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Empirical Determination of a Desirable Mesh Size for the Gill-net Fishery of *Oreochromis mossambicus* (Peters) in a Man-Made Lake in Sri Lanka

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Abstract

Experimental fishing with bottom-set gill nets of different mesh sizes was carried out in Parakrama Samudra, a man-made reservoir in Sri Lanka, May to September 1983. The optimum retention length of *Oreochromis mossambicus*, the dominant fish species in the reservoir fishery, was estimated for each mesh size using the Baranov-Holt method. The optimal length of *O. mossambicus* is a function of mesh size and is described by the equation: $Y = 3.4763 + 2.0237X$ ($r = 0.992$; $p < 0.01$) where Y = optimal total length in cm and X = stretched mesh size in cm. The desirable mesh size corresponding to the acceptable size of *O. mossambicus* to the consumer (20-28 cm) is 10.2 cm.

Natural mortality (M) was estimated to be 1.10 using $L_\infty = 31.3$ cm and $K = 0.48$ $year^{-1}$ estimated from length-frequency data of the catches. The long-term biological effects of the increase in mesh size in the gill-net fishery on the harvests and catch rates are discussed using length-structured yield-per-recruit and biomass-per-recruit analyses based on L_∞ and M/K for different levels of exploitation rates and different sizes of first capture corresponding to various mesh sizes.

Introduction

Parakrama Samudra is an ancient man-made reservoir (2,662 ha at full supply level) in Sri Lanka. The trends in growth of the fishery after the introduction of *Oreochromis mossambicus* (Peters) in 1952 have been documented by various workers (e.g., Fernando 1977; De

Silva and Fernando 1980). As in the other major reservoirs in Sri Lanka, *O. mossambicus* is the mainstay of the fishery of Parakrama Samudra accounting for 70-90% by weight of the commercial catches (De Silva 1985; Amarasinghe and Pitcher 1986). The gill net is the predominant fishing gear. The stretched mesh sizes of gill nets used in this reservoir range from 7.6 to 14.0 cm.

The Sri Lankan reservoir fishery has not been managed scientifically because it is a relatively recent development. However, the restriction upon the minimum mesh size (7.6 cm) of gill nets in Sri Lankan reservoir fisheries provides, to a certain extent, a management strategy to control the size of *O. mossambicus* landed. The need for suitable management strategies for the reservoir fisheries in Sri Lanka has arisen due to their significance as a cheap protein source for rural communities. The present paper attempts to determine the desirable mesh size of the gill nets used in the Parakrama Samudra fishery from a selectivity experiment through biological and socioeconomic considerations.

Materials and Methods

Experimental fishing trials with bottom-set gill nets of stretched mesh sizes 5.1 cm (2"), 6.4 cm (2-1/2"), 7.6 cm (3"), 8.9 cm (3-1/2"), 10.2 cm (4"), 11.4 cm (4-1/2") and 14.0 cm (5-1/2") were carried out from May to September 1983. The dimensions of the gill nets used and the number of trials are given in Table 1.

The gill nets were set 26 times at night in the offshore waters of Parakrama Samudra. A total of 489 specimens of *O. mossambicus* caught in these trials were used to analyze data for gill-net selectivity. Excluded were the five specimens caught in the gill nets of

Table 1. Dimensions of experimental gill nets and number of fishing trials.

Stretched mesh size (cm)	ply	Hanging ratio	Depth (No. meshes)	Length (No. meshes)	Area of net** (m^2)	No. fishing trials
5.1	2	0.5	62	1,500	60.47	2
6.4	2	0.5	62	1,500	95.23	9
7.6	4	0.5	37	1,500	80.14	10
8.9	4	0.5	37	1,500	109.90	4
10.2	4	0.5	37	1,500	144.36	1
11.4*	6	0.5	25	1,000	81.23	2
14.0*	6	0.5	25	1,000	122.50	2

*The fishes caught in these nets were excluded from the study as they were very few in number.
**Area of net = mesh size^2 x hanging ratio^2 x depth x length.

