AN EXAMINATION OF THE YIELD PER RECRUIT BASIS FOR A MINIMUM SIZE REGULATION FOR ATLANTIC YELLOWFIN TUNA, *THUNNUS ALBACARES*

W. H. LENARZ, W. W. FOX, JR., G. T. SAKAGAWA, AND B. J. ROTHSCHILD[1]

ABSTRACT

Some of the conceptual foundations of yield-per-recruit analysis as a management tool and as applied to the Atlantic yellowfin tuna fishery were critically explored. Problems examined include: (1) estimating the current state of the fishery in terms of a knife-edged recruitment approximation, (2) inferring consequences of management action from the yield-per-recruit isopleth, (3) the difficulty in achieving a maximum yield per recruit when there exist several gear types exploiting different size ranges, (4) the difficulty in obtaining projected increases in yield per recruit when the killing and discarding (dumping) of fish smaller than the optimum size occurs, and (5) the possible interaction between a size limit and the projection of the maximum sustainable yield.

In employing yield-per-recruit analysis to the Atlantic yellowfin tuna fishery, two approaches were taken—one approach makes use of a wide range of parameter estimates and a number of simplifying assumptions, but little data, and the other approach makes use of considerably more data, but is more confined in the parameter estimates and uses fewer of the simplifying assumptions. The general results of both approaches, assuming no dumping occurs, indicate that only minor increases in yield per recruit would occur if the size at recruitment is increased from our estimate of the present size at recruitment and fishing effort remains constant; an increase in fishing effort without changing other aspects of the fishery would not appreciably increase yield per recruit; and an increase in size at recruitment and in fishing effort would result in modest gains in yield per recruit. Specifically meeting the request of the International Commission for the Conservation of Atlantic Tunas, we recommended that a minimum size limit regulation in the vicinity of 55 cm (3.2 kg) be enacted.

The second regular meeting, in Madrid, Spain, on 2-7 December 1971, of the commission of ICCAT (International Commission for the Conservation of Atlantic Tunas) authorized the "Council to recommend to the Contracting Parties that they prohibit landing of yellowfin weighing less than a minimum weight somewhere between 3.2 and 10 kg." This recommendation was based on studies by members of the Subcommittee on Stock Assessment that showed that theoretically the size at first capture which maximizes the yield per recruit of yellowfin is between 10 and 25 kg.

A special ICCAT working group on stock assessment of yellowfin tuna met in Abidjan, Ivory Coast, 12-16 June 1972, to consider further scientific aspects of size regulation and other matters pertaining to the Atlantic yellowfin fishery (ICCAT, 1972).[2] Studies on yield per recruit were presented by Hayasi, Honma, and Suzuki (1972);[3] Joseph and Tomlinson (1972);[4] and Lenarz and Sakagawa (1972).[5] A similar study was published by Wise (1972)

[1] Southwest Fisheries Center, National Marine Fisheries Service, NOAA, LaJolla, CA 92037.

[2] ICCAT. 1972. Report of the meeting of the special working group on stock assessment of yellowfin tuna (Abidjan, June 12-16, 1972). Manuscript on file at ICCAT General Mola 17, Madrid, 1 Spain.

[3] Hayasi, S., M. Honma, and Z. Suzuki. 1972. A comment to rational utilization of yellowfin tuna and albacore stocks in the Atlantic Ocean. Far Seas Fisheries Research Laboratory, Orido 1000, Shimizu, Japan. Unpublished manuscript.

[4] Joseph, J., and P. K. Tomlinson. 1972. An evaluation of minimum size limits for Atlantic yellowfin. Inter-American Tropical Tuna Commission, La Jolla, Calif. Unpublished manuscript.

[5] Lenarz, W., and G. Sakagawa. 1972. A review of the yellowfin fishery of the Atlantic Ocean. Southwest Fisheries Center, National Marine Fisheries Service, La Jolla, Calif. Unpublished manuscript.

Manuscript accepted June 1973.

before the meeting. The report of the meeting may be considered as a summary of these papers, which indicated that increases in size at recruitment would probably increase yield per recruit but not by more than about 10%.

The special ICCAT working group also examined available evidence on the practicability of minimum size regulations. Scientists of the group were concerned that since the gears that fish for yellowfin in the Atlantic supposedly kill most fish that are captured, a minimum size regulation would reduce the number of small yellowfin that are landed but would not have the desired effect of reducing mortality rates of small yellowfin. This, of course, assumes that schools of yellowfin containing yellowfin less than any minimum size would actually be set upon. In this connection the group noted that the conditions which must be met before minimum size regulations can be effective are: (1) the fishermen must be able to estimate the size of yellowfin in a school, and (2) there must be little or no mixing of small yellowfin with large yellowfin within schools.

Very little evidence is available from the Atlantic on these subjects. Ten samples were presented at the Abidjan meeting that indicated considerable mixing of small yellowfin (<5 kg) with large yellowfin (>5 kg) within schools. The working group also took note of a study on the subject by Calkins (1965) when size regulations were being considered by the IATTC (Inter-American Tropical Tuna Commission) for the yellowfin fishery in the eastern tropical Pacific. Calkins, working with only one hypothetical minimum size out of a range of 12.7 to 25.0 kg, concluded that a 12.7-kg size regulation would be seriously complicated by size variation within sets. He also noted that a considerable amount of small yellowfin are often captured in sets that include skipjack. Thus it appears that it would not be possible to fish for skipjack without killing some small yellowfin. Evidence based on the few samples from the Atlantic indicated that sets would include yellowfin tuna larger and smaller than 5 kg; thus even if a minimum size regulation were set at this value it would be difficult to prevent the capture of fish smaller than 5 kg.

The working group recommended that more data should be collected on the subject from the Atlantic. The working group also noted that a reduction in the size at first recruitment should be prevented and that minimum size regulations of 3.2 kg that have been passed by several African nations should help prevent a reduction in size at recruitment.

The population dynamics of Atlantic yellowfin tuna are complex because the fishery is prosecuted by several types of gear: bait boats, small purse seiners, large purse seiners, and longliners. These gears tend to capture different sizes of fish and thus affect the population in different ways. FAO (1968) noted that longline gear tends to capture large yellowfin while the other gears capture small yellowfin. Lenarz (1970),[6] with more recent data, showed that American[7] purse seine gear tends to capture relatively more large yellowfin—in significant quantities—than was indicated for the earlier surface fishery. Joseph and Tomlinson (1972, see footnote 4) presented data that indicated small purse seiners of France-Ivory Coast-Senegal (FIS) tend to capture relatively more small yellowfin than the large FIS and American purse seiners. The differences among size selectivity of the four gears necessitates consideration of the physical makeup of the fleet when examining size regulations. Therefore, considerable attention was paid to this aspect of the problem during the study.

The above paragraph might be taken to imply that adequate data are available respecting the relative quantities and size distributions of fish caught by the various gears. It is our feeling that the adequacy of the data needs to be demonstrated. We cannot place much faith in the details of the relative size distributions per unit effort among the various fishing units, but we do feel that the general orders of magnitude are essentially correct. We should also point out that with the improvement in data over the last several years, the interpretations which accrue from the data and our appreciation of the considerable complexity of the fishery are more evident.

