	47.0	95.0	0.547
88/89	61.0	111.0	84.0	65.0	20.0	24.0	0.450
Means	186.0	927.3	1187.5	533.1	207.9	99.5	0.949

Fig. 1 and Table 1 show that the months with the greatest catches are October-November and December-January. In terms of the assumptions above, Fig. 1 represents a "pseudo-catch curve", which can be used to obtain rates of mortality from the slope of the descending, right arm of the plot. However, the natural logarithms of the bimonthly catches are expressed in weight, not numbers; therefore the following further assumptions must be made:

i) The descending, right arm of the plot in Fig. 1 represents the decline of bonito biomass by fishing. This can be expressed by

$$B_{t1} = B_{to}\, e^{-(Z-G)(t_1-t_o)} \qquad ...1)$$

where t_1 and t_o are the end and the beginning of the t time period, B is the available biomass, Z is the rate of total mortality, and G is the growth coefficient in weight (Ricker 1975; MacCall 1978).

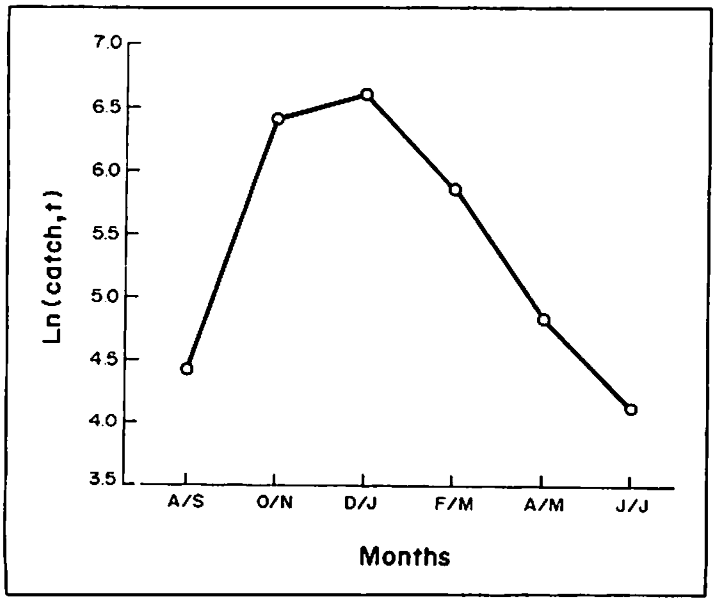

Fig. 1. *"Pseudo-catch curve" of* **Sarda chiliensis** *off northern Chile, based on average of bimonthly catch data for the period 1976/1977 to 1988/1989 (see text and Table 1).*

ii) The catch can be expressed by

$$Y_{t1,t2} = FB_{t1}(1 - e^{-(Z-G)(t_2-t_1)})/(Z-G) \qquad ...2)$$

where Y is the catch (in tonnes) between the times t_1 and t_2 and F is the instantaneous rate of fishing mortality.

In equation (2), B_{t1} can be replaced by equation (1); solving and then applying natural logarithms, the following expression is then obtained

$$L_n(Y_{t1,t2}) = a + b - (Z-G)t_1 \qquad ...3)$$

where

$$a = Ln(FBt_o/(Z-G)) + (Z-G)t_o, \text{ and}$$

$$b = Ln(1 - e^{-(Z-G)(t_2-t_1)}).$$

As might be seen, t_1 now appears in one linear term. The term "a" is a constant because Bt_o, F, t_o, Z and G are assumed to remain constant. The term "b" remains constant only when the difference between t_1 and t_2 is constant. Thus,

$$Ln\,(Y_{t1,t2}) = c - (Z-G)t_1 \qquad ...4)$$

where c = a + b, the terms of the above linearized catch curve.

Equation (4) was used to estimate Z-G for each year from the bimonthly catch data in Table 1.