11.4 cm and 14.0 cm mesh sizes. All 494 fishes were considered for estimating growth and survival parameters. The total length and the greatest depth of each fish caught in each mesh size were measured to the nearest 0.1 cm and the sex of each fish was determined.

Most *O. mossambicus* were enmeshed at the region of the greatest depth of the fish. The relationship between the greatest depth (Y) and the total length (X) for fish of each sex was found to be linear ($p < 0.001$) according to the following relationships:

For males : $Y = -0.2431 + 0.3718X$ ($r = 0.897$)

For females : $Y = -0.2420 + 0.3657X$ ($r = 0.849$)

These relationships were compared by the t-test and found to have no significant difference at the 95% confidence level ($t_{obs.} = 0.149$). The remaining analysis was performed using the combined data for both sexes.

The total length at intersection of adjacent distributions (optimal length) of fish captured by each mesh size was determined by the Baranov-Holt method (Baranov 1914; Holt 1957; Gulland 1969, 1983; Hamley 1975; Jones 1984). For this purpose, the length-frequency distributions in each mesh size were standardized according to the area of net and total fishing time. The area of each gill net (Table 1) was calculated using the dimensions of the net (i.e., mesh size, hanging ratio, depth and length). The frequencies in each length group in each mesh size were then adjusted to obtain the numbers per unit area of net per fishing trial. These standardized length-frequency distributions (expressed as numbers per fishing trial per 1,000 m^2 of gill net) for each mesh size were used to estimate the optimal length by the Baranov-Holt method. The step-wise procedure for this computation was as follows:

1. Relating the logarithms of ratios of catches by two adjacent mesh sizes to fish length (L) using linear regression methods according to the relationship: $Y = a + bL$ where Y = logarithm of ratio of catches at length L. It should be noted that the fish which appeared to be entangled (not gilled) were not considered to obtain the catch ratios (see Table 2).

2. Estimating the selection factor (SF) from the above regression coefficients (a and b) and the relationship

$$SF = -2a \cdot b^{-1} \cdot (m_1 + m_2)^{-1}$$

where m_1 and m_2 are the mesh sizes of the two gill nets.

Table 2. Standardized length-frequency distributions of *O. mossambicus* caught in each mesh size (expressed as numbers per fishing trial per 1,000 m^2 of gill net). The frequencies marked with asterisks appeared to include entangled fish.

Midpoint of (total) length group (cm)	Mesh size (cm)				
	5.1	6.4	7.6	8.9	10.2
11.5	74.4	-	-	-	-
12.5	272.8	-	-	-	-
13.5	99.2	-	-	-	-
14.5	99.2	16.3	-	-	-
15.5	49.6	75.8	-	-	-
16.5	8.3	114.3	-	-	-
17.5	-	39.7	2.5*	-	-
18.5	-	15.2	29.9	4.5	-
19.5	8.3*	7.0	24.9	9.1	6.9*
20.5	-	3.5	13.7	13.6	-
21.5	-	1.2	11.2	22.7	48.5*
22.5	-	-	12.5*	18.2	13.9
23.5	-	-	5.0*	27.3	76.2
24.5	-	-	-	4.5	55.4
25.5	-	-	-	2.3	76.2
26.5	-	-	-	4.5*	55.4*
27.5	-	-	-	-	27.7
28.5	-	-	-	-	13.9

3. Determining the optimal length (L_{opt}) using the relationship: $L_{opt} = SF \cdot m$ where m is the mean value of mesh sizes in each pair of gill nets. Here, the mean value of the two mesh sizes was used to reduce an error which has arisen from one of the assumptions in the Baranov-Holt method (i.e., the selection factors for the two mesh sizes are the same). According to this assumption, the differences in the selection factors in two adjacent mesh comparisons give two different values of optimal lengths for the same mesh size.

4. Estimating the standard deviation (S.D.) of the selection curve from the equation: $S.D. = ((L_2 - L_1) \cdot b^{-1})^{0.5}$ where L_1 and L_2 are optimal lengths, calculated as above, for mesh sizes of m_1 and m_2, respectively.