Definitions of Minimum Size

Because this paper discusses minimum size, it is necessary to define the term explicitly to

[6] Lenarz, W. 1970. Estimates of yield per recruit of Atlantic yellowfin tuna. Southwest Fisheries Center, National Marine Fisheries Service, La Jolla, Calif. Unpublished manuscript.

[7] Refers to vessels registered in Canada, Panama, and the U.S.A.

avoid ambiguity and to prevent possible misapplications of the results of this study. "Minimum size" may be viewed from two aspects: absolute minimum size and effective minimum size. Absolute minimum size is defined as the smallest fish in the catch and is related to the concept of knife-edged recruitment in defining the size at recruitment to the fishery. Recruitment is defined as the act of becoming vulnerable to fishing. In the case of knife-edged recruitment, no fish are vulnerable to fishing prior to the size at recruitment. Fish that are larger than the size at recruitment are fully vulnerable to fishing. Since most recruitment is size specific, hence sequential, the term effective minimum size is also needed. Effective minimum size is that size whose corresponding age is used as the lower bound for integration of the yield equation as if recruitment were knife-edged, and which gives the same yield per recruit as the sequential recruitment case.

Approaches to Yield-Per-Recruit Analysis

This paper examined several of the concepts involved in yield-per-recruit analyses because the question of what is the optimum minimum size for a given rate of exploitation is usually interpreted through such analyses. Both the classical approach, in which fishing mortality is constant with knife-edged recruitment, and the more complex approach, in which fishing mortality is size specific, are explored.

Throughout the paper we have intentionally kept mathematical notation to a bare minimum. We believe that most of the equations used are well known to readers actively involved in stock assessment. Readers who are not familiar with the equations can find excellent descriptions in the cited literature.

Employing the classical approach to yield-per-recruit analysis involves: (1) estimating the age or size at recruitment which represents an approximation of the current state of the fishery in terms of knife-edged recruitment; (2) finding the age or size at recruitment which maximizes the yield per recruit at a given level of fishing mortality; (3) imposing some regulation on the fishery such to achieve as its effective minimum size, the age or size at recruitment which maximizes the yield per recruit. The advice from the yield-per-recruit isopleth (in terms of the optimal age or size at recruitment) may be interpreted as either a knife-edged absolute minimum size or as an effective minimum size. Since for the fishery under consideration (and for many other fisheries as well) recruitment is not knife-edged, then we are talking about an effective minimum size. Now, on the other hand, if we assume that the absolute minimum size, the regulated size, and the effective minimum size are all the same, then we will have an inappropriate estimate of the yield per recruit, and the optimum may not be achieved. Somehow we need to determine the relationship between the effective minimum size and the regulated size; in some instances they can roughly be the same; but this equality will usually not obtain if the regulated size is chosen to be the absolute minimum size in the catch.

The more complex approach, which estimates size-specific fishing mortality, circumvents the first difficulty encountered in the classical approach, i.e., determining a knife-edged approximation to the current state of the fishery. The problem still remains, however, as to interpretation of the advice from the yield-per-recruit isopleth in terms of an effective minimum size. Joseph and Tomlinson (1972, see footnote 4) used the more complex approach in a recent study on minimum size regulations for the Atlantic yellowfin fishery. We have updated their analysis by using data made available at the Abidjan meeting and have also examined the sensitivity of the methodology to various sources of errors in the data.

DATA, PARAMETERS, AND COMPUTER PROGRAMS

Data

Catch- and length-frequency data for each type of gear for the 1967-71 period were obtained from the report of the meeting of the special ICCAT working group (Tables 10, 11, and 12 of ICCAT, 1972, see footnote 2) with the exception of length-frequency data of the 1967-68 FIS fishery and 1971 Japanese longline fishery. Length frequencies for the 1967-68 FIS fishery were compiled from various ORSTOM (Office de la Recherche Scientique et Technique Outre-Mer) publications (Lenarz and Sakagawa, 1972, see footnote 5). Length frequencies from the 1971 Japanese longline fishery are assumed to be the same as those of the 1970 Japanese longline fishery; this assumption appears justifiable because year to year changes in length frequencies from longline fisheries tend to be less than differences in length frequencies between longline fisheries and surface fisheries.

Length-frequency data were available only from the Japanese longline fishery, FIS surface fisheries, and American large purse seine fishery. Thus it was necessary to make several assumptions before estimating the length frequencies of the total catch of yellowfin in the Atlantic. Length frequencies for longline fisheries other than Japan are assumed to be the same as Japan's. Length frequencies for the bait boat and small purse seine fisheries other than FIS were assumed to be the same as the FIS fishery. Length frequencies for the large purse seine fisheries other than FIS and American were assumed to be the same as those two fisheries.

Parameters

The growth equation $[L = 194.8 \times (1 - e^{-0.42(t - 0.62)})]$ presented in LeGuen and Sakagawa (1973) and length-weight relationship ($W = 0.0000214L^{2.9736}$) given by Lenarz (1971a)[8] were used, where L is fork length in cm, t is age in years, and W is weight in kg.

The annual instantaneous coefficient of natural mortality (M) is a difficult parameter to estimate and due to a lack of data only preliminary estimates have been made for the parameter in the Atlantic. We assume as most authors have that M is constant over the exploited phase. Estimates of $M = 2.61$ and 1.50 for the Atlantic were made by Pianet and LeHir (1971) based on data from bait boats and seiners, respectively. These estimates seem unreasonably high perhaps because their data were only from the Pointe Noire region which is a small area compared to the total region in the Atlantic where yellowfin tuna are found. Hennemuth (1961) estimated that M is 0.8 in the Pacific while Davidoff (1969) chose the upper bound of Hennemuth's estimate, 1.0. Hennemuth's work was based on estimates of instantaneous coefficient of total mortality (Z) made from age compositions of catches by primarily bait boats and an estimate of instantaneous coefficient of fishing mortality (F) from Schaefer (1957). Since bait boats appear to be selective for small yellowfin, F and Z are not constant, and methods of ageing yellowfin have not been proven correct, Hennemuth's estimate must be considered a first approximation. However, his estimate seems reasonably consistent with what is thought to be the life span of yellowfin. We assumed for the purposes of our calculations here that M is 0.8 as is conventional (based on Hennemuth's work in the Pacific); we also used values of 0.6 and 1.0 to encompass what we believe is the range of reasonable values.

Pianet and LeHir (1971) also estimated an average F of 0.88 for the segment of the Atlantic yellowfin tuna population that is exploited in the Pointe Noire region. As we have indicated, their estimate is not representative for the population as a whole.

Our range of estimates of Z for 1967-71 is 0.91 to 1.82 (Lenarz and Sakagawa, 1972, see footnote 5). If we assume that $M = 0.8$ for the Atlantic population, then F is 0.11 to 1.02. We believe that F is about 0.6 for recent years. However, we used a range of F values in our study.

