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DETERMINING THE EFFECT OF INCIDENTAL UNDERSIZED CATCHES ON EXPECTED YIELD PER RECRUIT OF YELLOWFIN TUNA

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Introduction

The question of the effect on yield per recruit (Y/R) of catches of eastern Atlantic yellowfin tuna less than ICCAT's minimum size level has persisted since ICCAT instituted a minimum size regulation in 1973. The regulation prohibits the catching of yellowfin tuna below 55 cm fork length (or 3.2 kg), with a 15% (by number) tolerance for incidental catch. The purpose was to increase the Y/R in the fishery, with benefits most likely to accrue if the exploitation level were to increase greatly.

Yield per recruit studies of this fishery have indicated that controlling the age at entry at 55 cm fork length could increase Y/R most probably by less than 10%. The difficulties of management for this level of increased Y/R in the face of large uncertainties regarding age specific exploitation levels, variations in annual production or availability, and non-uniform enforcement policy of countries involved were discussed by Wise (1983).

The purpose of this paper is to show the procedure for examining the percentage change in Y/R due to different amounts of catches of <55 cm fish from different possible levels of selection of such fish by the fishery given a certain level of exploitation of the stock. The resulting possible changes in Y/R will be discussed with respect to the detectibility of such changes. The question of changes in Y/R due to different levels of overall exploitation is not discussed here.

Method

Yield per recruit of hypothetical cohorts was calculated according to the incremental method of Ricker (1958). With any age interval (Δ t) yield in weight (Y_w) is

$$Y_w = F \int_0^{\Delta t} N_t w_t \, dt$$

where F is the instantaneous fishing mortality rate, and N_t and w_t are the number and individual weight of fish at time t respectively. There are at least two ways of calculating Y_w, according to the assumption of how w_t changes within Δ t:

(1) Assume $w_t = w_o e^{gt}$, where w_o is the weight at the beginning of the interval and g is the instantaneous growth rate during the interval. Then

$$Y_w = F \int_0^{\Delta t} N_o e^{-zt} w_o e^{gt} dt$$

$$= \frac{F\ No\ Wo}{g-z} \left(e^{(g-z)\ \Delta t} -1\right)$$

where N_0 is number of fish at the beginning of the interval and z is the total instantaneous mortality rate. This is the classic method of calculation.

(2) Assume $w_t = w_0 + \frac{\Delta w}{\Delta t} t$, where $\Delta w/\Delta t$ is a linear rate of change in weight during Δt. Then

$$Y_w = \int_0^{\Delta t} F\ N_o e^{-zt} \left(w_o + \frac{\Delta w}{\Delta t} t\right) dt$$

$$= FN_0 \left\{ \frac{w_o}{z} \left(i-e^{-z\Delta t}\right) + \frac{\Delta w/\Delta t}{Z^2} \left[i-e^{-z\Delta t} \quad (z\Delta t+1)\right] \right\}$$

$$= \frac{F\ No}{z} \left\{ \left(wo + \frac{\Delta w/\Delta t}{z}\right) \left(i-e^{-z\Delta t}\right) - \Delta we^{-z\Delta t} \right\}$$

This second method employs a more realistic assumption about growth during Δt, though the two methods are virtually the same when Δt is small. The example given in this paper is computed according to the second method. A computer program for the calculation is available.

Growth rate of individual fish was calculated using the von Bertalanffy equation of Le Guen and Sakagawa (1973). The conversion of length to weight was by the allometric relationship of Lenarz (1971). Natural mortality M was assumed to be 0.80/year.

The fishing mortality (F) schedules were derived from that of Bartoo and Coan (1979), utilizing their estimate for the fishery in 1975. Their F-schedule for that year reflected a higher exploitation level than during the 1965-1968 period, indicating changes had occurred in the fishery. Their quarterly values of F showed much variability that was not clearly seasonal. Since this "noise" contributes to the uncertainty of Y/R calculations, the quarterly F's were smoothed by running averages of 5. This was done for the baitboat, purse seine, and long line fisheries to derive smoothed schedules, from age 1.5 years onward, suitable for Y/R calculation and evaluation of benefits (Table 1). The quarterly values were transformed to annual rates before actually calculating Y/R.

Yellowfin tuna are recruited to the surface fishery mostly between 1 and 2 years. Lenarz et al. (1974) stated that effective full recruitment probably was at 1.4 years (= 55 cm). Catch curves by Bartoo and Coan (1979) showed that full recruitment had frequently shifted to age 1 fish in recent years, though they concluded that first recruitment into the fishery had remained at 30 cm (= 1.0 years).