The relationship between the mesh size of gill net and the optimal length of *O. mossambicus* caught in each mesh size was computed. Based on consumer preference for *O. mossambicus*, the desirable mesh size was determined. Yield-per-recruit computations were then used to investigate its biological effect.

Standard methods for estimating asymptotic length (L_∞) are not reliable for the length-frequency data of *O. mossambicus* caught in experimental gill nets due to the selectivity of gill nets used and the relatively short sampling period (May to September). As such, the available information on L_∞ of *O. mossambicus* populations in Sri Lankan reservoirs (De Silva et al. 1988) and an estimate based on the maximum length (L_{max}) of the catch sample were used to determine

L_∞ of *O. mossambicus* in Parakrama Samudra. The mean of L_∞ values of twelve Sri Lankan reservoirs (De Silva et al. 1988) and $L_{max}/0.95$ (Pauly 1981) were averaged and used as the L_∞ of *O. mossambicus* in the reservoir. The growth constant (K) of *O. mossambicus* was estimated by the following equation (Pauly and Munro 1984; Moreau et al. 1986).

$$\mathrm{Log}_{10} K = \phi' - 2\mathrm{Log}_{10} L_\infty$$

where ϕ' is a species-specific index of growth performance. Natural mortality (M) was estimated using the following empirical equation (Pauly 1980):

$$\mathrm{Log}_{10} M = -0.0066 - 0.279\mathrm{Log}_{10} L_\infty + 0.6543\mathrm{Log}_{10} K + 0.4634\mathrm{Log}_{10} T$$

where T is the annual mean water temperature.

Relative yield-per-recruit and relative biomass-per-recruit analyses (Beverton and Holt 1964; Pauly 1984; Pauly and Soriano 1986) were performed using these estimated parameters for *O. mossambicus*.

Results

The length (total)-frequency distributions of catches of *O. mossambicus* by mesh size are shown in Fig. 1 for males and females separately. Standardized length-frequency distributions according to the areas of gill nets and total fishing time for each mesh size are given in Table 2. Relationships between the logarithm of ratios of catches by two adjacent mesh sizes and total length are shown in Fig. 2 for each mesh comparison. Linear regression equations of these logarithmic plots, selection factors, estimated optimal lengths and selection range (optimal length ± S.D.) are given in Table 3. The relationship of the estimated optimal length of *O. mossambicus* to the mesh size was found to be linear (Fig. 3) and is described by the equation: $Y = 3.4763 + 2.0237X$ ($r = 0.992$; $p < 0.01$) where Y = optimal length in cm and X = stretched mesh size in cm.

The range of acceptable sizes of *O. mossambicus* to the consumer is 20-28 cm with a mean value of 24.5 cm (pers. obs.). Using the relationship between the optimal length and mesh size, the minimum desirable mesh size for the gill-net fishery of Parakrama Samudra is found to be 10.2 cm (4") stretched mesh size.

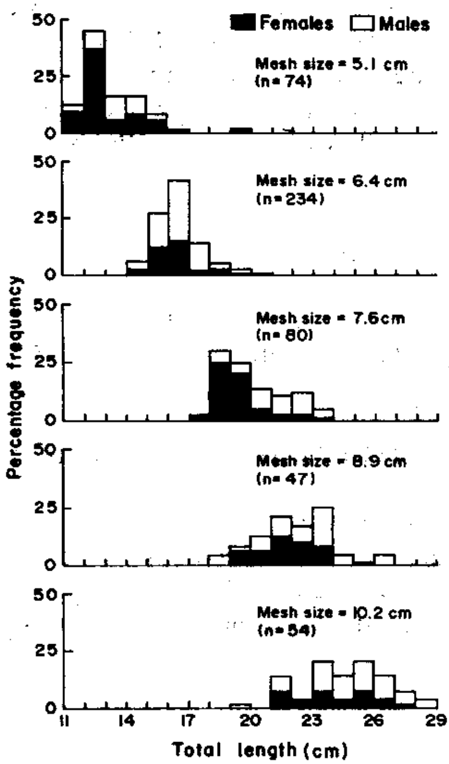

Fig. 1. The length-frequency distributions of *O. mossambicus* catches by mesh size for males and females separately. Number of fish caught in each mesh size is given in parentheses.