Computer Programs

Most of the calculations were performed on the Burroughs 6700[9] computer at the University of California at San Diego. Programs used in the analysis, except for FRG708 (Paulik and Bayliff, 1967), were written by the authors; they are as follows:

1. Simplified Beverton and Holt yields per recuit—YPER.
2. Accuracy of knife-edged approximations of age at entry and interactions between minimum size and catch quota regulations—GXPOPS.
3. Yield-per-recruit isopleths under knife-edged recruitment—FRG708.

[8] Lenarz, W. 1971a. Length-weight relations for five Atlantic scombrids. Southwest Fisheries Center, National Marine Fisheries Service, La Jolla, Calif. Unpublished manuscript.

[9] Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

4. Size-specific rates of fishing mortality—COHORT.

5. Yield-per-recruit isopleths for multigear fisheries with size-specific F—MGEAR.

6. Optimum size at recruitment under different levels of effort by two gears—OPSIZE.

ANALYSIS

As previously mentioned in the introduction, we use two approaches in analyzing the data, the knife-edged recruitment approach and the size-specific F approach.

Knife-Edged Recruitment Approach

Introduction

Two commonly used models for computing yield per recruit and determining the size at recruitment which maximizes yield per recruit are those of Beverton and Holt (1957) and Ricker (1958). We employed both models for knife-edged approximation analyses—the simplified Beverton and Holt model, making use of a wide range of parameter estimates or extrapolations from fisheries for similar species, and the Ricker model, making use of the best parameter estimates and giving a more detailed analysis of yield per recruit. We used the Ricker model instead of the Beverton and Holt model for calculating yield-per-recruit isopleths because the Ricker model allows the use of exponents in the length-weight relationship with values other than 3. It is important to stress that the material in the simplified Beverton and Holt model involves fewer assumptions than the material in subsequent sections. This is important because as our approach becomes more complex the data requirements become more rigorous. It can be argued that we have sufficient data for this simplified approach. In the more complex approaches this assertion becomes more tenuous; because we use more assumptions in the more complex approaches we do not necessarily obtain more information, even though it may appear that way. However, it should be noted that the assumption of a constant rate of mortality over the fishable life span contained in the simplified approach may be important, and we believe that it is not fulfilled. These analyses are followed by sections discussing the problems of determining the proper parameters which represent the current situation of the fishery.

Simplified Beverton and Holt Model

The Beverton and Holt yield-per-recruit model may be simplified such that relative yield per recruit, Y', is a function of three ratios:

$$C = l_r'/L_\infty$$
$$Q = M/K$$
$$E = F/(F + M)$$
$$Y' = Y/(RW_\infty)$$

and where l_r' is the size (length) at recruitment, W_∞, L_∞, and K are parameters of the von Bertalanffy growth equation, Y is yield in weight, and R is recruitment. Y' is tabulated in Beverton and Holt (1966), but more extensive calculations were performed with program YPER.[10] Beverton and Holt (1959) concluded that, within reason, there exists a common ratio between M and K within related species groups. Therefore, a range of estimates for the various parameters is utilized along with other information obtained by examining parameter estimates for M and K for yellowfin tuna from areas other than the Atlantic.

The range of values for the various parameters is as follows: K = 0.28 to 0.53 and L_∞ = 175.2 to 223.0 cm from LeGuen and Sakagawa (1973), Z = 0.91 to 1.82 from Lenarz and Sakagawa (1972, see footnote 5), and M = 0.6 to 1.0. From these ranges of estimates, a maximum range for E is 0.0 to 0.67 and for Q is 1.13 to 3.57. Using our most reasonable parameter estimates of K = 0.42, M = 0.8, and Z = 1.4, however, a reasonable range for E and Q was established by allowing either the numerator or denominator of the ratio to be one of our most reasonable estimates—the reasonable ranges are E = 0.12 to 0.56 and Q = 1.42 to 2.86. With K = 0.42, M = 0.8, and Z = 1.4, our most reasonable estimates of E and Q are 0.43 and 1.9, respectively.

Table 1 contains optimal values of size (cm) at recruitment, $l^{*\prime}_r$, for the maximum range of estimates of E and Q (deleting the impossible E = 0.0) for the range and most reasonable estimates of L_∞. The dashed lines enclose the

[10] For some values of c, Table IIb of Beverton and Holt (1966) was slightly higher than computed by YPER; this may be due to differing methods of rounding.

Table 1.—Optimal values of size at recruitment (cm) as a function of the rate of exploitation (E) and the ratio of M to K (Q) for three estimates of L_∞.[1]

Q	E 0.1	0.2	0.3	0.4	0.5	0.6	0.7
				L_∞ = 175.2 cm			
1.0	56.6	73.1	84.4	94.3	102.3	109.5	115.8
1.5	49.4	64.1	74.8	83.4	90.8	97.1	102.8
2.0	43.8	57.1	66.9	74.8	81.5	87.2	92.5
2.5	39.4	51.7	60.4	67.8	73.9	79.4	84.1
3.0	35.9	47.1	55.4	62.0	67.6	72.7	77.1
3.5	32.9	43.3	51.0	57.1	62.4	66.9	71.1
				L_∞ = 194.8 cm			
1.0	62.9	81.2	94.3	104.8	113.8	121.8	128.8
1.5	54.9	71.3	83.2	92.7	100.9	107.9	114.4
2.0	48.7	63.5	74.4	<u>83.2</u>	90.6	97.0	102.8
2.5	43.8	57.5	67.2	75.4	82.2	88.2	93.5
3.0	39.9	52.4	61.6	69.0	75.2	80.8	85.7
3.5	36.6	48.1	56.7	63.5	69.4	74.4	79.1
				L_∞ = 223.0 cm			
1.0	72.0	93.0	107.9	120.0	130.2	139.4	147.4
1.5	62.9	81.6	95.2	106.2	115.5	123.5	130.9
2.0	55.8	72.7	85.2	95.2	103.7	111.0	117.7
2.5	50.2	65.8	76.9	86.3	94.1	101.0	107.0
3.0	45.7	60.0	70.5	78.9	86.1	92.6	98.1
3.5	41.9	55.1	64.9	72.7	79.4	85.2	90.5

[1] Dashed lines encompass our reasonable range of values; underlined value is our most reasonable estimate.

reasonable range of estimates (deleting the unreasonably low $E = 0.12$), and the underlined value in the center of Table 1 is our most reasonable estimate. One can see in Table 1 that the values are all greater than the approximate absolute minimum size of 32.5 cm[11] for the Atlantic yellowfin tuna fishery over the range of the estimates of L_∞.