In this study, all partial recruitment is assumed to occur between ages 1 and 1.4 years, with full recruitment by age 1.4 (= 55 cm). The fish then suffer the total fishing mortality equal to the mean level between ages 1.5 and 2.0 years (F = .0294/yr.). The partial F-schedules during the recruitment interval are assumed to increase linearly in the various cases studied (Figure 1). Each case amounted to a different percentage of catch in numbers comprised of <55 cm fish. Computationally, the Y/R was calculated by 0.1 year intervals between ages 1 and 1.4 years, and the F during each interval was taken as the mean level of the linearly increasing F-values (Table 2).

Results

The Y/R of 7 possible cases is given in Table 3, along with the percentages of <55 cm fish in the total catch and the percentage changes in Y/R relative to the situation of knife edge selection at 55 cm fork length (i.e. case 1). The percentage changes are also shown in Figure 2.

Between the limits of zero percent <55 cm fish in the catch (equivalent to "knife-edge" selection at 55 cm) and 32.2 percent <55 cm fish in the catch (equivalent to full fishing mortality, F = 0.294/year, at all age intervals between ages 1.0 and 1.4 years), the percent change in Y/R (relative to the case of "knife-edge" selection at 55 cm) decreased from 0 to about 10% in the total, purse seine, and long line fisheries, and increased from 0 to 2.2% in the bait boat fishery (Figure 2). At the allowable incidental catch of 15% by number of <55 cm fish, the decrease was about 4% in the total, purse seine, and long line fisheries, and the increase was 2.5% in the bait boat fishery. Yellowfin are not recruited into the long line fishery until age 2, so the Y/R for this fishery is unaffected by catches of <55 cm fish, except indirectly through the catches in the surface fisheries. The negative changes in Y/R for the long line fishery are shown by the lower curve in Figure 2. This curve also represents the case for the total and all component fisheries where fish less than 55 cm are taken but discarded with no survival.

Discussion

All yield per recruit studies of the eastern Atlantic yellowfin tuna fishery have suggested that a 55 cm minimum size limit would increase Y/R most probably by less than 10%. Lenarz et al. (1974) found this the most probable range of benefit under likely exploitation rates and ages at entry to the fishery. Larger increases were more improbable because of uncertainties in growth and mortality rate schedules. Bartoo and Coan (1979) concurred with Lenarz et al. that increase in Y/R would likely be less than 10%. They found that the 1975 fishery might be operating to give a 3% increase in Y/R relative to the pre-regulatory period. The fishing mortality (F) schedules they derived from cohort analysis showed large fluctuations in the quarterly rates. They warned about simple conclusions about Y/R in a dynamic fishery where age structure and hence F-schedules are likely to vary as different exploitation patterns are pursued. Wise (1983) showed that the variability in annual catches are greater than 10% so that the predicted 10% increase in Y/R from the minimum size regulations is unlikely to be demonstrated. He also showed that there was little evidence that the 55 cm limit had been enforced.

To be credible, Y/R calculations must use a reasonable F-schedule. When this is uncertain, the usefulness of these calculations are limited (Fonteneau 1982). Whereas Lenarz et al. (1974) and Bartoo and Coan (1979) derived, from backward-solution cohort analyses, F-schedules increasing strongly with age, Rinaldo (1983) showed, using the forward solution of cohort analysis from the mean recruitment levels of Laurec and Fonteneau (1979), that F could have little trend with age. Rinaldo (MS) has also shown, using a Monte Carlo procedure, that variability in catches at age can make Y/R calculations too imprecise to detect a 10% increase. The precision of F-schedules from cohort anlaysis was examined by Pope (1972), who showed that the variance of F_i increased rapidly when there were less than 5 age classes following age i.

The F-schedule utilized in this analysis was a smoothed version of that of the 1975 fishery (Bartoo and Coan 1979). While the F-values after age 5 must be suspect, being very erratic prior to smoothing, this schedule is considered reasonable for this study. The F-schedule reflects a high exploitation level for recent years, especially that due to the purse seiner fleet. The F-schedule used for the different cases of fishing on <55 cm fish was varied between ages 1.0 and 1.4 years (= 55 cm). This was considered a reasonable approach because recruitment takes place between ages 1.0 and 2.0, and full recruitment has decreased from age 2.0 in recent years.

According to our analysis, with the relatively high exploitation levels of recent years, changes in Y/R are almost entirely less than 10% as the percent catch comprised of <55 cm fish varies from 0 to 33%. This amount of change in Y/R is relatively small and not likely to be detectable by current fishery monitoring techniques.