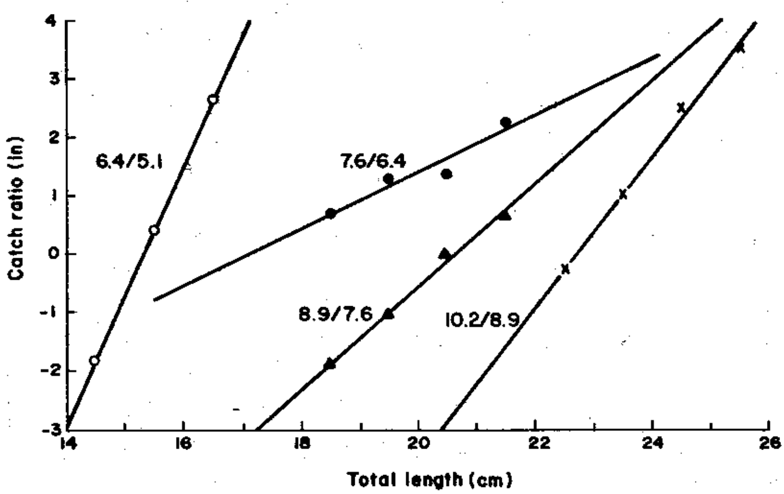

Fig. 2. The logarithmic plots of the catch ratios in each mesh comparison of gill nets.

Table 3. Linear regression equations of the logarithmic plots of catch ratios in each mesh comparison, selection factor, estimated optimal lengths and selection ranges.

Mesh comparison (cm)	Mean mesh size (cm)	Regression equation (Y = ln catch ratio; L = mid-length cm)	Selection factor	Optimal length (cm)	Selection range (cm) (Optimal length ± S.D.)
6.4/5.1	5.75	Y = -33.9230 + 2.2164L ($r = 0.9999$; $p < 0.0001$)	2.66	15.3	14.06-16.56
7.6/6.4	7.00	Y = -8.2997 + 0.4848L ($r = -0.9570$; $p < 0.05$)	2.45	17.1	14.66-19.58
8.9/7.6	8.25	Y = -18.0963 + 0.8774L ($r = 0.9979$; $p < 0.01$)	2.50	20.6	16.70-22.54
10.2/8.9	9.55	Y = -29.1244 + 1.2839L ($r = 0.9975$; $p < 0.01$)	2.38	22.7	21.13-24.23

The value of L_∞ obtained from L_{max} of the length distribution and the mean of L_∞ values (30.1 cm) of twelve Sri Lankan reservoir populations of *O. mossambicus* (De Silva et al. 1988) is 31.3 cm (total length). The ϕ' value for *O. mossambicus* in Sri Lanka was considered as 2.67 by taking the average ϕ' value for eleven *O. mossambicus* populations in Sri Lanka (De Silva and Senaratne, in press). Using this value and L_∞ calculated above, K was determined to be 0.48 $year^{-1}$. These growth parameters and the mean annual water temperature of 28.5°C, calculated using the available information (Amarasinghe et al. 1983), were used in the equation of Pauly (1980) and M was estimated to be 1.10 $year^{-1}$. Hence, M/K for *O. mossambicus* in Parakrama Samudra is 2.29.

For the *O. mossambicus* fishery in Parakrama Samudra, isometric von Bertalanffy growth was assumed and M, fishing mortality (F) and total mortality (Z) were assumed to be expressed by negative exponential curves. Knife-edge recruitment was also assumed for the fishery and the age of recruitment was set at zero in computing relative yield per recruit and relative biomass per recruit. Lengths of first capture (L_c) for various mesh sizes were calculated using the relationship between the optimal length and mesh size (Fig. 3). Relative yield-per-recruit (Y'/R) values (Fig. 4a) and relative biomass-per-recruit (B'/R) values (Fig. 4b) were computed for different levels of exploitation rates (E) or F/Z for the L_c values corresponding to different mesh sizes using the parameters L_c/L_∞, E and M/K. These analyses indicate that Y'/R declines with increasing mesh size and that only a slight increase occurs in B'/R with increasing mesh size.