For the moment let us assume that recruitment is knife-edged at 32.5 cm (0.67 kg) and that the fishery can be regulated such to obtain a knife-edged recruitment at any desired size. Therefore, the maximum possible increases in yield per recruit may be computed. Our smallest reasonable values for optimal size at recruitment are 47.1 cm (2.0 kg), 52.4 cm (2.8 kg), or 60.0 cm (4.1 kg) depending on L_∞. The respective predicted values of yield per recruit are 2.0%, 3.1%, and 4.3% higher than when size at recruitment is 32.5 cm. Our largest reasonable estimates of optimal size at recruitment are 97.1 cm (17 kg), 107.9 cm (24 kg), or 123.5 cm (36 kg). The respective predicted increases in yield per recruit are 65%, 73%, and 82%. The predicted increase in yield per recruit using all of our most reasonable parameter estimates, i.e., raising 32.5 cm to 83.2 cm (11 kg), is 23%. The bounds on an increase in yield per recruit, 2% to 82%, and the most likely value of 23%, are estimated under the assumptions of knife-edged recruitment, and that size at recruitment represents an absolute minimum size. The Atlantic yellowfin tuna fishery, however, does not have knife-edged recruitment.

We used equation 1b of this paper to obtain our most reasonable estimate of the 1967-71 average effective minimum size for the Atlantic yellowfin tuna fishery from average lengths given in Table 15 of Lenarz and Sakagawa (1972, see footnote 5). The estimate of average effective minimum size is about 55 cm (3.2 kg). Nearly all the values within the dashed lines in Table 1, however, are greater than 55. The only smallest reasonable estimate of optimal effective minimum size greater than 55 cm is 60.0 cm with L_∞ = 223.0 cm. An increase from 55 to 60.0 cm would give an increase in yield per recruit $< 0.2\%$. The largest reasonable estimates of optimal effective minimum size predict increases in yield per recruit of 28%, 36%, or 45% with in-

[11] The value of 32.5 cm represents our selection for an approximate absolute minimum size for the Atlantic yellowfin tuna fishery, which also agrees with that chosen by Joseph and Tomlinson (1972, see footnote 4).

creases from 55 cm to 97.1, 107.9, and 123.5 cm, respectively depending on L_∞. The increase in yield per recruit by increasing the effective minimum size from 55 to 83.2 cm, our most reasonable estimate, is only 7.9%.

From the above analysis using a wide range of parameter estimates, we can conclude with reasonable assurance that virtually any increase in the effective minimum size will cause an increase in yield per recruit. Our most likely estimate of this increase in yield per recruit is only 7.9% which is bounded, with reasonable parameter estimates, by 0% and 45%.

Ricker Model

Ricker model yield-per-recruit isopleths were calculated using values of M of 0.6, 0.8, and 1.0 to illustrate our estimates of actual (rather than relative) yield per recruit (Figures 1, 2, and 3). As will be mentioned in the next section it is difficult to estimate the location of the fishery on the graphs, i.e., when fishing mortality is size specific it is not a trivial matter to make reasonable estimates of age at recruitment, t_r', and a constant total mortality coefficient, Z. Our most reasonable estimates, taken from Lenarz and Sakagawa (1972, see footnote 5), of these parameters are: t_r' is 1.41 yr and Z is 1.4.

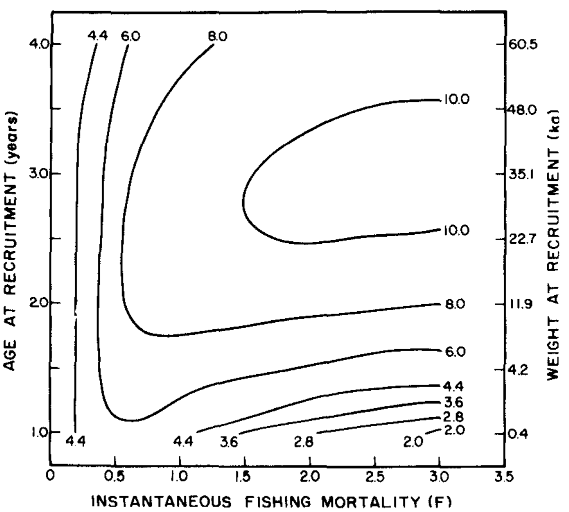

FIGURE 1.—Yield-per-recruit isopleths as functions of fishing mortality and age (and weight) at recruitment when $M = 0.6$.

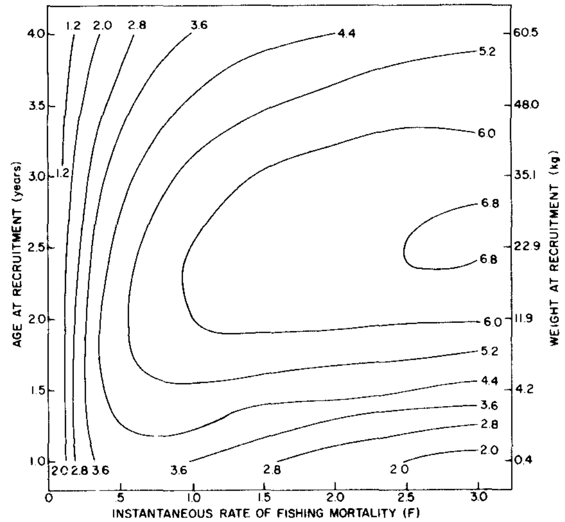

FIGURE 2.—Yield-per-recruit isopleths as functions of fishing mortality and age (and weight) at recruitment when $M = 0.8$.

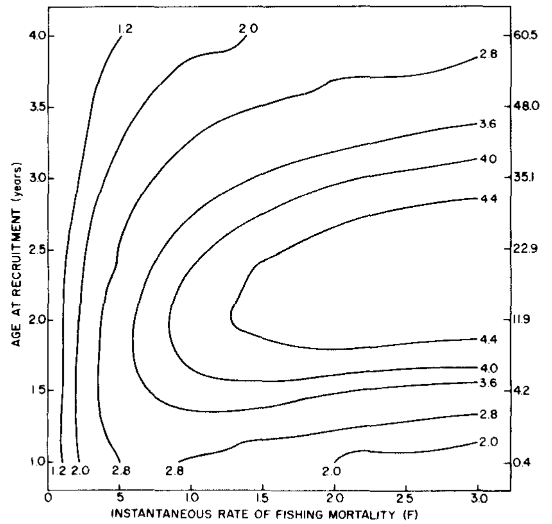

FIGURE 3.—Yield-per-recruit isopleths as functions of fishing mortality and age (and weight) at recruitment when $M = 1.0$.

The results (Figures 1, 2, and 3) show, for example, that with $M = 0.6$ and Z remaining constant (1.4), an increase in age at recruitment from 1.41 to 1.83 yr (or 77.5 cm) raises the yield per recruit about 20%; if $M = 0.8$, the same change raises the yield per recruit on the order of 10%; and if $M = 1.0$, the same change does not change yield per recruit. If age at recruitment is held constant and fishing mortality is doubled, when $M = 0.6$ yield per recruit decreases by some 20%; when $M = 0.8$ yield per recruit increases on the order of 5%; and when $M = 1.0$ yield per recruit increases about 30%. If effort is doubled and age at recruitment is raised to 1.83 yr, when $M = 0.6$ or $M = 0.8$ yield per recruit increases on the order of 20%; and when $M = 1.0$ yield per recruit increases by about 40%.