Manipulation of a fishery for changes in Y/R that cannot be detected or clearly demonstrated fishermen is not very useful. With large variation in catches from year to year, it will always be difficult to transfer the concept of Y/R of a cohort to the steady state situation represented by the catches at age during a single year. It is the latter catches that are reality to fishermen. Yield per recruit considerations imply that a fishery can manipulate stock structure to make the stock more productive. There is little evidence that this occurs in the tuna fisheries, whose stocks have structures apparently poorly behaved with respect to the effects of exploitation. Length frequencies of yellowfin tuna catches have not changed systematically under exploitation (see Coan and Weber 1981). Management for gains in Y/R at present levels of exploitation may be inappropriate in the dynamic yellowfin tuna fishery. Further examination of this question can be pursued, as per this example, by substituting other F-schedules in the algorithm for calculating Y/R.

Table 1. Smoothed[1] instantaneous fishing mortalities (F/quarter year) for use in yield per recruit computations.

Age	Quarter	Baitboats	Purse Seiners	Longliners	Total
1	1				
	2				
	3	.0367	.0367		.0734
	4	.0319	.0469		.0788
2	1	.0293	.0651	.0011	.0955
	2	.0219	.0638	.0020	.0877
	3	.0164	.0604	.0042	.0810
	4	.0092	.0620	.0060	.0772
3	1	.0036	.0796	.0097	.0929
	2	.0027	.0925	.0134	.1086
	3	.0029	.0903	.0258	.1190
	4	.0033	.1336	.0321	.1690
4	1	.0033	.1842	.0340	.2215
	2	.0033	.2953	.0477	.3463
	3		.3450	.0659	.4109
	4		.3630	.0772	.4402
5	1		.3830	.1082	.4912
	2		.4000	.1188	.5188
	3		.4140	.1295	.5435
	4		.4290	.1523	.5813
6	1		.4450	.1833	.6283
	2		.4580	.1778	.6358
	3		.4690	.1757	.6447
	4		.4800	.1526	.6326
7	1		.4910	.1412	.6322
	2		.5020	.0940	.5960
	3		.5120	.0500	.5620
	4				

[1]by moving averages of 5, using the 1975 F-schedule of Bartoo and Coan (1979).

Table 2. Instantaneous fishing mortalities (F/year) used in the partial recruitment interval between 1.0 and 1.4 years, according to various assumed cases of recruitment pattern.

	Case 1					Case 2				
Age (years)	1.0 - 1.1	1.1 - 1.2	1.2 - 1.3	1.3 - 1.4	1.4 - 1.5	1.0 - 1.1	1.1 - 1.2	1.2 - 1.3	1.3 - 1.4	1.4 1.5
Baitboats[1]	0	0	0	0	.1468	0	0	0	0.098	.1468
Purse seiners[2]	0	0	0	0	.1468	0	0	0	0.049	.1468
Longliners	0	0	0	0	0	0	0	0	0	0
Total	0	0	0	0	.2936	0	0	0	0.147	.2936

	Case 3					Case 4				
Age (years)	1.0 - 1.1	1.1 - 1.2	1.2 - 1.3	1.3 - 1.4	1.4 - 1.5	1.0 - 1.1	1.1 - 1.2	1.2 - 1.3	1.3 - 1.4	1.4 - 1.5
Baitboats	0	0	0.049	0.147	.1468	0.025	0.073	0.123	0.171	.1468
Purse seiners	0	0	0.025	0.074	.1468	0.012	0.037	0.061	0.086	.1468
Longliners	0	0	0	0	0	0	0	0	0	0
Total	0	0	0.074	0.221	.2936	0.037	0.110	0.184	0.257	.2936

	Case 5					Case 6				
Age (years)	1.0 - 1.1	1.1 - 1.2	1.2 - 1.3	1.3 - 1.4	1.4 - 1.5	1.0 - 1.1	1.1 - 1.2	1.2 - 1.3	1.3 - 1.4	1.4 1.5
Baitboats	0.083	0.115	0.147	0.180	.1468	0.141	0.157	0.173	0.188	.1468
Purse seiners	0.041	0.058	0.074	0.090	.1468	0.071	0.078	0.086	0.094	.1468
Longliners	0	0	0	0	0	0	0	0	0	0
Total	0.124	0.173	0.221	0.270	.2936	0.212	0.235	0.259	0.282	.2936

	Case 7				
Age (years)	1.0 - 1.1	1.1 - 1.2	1.2 - 1.3	1.3 - 1.4	1.4 - 1.5
Baitboats	0.196	0.196	0.196	0.196	.1468
Purse seiners	0.098	0.098	0.098	0.098	.1468
Longliners	0	0	0	0	0
Total	0.294	0.294	0.294	0.294	.2936

[1] 2/3 of fishing mortality is assumed to be due to baitboats.
[2] 1/3 of fishing mortality is assumed to be due to purse seiners.