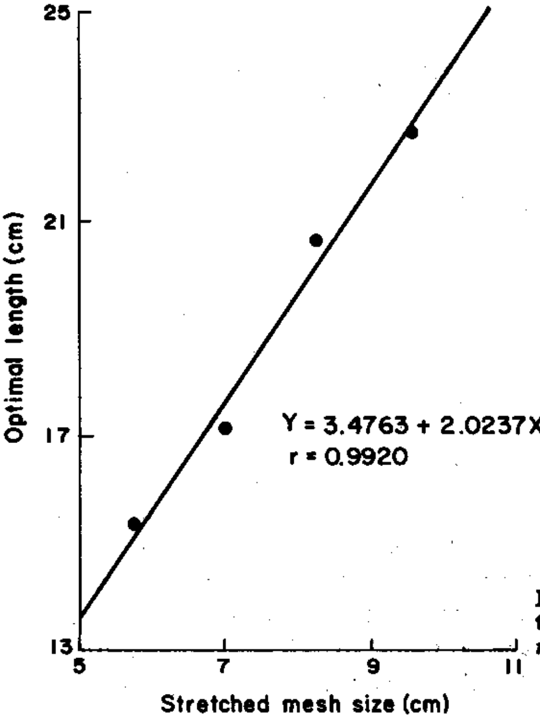

Fig. 3. The relationship between the optimal length of *O. mossambicus* and mesh size.

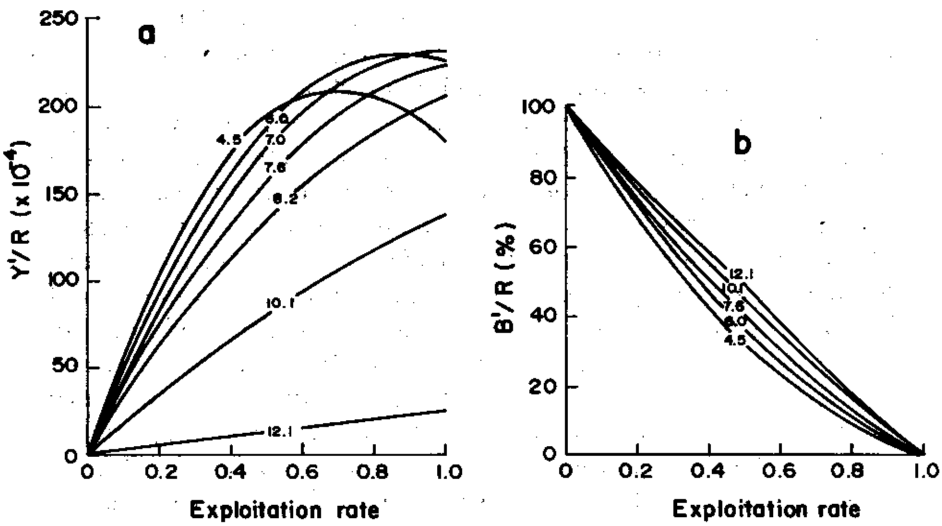

Fig. 4. (a) Relative yield per recruit (Y'/R) and (b) Relative biomass per recruit (B'/R) as functions of exploitation rates. The values on the curves represent mesh sizes (in cm) for the respective curves.

Discussion

One of the limitations in this study is that some fishes were entangled in the meshes because of the low hanging ratio (0.5) of the experimental gill nets which were identical to those used by the commercial fishermen in the reservoir. The proportion of entangled (nongilled) fish could probably have been reduced by using a hanging ratio of 0.6.