Estimation of t_r'

In employing a knife-edged approximation to size-specific recruitment protracted over some time period, the first problem is to determine the proper age at recruitment (t_r') such that the integration reflects the same yield per recruit as the size-specific recruitment case. There are two problems in doing so. First, there are two values for t_r' that will give the same yield per recruit as the size-specific recruitment case, unless eumetric fishing obtains. Often, however, this may be of little consequence, since one of the two values for t_r' could be obviously infeasible. Second, t_r' will depend on the fishing mortality.

Two estimators of t_r' are provided, at least implicitly, by Beverton and Holt (1957): (1) the age corresponding to the mean selection length, and (2) the resultant of a formula depending on Z and the average age, $\overline{t}$ (or average length, $\overline{l}$), in the catch. The mean selection length is the 50% selection length if the selection curve is symmetrical, and it is not dependent on the magnitude of the fishing mortality coefficient, F. The second estimator of t_r' is

$$t_r' = \overline{t} - 1/Z \tag{1a}$$

or, in terms of length

$$l_r' = \overline{l} - K(L_\infty - \overline{l})/Z. \tag{1b}$$

These two equations were obtained from manipulations of the Beverton and Holt yield equation.

Several computations of yield per recruit with the program GXPOPS were made utilizing $F = 0.1$ and $F = 2.0$, $M = 0.8$, the von Bertalanffy equation for Atlantic yellowfin tuna, and an arbitrary age-specific selection curve (Figure 4) in order to demonstrate the two

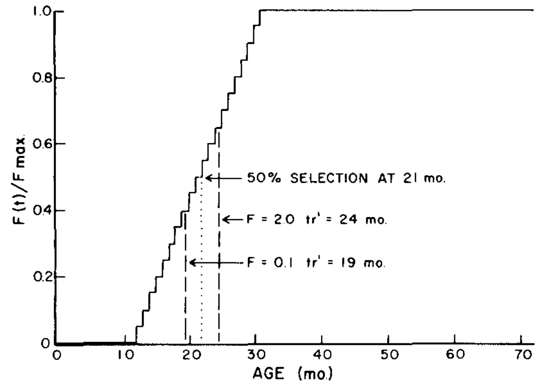

FIGURE 4.—Arbitrary age-specific recruitment curve.

problems and to evaluate the two estimators of t_r'. At $F = 0.1$, the values of t_r' giving the same yields per recruit as the selection curve are <8 mo (t_0 of the von Bertalanffy growth curve is 7.48 mo) or 24 mo, and 19 or 45 mo for $F = 2.0$. Since the state of the simulated fishery is not eumetric for either value of F, there are two knife-edged approximation locations. The effect of the magnitude of F on the true t_r' is obvious, with the lower value increasing from <8 to 19 mo and the upper value increasing from 24 to 45 mo as F is changed from 0.1 to 2.0. The reasonable values for t_r' to approximate the selection curve, however, are 24 mo for $F = 0.1$ and 19 mo for $F = 2.0$, a change of 5 mo.

Estimator 1, the mean selection age, is 21 mo and is shown along with the reasonable values in Figure 4. Using 21 mo for t_r' would result in yields per recruit that are 4% and 15% too high for $F = 0.1$ and $F = 2.0$ respectively. Estimator 1 does not change with F, of course, but in this case it lies intermediate between the true t_r' values. Estimator 2 gives 19 mo for $F = 0.1$ and 18 mo for $F = 2.0$. We emphasize that this estimator does depend on the magnitude of F.

Neither estimator is exact in this example where the catches, their ages, and the selection curve are known without error. This places doubt on their estimates from the usual catch at age data where considerable random error would be involved. Encouraging, though, is that both estimators indicate the proper direction that the fishery's selectivity should proceed to approach the optimal yield per recruit—about

15 mo for $F = 0.1$ and 30 mo for $F = 2.0$. Since estimator 1 requires size-selective data not frequently available and does not respond to changes in F, estimator 2 appears to be the most attractive for knife-edged approximations. The Atlantic yellowfin tuna fishery, however, has a much more complex recruitment pattern and size-specific F than this simple example owing to the diverse gear types. The mix of relative F among the various gear types makes the determination of the appropriate current t_r' somewhat tenuous.

Estimation of Constant Z

The yield-per-recruit isopleths shown in Figures 1, 2, and 3 were calculated under the assumption that fishing mortality and Z are constant after the fish are recruited. The value of Z was also estimated under the same assumption. The section on size-specific fishing mortality will indicate that F is not a constant, but is related to size. Thus our estimate of a constant Z may not be realistic but may be a more reasonable approach to estimating yield per recruit than the size-specific F approach given the quality of the data. It is the average of values of Z estimated for the FIS bait boat and purse seine fisheries (Lenarz and Sakagawa, 1972, see footnote 5). The size-specific F section indicates that F decreases with size for bait boats and increases with size for purse seiners. Beverton and Holt (1956) gave examples that indicated that when F decreases with age, constant Z will be overestimated and when F increases with age, constant Z will be underestimated. Hopefully we have obtained a reasonable estimate by taking the average of Z's for the two gears.

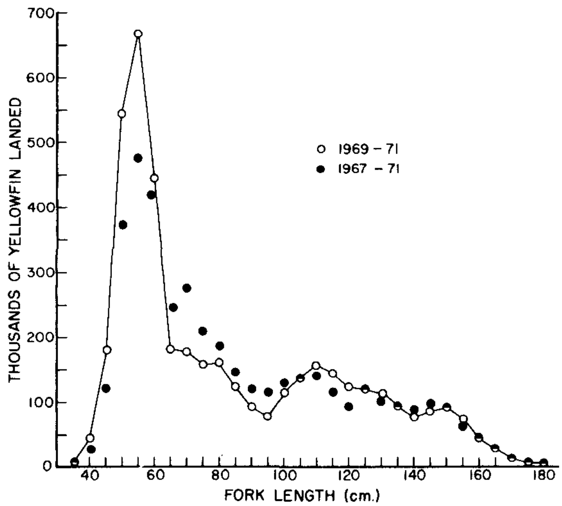

FIGURE 5.—Average length frequencies for the Atlantic yellowfin tuna fisheries for two periods, 1967-71 and 1969-71.

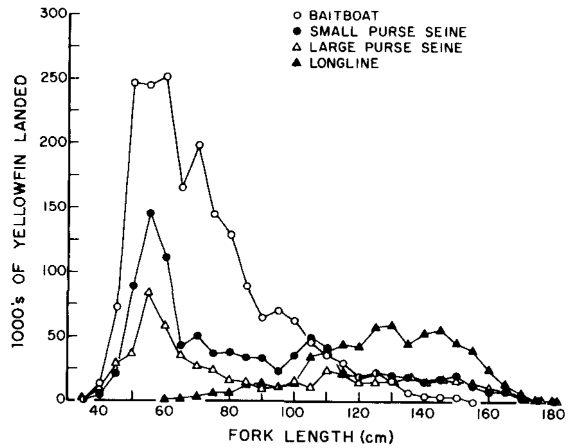

FIGURE 6.—Average length frequencies (1967-71) of Atlantic yellowfin tuna caught by four gear types.