Table 3. Summary of yield per recruit (Y/R) calculations.

	Baitboats			Purse seiners			Longliners			Total		
Case	Y/R	%[1]D	%[2]<55	Y/R	%D	%<55	Y/R	%D	%<55	Y/R	%D	%<55
1	0.697	0	0	3.919	0	0	0.534	0	0	5.150	0	0
2	0.706	+1.29	10.32	3.872	-1.20	2.43	0.526	-1.50	0	5.103	-0.91	4.73
3	0.712	+2.15	19.14	3.824	-2.42	4.92	0.518	-3.00	0	5.054	-1.86	9.30
4	0.716	+2.73	33.63	3.725	-4.95	9.87	0.503	-5.81	0	4.944	-4.00	17.95
5	0.714	+2.44	41.32	3.658	-6.66	13.~~48~~23	0.493	-7.68	0	4.866	-5.51	23.32
6	0.713	+2.30	47.57	3.592	-8.34	16.68	0.483	-9.55	0	4.788	-7.03	28.13
7	0.712	+2.15	52.40	3.531	-9.90	19.~~56~~22	0.474	-11.24	0	4.718	-8.39	32.21

[1] Percent difference in Y/R relative to case 1 = "knife edge" selection at 55 cm.
[2] Percent of catch in numbers comprised of <55 cm fish.

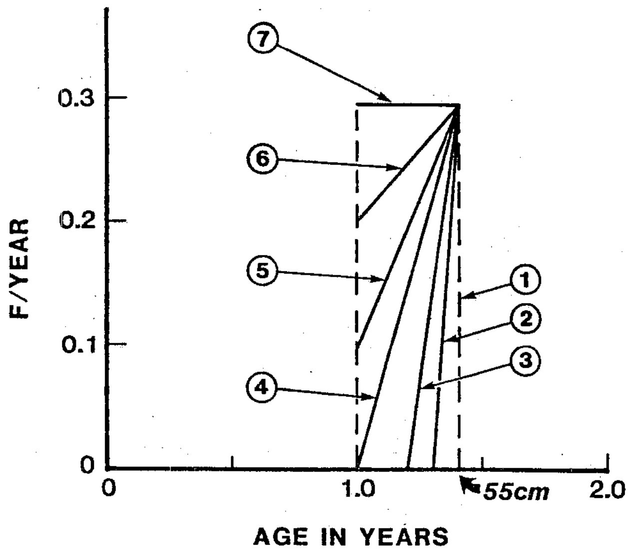

Figure 1. Models of partial F rates between 1.0 and 1.4 (= 55 cm) years, showing 7 hypothetical cases.

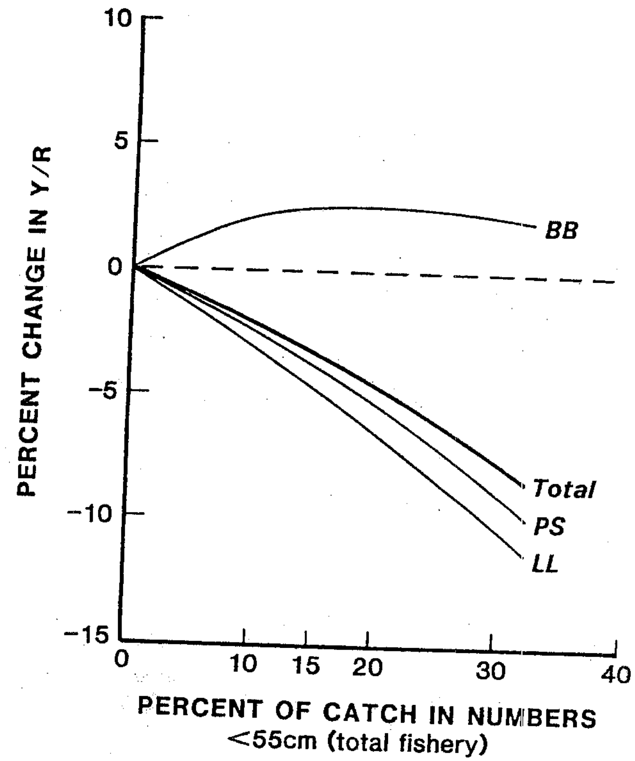

Figure 2. Change (%) in Y/R (relative to case of "knife-edge" selection at 55 cm) as a function of percent of <55 cm fish caught.