The low gradient of catch ratios of the 7.6/6.4 cm mesh nets (Fig. 2) and the greater selection range (Table 3) may be due to the differences between the filament characteristics (ply) of these gill nets (see Table 1). The selection range of a gill net increases with the flexibility of the netting material (Gulland 1983). However, this will not affect the calculations in the present study because the optimal length of fish caught by gill nets is independent of the flexibility of netting material. The estimated optimal lengths in the present study compared well with the values determined for *O. mossambicus* caught in different mesh size gill nets in Plover Cove reservoir in Hong Kong (Hodgkiss and Man 1977).

With regard to the estimation of parameters for yield-per-recruit analysis, L_∞ (31.3 cm) and K (0.48) values for *O. mossambicus* are biologically reasonable. Also, a high value of M can be expected for the *O. mossambicus* population in Parakrama Samudra where a high predatory pressure occurs due to fish-eating birds. Winkler (1983) has estimated that cormorants consume 112-161 $kg \cdot ha^{-1}$ annually in Parakrama Samudra of which *O. mossambicus* forms a major part.

From the relationship between the optimal length of *O. mossambicus* and mesh size which has been determined by the gill-net selectivity experiment, the desirable mesh size (10.2 cm) was determined depending on the acceptable size of *O. mossambicus* to the consumer. Usually the management strategies for the artisanal fisheries have to be viewed in the sociological context (Marr 1982). In the fishery of Parakrama Samudra, consumer preference on the landing size of *O. mossambicus* seems to be a crucial factor in developing management strategies. Also in the gill-net fishery of Pimburettewa Wewa, another Sri Lankan reservoir where the fishermen have restricted themselves to catching *O. mossambicus* above 24.6 cm, overexploitation is not evident as indicated by a yield-per-recruit analysis (Amarasinghe 1987).

However, relative yield-per-recruit analysis (Fig. 4a) indicates that a decline in harvest could result by increasing the minimum permissible mesh size from 7.6 cm to 10.2 cm. From the relative biomass-per-recruit analysis (Fig. 4b), only a slight increase is evident in the catch rates by increasing the mesh size in the gill-net fishery. However, consumer-determined mesh size may be worthwhile for assuring a large spawning biomass. The mean sizes of maturity for male and female *O. mossambicus* in Parakrama Samudra in 1979 were recorded to be 27.5 cm and 17.0 cm, respectively (De Silva and Chandrasoma 1980). Hopefully, this analysis will be of use for planning management measures for the reservoir fishery through mesh size regulations.

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References

Amarasinghe, U.S. 1987. Status of the fishery of Pimburettewa wewa, a man-made lake in Sri Lanka. Aquacult. Fish. Manage. 18: 375-385.

Amarasinghe, U.S. and T.J. Pitcher. 1986. Assessment of fishing effort in Parakrama Samudra, an ancient man-made lake in Sri Lanka. Fish. Res. 4: 271-282.

Amarasinghe, U.S., H.H. Costa and M.J.S. Wijeyaratne. 1983. Limnology and fish production potential of some reservoirs in Anuradhapura district, Sri Lanka. J. Inland Fish. Sri Lanka 2: 14-29.

Baranov, F.I. 1914. The capture of fish by gill nets. Mater. Poznaniyu Russ. Rybolov. 3(6): 56-99. (Selected work on fishing gear. Vol. 1. Commercial fishing technique. Israel Program for Scientific Translations, Jerusalem. 1976.)

Beverton, R.J.H. and S.J. Holt. 1964. Manual of methods for fish stock assessment. Part 2. Tables of yield functions. FAO Fish. Tech. Pap. 38 (Rev. 1). 67 p.

De Silva, S.S. 1985. Status of the introduced cichlid, *Sarotherodon mossambicus* (Peters) in the reservoir fishery of Sri Lanka: a management strategy and ecological implications. Aquacult. Fish. Manage. 16: 91-102.

De Silva, S.S. and J. Chandrasoma. 1980. Reproductive biology of *Sarotherodon mossambicus*, an introduced species in an ancient man-made lake in Sri Lanka. Env. Biol. Fish. 5: 253-259.

De Silva, S.S. and C.H. Fernando. 1980. Recent trends in the fishery of Parakrama Samudra, an ancient man-made lake in Sri Lanka, p. 927-937. *In* J.I. Furtado (ed.) Tropical ecology and development. University of Malaya Press, Kuala Lumpur, Malaysia.