Size-Specific F Approach

Estimates of Length Frequencies

Length frequencies, numbers of yellowfin caught by 5-cm intervals starting at 35 cm (32.5 cm ≤ fork length <37.5 cm), were estimated for each gear and the total fishery for two overlapping periods, 1967-71 and 1969-71 (Figure 5). The first period was used with the hope that the effect caused by unequal strength of year classes would be minimized by averaging. The second period was used because it was felt that the data are more accurate. Length frequencies of the two periods are quite similar and produce similar estimates of size-specific fishing mortality and estimates of yield per recruit. Thus, to avoid redundancy, only the data for the 1967-71 period are used. Figure 6 and Table 2 show the length frequencies for each gear. The curves are as described earlier (see introductory section.)

Estimates of Size-Specific Fishing Mortality

Size-specific instantaneous coefficients of fishing mortality were estimated with the method of Gulland (1965) and Murphy (1965) as suggested

TABLE 2.—Basic data on size (age) composition of catch of yellowfin tuna from the tropical Atlantic Ocean.

Midpoint of size interval (cm)	Weight at beginning of interval (kg)	Age at beginning of interval (yr)	1967-71 average number of yellowfin landed				
			Bait boats	Small purse seiners	Large purse seiners	Longliners	Total
35	0.67	1.0579	1,886	372	100		2,358
40	1.03	1.1325	14,551	5,445	9,057		29,053
45	1.49	1.2093	72,972	21,782	28,372		123,126
50	2.08	1.2888	246,924	89,614	36,684	7	373,229
55	2.79	1.3710	245,206	146,883	83,153	22	475,264
60	3.66	1.4562	251,017	110,755	59,648	451	421,871
65	4.69	1.5445	165,328	42,427	35,891	647	244,293
70	5.90	1.6363	197,855	49,929	26,992	2,151	276,927
75	7.30	1.7317	143,885	36,942	23,263	5,435	209,525
80	8.90	1.8310	128,810	37,082	15,528	5,694	187,114
85	10.72	1.9348	89,637	31,143	13,338	12,025	146,143
90	12.77	2.0432	64,128	31,135	9,818	13,049	118,130
95	15.06	2.1568	70,422	22,248	10,062	11,665	114,397
100	17.61	2.2761	63,619	36,483	13,323	15,074	128,499
105	20.43	2.4017	45,582	48,274	11,647	34,071	139,574
110	23.54	2.5343	36,414	42,283	24,296	40,209	143,202
115	26.95	2.6748	29,227	21,268	21,466	44,034	115,995
120	30.67	2.8240	18,877	18,311	15,144	42,859	95,191
125	34.72	2.9832	22,228	23,711	15,018	57,358	118,915
130	39.10	3.1538	15,152	20,612	16,238	58,544	110,546
135	43.84	3.3376	7,142	18,304	18,504	44,690	88,640
140	48.95	3.5368	4,137	15,790	13,569	52,070	85,566
145	54.43	3.7542	3,393	17,301	17,886	55,582	94,162
150	60.31	3.9935	3,459	20,222	16,711	45,648	86,040
155	66.60	4.2595	1,511	12,057	14,926	39,108	67,602
160	73.30	4.5590	793	8,754	10,678	24,489	44,714
165	80.44	4.9017	634	7,803	6,633	13,659	28,729
170	88.03	5.3021	327	2,470	2,918	6,265	11,980
175	96.07	5.7838	209	2,132	1,383	241	3,965
180	104.59	6.3883	49	1,429	361	55	1,894
	113.60	7.2004					
Total			1,945,374	942,961	573,207	625,102	4,086,645

by Lenarz (1971b).[12] We followed the modification of Joseph and Tomlinson (1972, see footnote 4) by using the inverse of the von Bertalanffy growth equation to convert size distributions to age distributions. This method assumes that there is a reasonably accurate relationship between length and age of yellowfin tuna. This assumption has not been verified. Ageing by modal progression would probably be more satisfactory, if more complete length composition data were available on a monthly or quarterly basis.

The reverse iterative procedure with computer program COHORT and $M = 0.8$ was used to estimate size-specific values of fishing mortality (F) starting at the 180-cm interval. Four initial values of F were tried: 0.2, 0.4, 0.6, and 0.8 (Figure 7). Estimates of F tend to converge as size of the yellowfin tuna decreases with the range of initial values tried as is characteristic

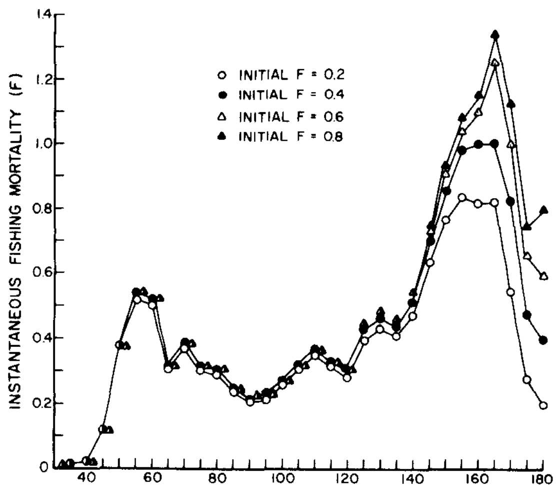

FIGURE 7.—Estimates of size-specific instantaneous fishing mortality coefficients (F) with several initial F values.

[12] Lenarz, W. 1971b. Yield per recruit of Atlantic yellowfin tuna for multigear fisheries. Southwest Fisheries Center, National Marine Fisheries Service, La Jolla, Calif. Unpublished manuscript.

of the methodology (Tomlinson, 1970). Calculations of yield per recruit using initial values of F of 0.2 and 0.8 are shown in Figures 8 and 9 as functions of initial values of F, effort, and size at recruitment. The values of yield per recruit do not vary significantly (<10%) with changes in the initial values of F, and the relative values are quite similar. Values of size specific F are shown for each gear in Figure 10 when initial values of F are 0.2 and 0.8. When the initial value of F is 0.8, values of F for small purse seiners increase sharply with size from 170 to 180 cm. This does not occur when the initial value of F is 0.2. Intuitively we do not expect an increase in F with size past 170 cm and thus choose to use the results when the initial value of F is 0.2 in the remainder of the paper. Validity of the estimates of F depends on the validity of the assumption that recruitment has been fairly constant for the cohorts included in the analysis. The special ICCAT working group noted that the cohort which entered the surface fisheries in 1969 appears to be weaker than the following two cohorts (ICCAT, 1972, see footnote 2). Although inclusion of 5 yr of data in the analysis may minimize the source of error, future studies should examine the sensitivity of the results to errors of this type.

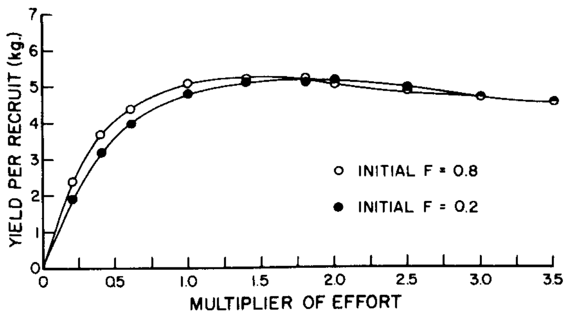

FIGURE 8.—Yield-per-recruit (kg) of Atlantic yellowfin tuna, when size at recruitment is 32.5 cm, as a function of the multiplier of fishing effort.