To estimate the MSY of bonito, the surplus yield model of Csirke and Caddy (1983) was modified to take account of the fact that G is unknown. The Csirke and Caddy model is expressed by a parabolic plot of total annual catch (Y) *vs.* total mortality, i.e.,

$$Y = a + b_1Z + b_2Z^2$$

The modification implemented here consists of replacing Z by Z-G, i.e.,

$$Y = a' + b_1'(Z\text{-}G) + b_2'(Z\text{-}G)^2 \qquad ...5)$$

from which the following parameters can be estimated:

$$M\text{-}G = (-b_1 + (b_1^2 - 4a'b_2')^{0.5})/2b'_2$$

$$(Z\text{-}G)_{msy} = -b'_1/2b'_2$$

$$F_{msy} = 0.5\ r_m = (Z\text{-}G)_{msy} - (M\text{-}G)$$

$$MSY = a' - (b_1')^2/4b'_2$$

where M is the rate of natural mortality, F_{msy} is the fishing mortality that produces MSY, and r_m is the intrinsic rate of population increase (Csirke and Caddy 1983).

Fitting of equation (5) to the data was done using the nonlinear fitting routine incorporated in the FISHPARM package (Saila et al. 1988).

Results and Discussion

Table 1 (last column) presents the Z-G estimates obtained by applying equation (3) to the available bimonthly catches.

Fig. 2 presents the modified Csirke and Caddy model. As might be seen, the data points are rather scattered; however, the fit of the model is significant ($R = 0.4$; $P < 0.05$).

Obviously, the results presented here are tentative because the estimates of Z-G are strongly dependent on the catch pattern, which can be affected by numerous factors. In fact, in the northern part of Chile, the catch of bonito is seasonal and sustained mainly by the spawning stock, which carries out southward migrations during spring and summer (Barret 1971; Serra et al. 1980). These migrations may bias the estimates of Z-G, especially during very warm and/or very cold years (Robles et al. 1976).

The low MSY estimate of about 4,500 t obtained here may be applicable for the fraction of the bonito population that remains nearshore during the whole year, suggesting that the stock as a whole is underexploited in Chilean waters. This contrasts with the status of the "Peruvian stock", shown by Pauly et al. (1987) to be overexploited, and for which the MSY estimates range from 73,600 to 82,400 t.

The low catches and MSY estimates for bonito for the northern part of Chile - about 6% of the values for Peru - is due to this fish not being a target species of the industrial pelagic fisheries of northern Chile and especially to the fact that northern Chile represents the southern boundary of the distribution area of bonito. Little can be done about these factors, and I wish therefore to stress here the usefulness of the method represented by equations (1) to (4) for assessing similar resources exploited by a seasonal fisheries.

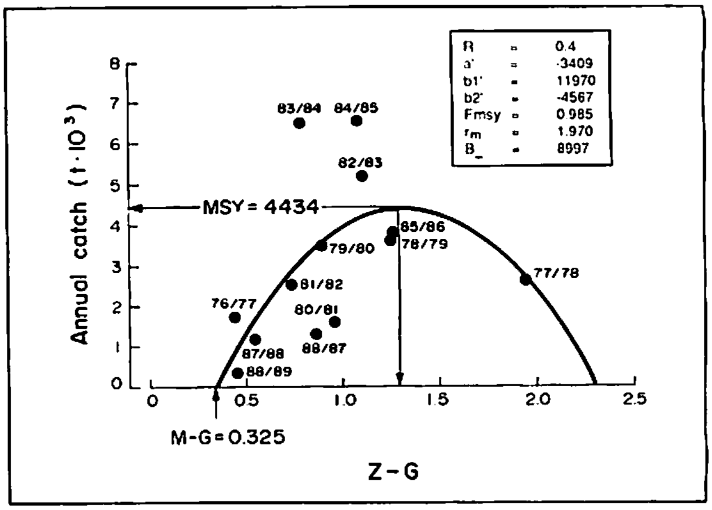

Fig. 2. ***Modified "Csirke and Caddy" model, with preliminary estimates of MSY for bonito in northern Chile.***

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