De Silva, S.S. and K.A.D.W. Senaratne. *Oreochromis mossambicus* is not universally a nuisance species: The Sri Lankan experience. *In* R.S.V. Pullin, T.

Bhukasawan, K. Tonguthai and J.L. Maclean (eds.) The Second International Symposium on Tilapia in Aquaculture. ICLARM Conference Proceedings 15. Department of Fisheries, Bangkok, Thailand, and International Center for Living Aquatic Resources Management, Manila, Philippines. (In press).

De Silva, S.S., J. Moreau and K.A.D.W. Senaratne. 1988. Growth of *Oreochromis mossambicus* (Pisces, Cichlidae) as evidence of its adaptability to Sri Lankan reservoirs. Asian Fish. Sci. 1: 147-156.

Fernando, C.H. 1977. Reservoir fisheries in South East Asia: past, present and future. Proc. Indo-Pac. Fish. Counc. 17(3): 475-489.

Gulland, J.A. 1969. Manual of methods for fish stock assessment. Part 1. Fish Population Analysis. FAO Man. Fish. Sci. 4, 154 p.

Gulland, J.A. 1983. Fish stock assessment. A manual of basic methods. John Wiley, New York.

Hamley, J.M. 1975. Review of gillnet selectivity. J. Fish. Res. Board Can. 32: 1943-1969.

Hodgkiss, I.J. and S.H. Man. 1977. Stock density and mortality assessment of *Sarotherodon mossambicus* (Cichlidae) in Plover Cove Reservoir. Env. Biol. Fish. 1: 171-180.

Holt, S.J. 1957. A method for determining gear selectivity and its application. ICNAF/ICES/FAO Joint Scientific Meeting, Lisbon, Portugal. Contribution S-15. 21 p.

Jones, R. 1984. Assessing the effects of changes in exploitation pattern using length composition data (with notes of VPA and cohort analysis). FAO Fish. Tech. Pap. 256. 118 p.

Marr, J.C. 1982. The realities of fishery management in the Southeast Asian region, p. 299-307. *In* D. Pauly and G.I. Murphy (eds.) Theory and management of tropical fisheries. ICLARM Conf. Proc. 9, 360 p. International Center for Living Aquatic Resources Management, Manila, Philippines and Division of Fisheries Research, Commonwealth Scientific and Industrial Research Organisation, Cronulla, Australia.

Moreau, J., C. Bambino and D. Pauly. 1986. Indices of overall growth performance of 100 tilapia (Cichlidae) populations, p. 201-206. *In* J.L. Maclean, L.B. Dizon and L.V. Hosillos (eds.) The First Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines.

Pauly, D. 1980. On the relationships between natural mortality, growth parameters and mean environmental temperature in 175 fish stocks. J. Cons., CIEM 39: 175-192.

Pauly, D. 1981. The relationships between gill surface area and growth performance in fish: a generalization of von Bertalanffy's theory of growth. Meeresforsch. 28: 251-282.

Pauly, D. 1984. Fish population dynamics in tropical waters: a manual for use with programmable calculators. ICLARM Stud. Rev. 8, 325 p. International Center for Living Aquatic Resources Management, Manila, Philippines.

Pauly, D. and J.L. Munro. 1984. Once more on the comparison of growth in fish and invertebrates. Fishbyte 2(1): 21.

Pauly, D. and M.L. Soriano. 1986. Some practical extensions to Beverton and Holt's relative yield-per-recruit model, p. 491-495. *In* J.L. Maclean, L.B. Dizon and L.V. Hosillos (eds.) The First Asian Fisheries Forum. Asian Fisheries Society, Manila, Philippines.

Winkler, H. 1983. The ecology of cormorants (genus *Phalacrocorax*), p. 193-199. *In* F. Schiemer (ed.) Limnology of Parakrama Samudra-Sri Lanka. A case study of an ancient man-made lake in the tropics. Developments in Hydrobiology 12, Junk Publishers, The Hague.

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