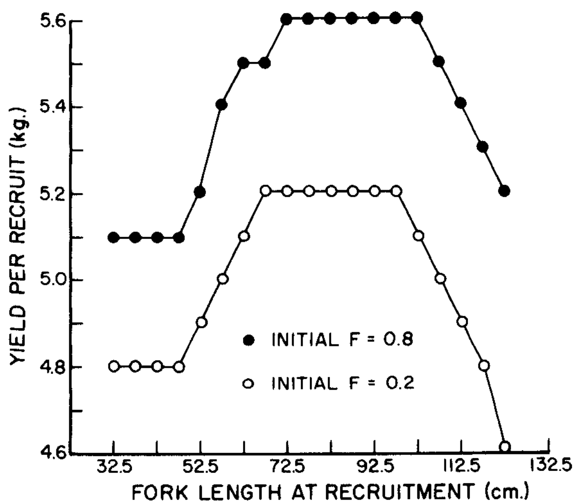

FIGURE 9.—Yield-per-recruit (kg) of Atlantic yellowfin tuna, with the current level of fishing effort, as a function of length at recruitment.

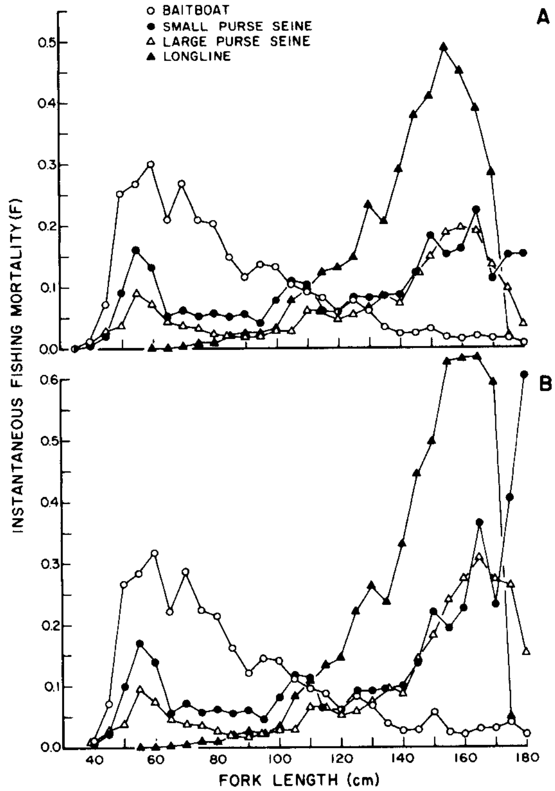

FIGURE 10.—Estimates of size-specific instantaneous fishing mortality coefficients (F) by gear type when initial values of F are (A) F = 0.2, (B) F = 0.8.

Estimates of Yield Per Recruit

Results of the yield-per-recruit calculations using the estimates of size-specific F when the initial value of F is 0.2 and with M = 0.8 are shown by gear in Table 3. Yield-per-recruit isopleths and the line of eumetric fishing (size at recruitment, $l^{*\prime}_{r}$, which maximizes yield per recruit at a given effort) for the entire fishery

TABLE 3.—Estimates of yield per recruit (kg) when $M = 0.8$, initial $F = 0.2$, and growth curve of LeGuen and Sakagawa (1973) is used.

BAIT BOATS

MINIMUM SIZE CM	KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.08	0.15	0.21	0.31	0.39	0.46	0.49	0.56	0.62	0.68
117.5	30.6	0.09	0.17	0.24	0.36	0.46	0.54	0.58	0.66	0.73	0.80
112.5	26.9	0.11	0.21	0.29	0.43	0.55	0.65	0.69	0.80	0.89	0.96
107.5	23.5	0.13	0.24	0.33	0.50	0.64	0.75	0.80	0.92	1.02	1.11
102.5	20.4	0.15	0.27	0.38	0.57	0.73	0.86	0.92	1.06	1.17	1.27
97.5	17.6	0.17	0.31	0.44	0.66	0.85	1.01	1.08	1.24	1.38	1.50
92.5	15.0	0.19	0.35	0.50	0.75	0.96	1.15	1.23	1.41	1.58	1.72
87.5	12.7	0.20	0.38	0.54	0.81	1.04	1.24	1.32	1.52	1.69	1.84
82.5	10.7	0.22	0.41	0.58	0.88	1.12	1.34	1.43	1.64	1.82	1.98
77.5	8.9	0.24	0.45	0.63	0.95	1.22	1.45	1.55	1.78	1.97	2.13
72.5	7.3	0.26	0.48	0.68	1.02	1.30	1.54	1.64	1.87	2.07	2.23
67.5	5.9	0.27	0.51	0.72	1.08	1.38	1.62	1.73	1.96	2.14	2.30
62.5	4.7	0.29	0.53	0.75	1.12	1.41	1.65	1.76	1.98	2.16	2.30
57.5	3.7	0.30	0.56	0.78	1.15	1.43	1.66	1.76	1.96	2.11	2.22
52.5	2.8	0.31	0.57	0.79	1.15	1.42	1.63	1.72	1.88	2.00	2.08
47.5	2.1	0.31	0.58	0.80	1.15	1.42	1.61	1.69	1.84	1.94	2.00
42.5	1.5	0.31	0.58	0.80	1.15	1.41	1.60	1.68	1.82	1.91	1.97
37.5	1.0	0.31	0.58	0.80	1.15	1.41	1.60	1.67	1.81	1.90	1.96
32.5	0.7	0.31	0.58	0.80	1.15	1.41	1.60	1.67	1.81	1.90	1.95

SMALL PURSE SEINERS

MINIMUM SIZE CM	KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.34	0.58	0.75	0.97	1.09	1.16	1.19	1.24	1.28	1.31
117.5	30.6	0.35	0.60	0.77	0.99	1.11	1.18	1.21	1.27	1.30	1.33
112.5	26.9	0.36	0.61	0.79	1.01	1.13	1.20	1.23	1.28	1.31	1.34
107.5	23.5	0.38	0.64	0.83	1.06	1.20	1.28	1.32	1.38	1.43	1.47
102.5	20.4	0.40	0.67	0.87	1.12	1.27	1.37	1.41	1.49	1.55	1.60
97.5	17.6	0.41	0.69	0.89	1.14	1.30	1.40	1.44	1.52	1.59	1.64
92.5	15.0	0.41	0.70	0.90	1.15	1.30	1.39	1.43	1.50	1.56	1.61
87.5	12.7	0.42	0.71	0.91	1.16	1.31	1.40	1.44	1.51	1.56	1.60
82.5	10.7	0.42	0.71	0.91	1.16	1.30	1.39	1.43	1.49	1.53	1.57
77.5	8.9	0.43	0.71	0.91	1.15	1.29	1.37	1.40	1.45	1.49	1.51
72.5	7.3	0.43	0.71	0.91	1.14	1.27	1.34	1.36	1.41	1.43	1.44
67.5	5.9	0.43	0.72	0.91	1.13	1.24	1.30	1.32	1.35	1.36	1.35
62.5	4.7	0.43	0.71	0.90	1.11	1.22	1.27	1.28	1.30	1.29	1.28
57.5	3.7	0.43	0.71	0.90	1.10	1.19	1.23	1.24	1.24	1.23	1.21
52.5	2.8	0.44	0.72	0.89	1.08	1.16	1.19	1.20	1.19	1.17	1.14
47.5	2.1	0.44	0.71	0.89	1.06	1.13	1.15	1.15	1.14	1.11	1.07
42.5	1.5	0.44	0.71	0.88	1.06	1.12	1.14	1.14	1.11	1.08	1.05
37.5	1.0	0.44	0.71	0.88	1.06	1.12	1.13	1.13	1.11	1.08	1.04
32.5	0.7	0.44	0.71	0.88	1.06	1.12	1.13	1.13	1.11	1.08	1.04

LARGE PURSE SEINERS

MINIMUM SIZE CM	KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.31	0.54	0.69	0.89	0.99	1.05	1.07	1.10	1.12	1.12
117.5	30.6	0.32	0.55	0.71	0.90	1.01	1.06	1.08	1.11	1.12	1.13
112.5	26.9	0.33	0.56	0.73	0.92	1.03	1.09	1.11	1.14	1.16	1.17
107.5	23.5	0.34	0.58	0.74	0.94	1.04	1.10	1.12	1.15	1.17	1.18
102.5	20.4	0.34	0.58	0.74	0.93	1.02	1.06	1.08	1.10	1.10	1.10
97.5	17.6	0.35	0.58	0.74	0.92	1.00	1.04	1.05	1.06	1.06	1.06
92.5	15.0	0.35	0.58	0.73	0.91	0.99	1.02	1.03	1.03	1.03	1.02
87.5	12.7	0.35	0.58	0.73	0.90	0.97	1.00	1.00	1.00	0.99	0.97
82.5	10.7	0.35	0.58	0.73	0.89	0.96	0.98	0.98	0.97	0.95	0.93
77.5	8.9	0.35	0.58	0.72	0.88	0.93	0.95	0.95	0.93	0.91	0.88
72.5	7.3	0.35	0.57	0.72	0.86	0.92	0.92	0.92	0.90	0.87	0.84
67.5	5.9	0.35	0.57	0.71	0.85	0.89	0.89	0.88	0.86	0.82	0.79
62.5	4.7	0.35	0.57	0.71	0.84	0.87	0.87	0.86	0.83	0.80	0.76
57.5	3.7	0.35	0.57	0.70	0.82	0.85	0.84	0.82	0.79	0.75	0.71
52.5	2.8	0.35	0.57	0.69	0.80	0.82	0.80	0.79	0.75	0.71	0.67
47.5	2.1	0.35	0.56	0.68	0.78	0.79	0.77	0.75	0.71	0.66	0.62
42.5	1.5	0.35	0.56	0.68	0.78	0.79	0.76	0.75	0.70	0.65	0.61
37.5	1.0	0.35	0.56	0.68	0.78	0.79	0.76	0.75	0.70	0.65	0.61
32.5	0.7	0.35	0.56	0.68	0.78	0.79	0.76	0.74	0.70	0.65	0.61

TABLE 3.—Estimates of yield per recruit (kg) when $M = 0.8$, initial $F = 0.2$, and growth curve of LeGuen and Sakagawa (1973) is used.—Continued.

LONG LINERS											
MINIMUM SIZE		MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.80	1.40	1.86	2.49	2.87	3.12	3.21	3.38	3.49	3.57
117.5	30.6	0.82	1.44	1.90	2.53	2.90	3.14	3.23	3.38	3.47	3.54
112.5	26.9	0.84	1.46	1.93	2.54	2.90	3.12	3.19	3.32	3.39	3.43
107.5	23.5	0.85	1.48	1.93	2.52	2.84	3.02	3.08	3.17	3.20	3.21
102.5	20.4	0.86	1.48	1.93	2.49	2.78	2.93	2.97	3.03	3.03	3.01
97.5	17.6	0.86	1.47	1.90	2.43	2.69	2.81	2.83	2.85	2.82	2.76
92.5	15.0	0.86	1.46	1.89	2.38	2.62	2.71	2.72	2.71	2.66	2.58
87.5	12.7	0.86	1.46	1.87	2.34	2.55	2.62	2.63	2.59	2.52	2.43
82.5	10.7	0.86	1.45	1.85	2.29	2.48	2.52	2.52	2.46	2.36	2.25
77.5	8.9	0.85	1.43	1.82	2.23	2.38	2.40	2.38	2.29	2.17	2.04
72.5	7.3	0.85	1.41	1.79	2.17	2.29	2.28	2.24	2.13	1.99	1.85
67.5	5.9	0.84	1.39	1.75	2.09	2.18	2.13	2.09	1.95	1.79	1.63
62.5	4.7	0.84	1.38	1.72	2.03	2.09	2.03	1.98	1.82	1.64	1.48
57.5	3.7	0.83	1.35	1.67	1.95	1.97	1.88	1.81	1.63	1.44	1.27
52.5	2.8	0.82	1.33	1.63	1.86	1.85	1.73	1.66	1.46	1.26	1.09
47.5	2.1	0.82	1.31	1.60	1.81	1.77	1.64	1.56	1.35	1.15	0.98
42.5	1.5	0.82	1.31	1.59	1.79	1.75	1.61	1.53	1.32	1.12	0.94
37.5	1.0	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94
32.5	0.7	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94

are shown in Figure 11. Table 3 and Figures 8, 9, and 11 indicate that if size at recruitment remains constant at 32.5 cm, very little increase in yield per recruit (~5%) can be expected if effort is increased, and if effort remains constant, very little (~10%) increase in yield per recruit can be expected by increasing size at recruitment. However, if fishing effort is doubled (i.e., multiplier = 2.0) and size at recruitment increased to 55 cm (3.2 kg), yield per recruit would increase 15%, or if size at recruitment is increased to 77.5 cm (~10 kg), yield per recruit would increase about 30% (Table 3). Since the line of eumetric fishing shows that optimum size at recruitment changes with fishing effort, any "minimum size" regulation must be geared to fishing effort.

If fishermen are unable to distinguish the size of yellowfin before capturing them and a minimum size regulation prevents their landing, then the discarding of dead yellowfin will occur. Table 4 presents landings per recruit by gear and Figure 12 the landings per recruit for the total fishery when killing and discarding ("dumping") of all yellowfin smaller than the size limit occurs. If the minimum size limit is 55 cm and effort remains the same, then a 2.7% decrease in landings per recruit would occur; and a 13% decrease in landings per recruit would occur if the minimum size is set at 77.5 cm. If effort is doubled and the minimum size is 55 cm, then a 1% increase in landings per recruit would occur; with a minimum size of 77.5 cm, a 16% decline in landings per recruit would

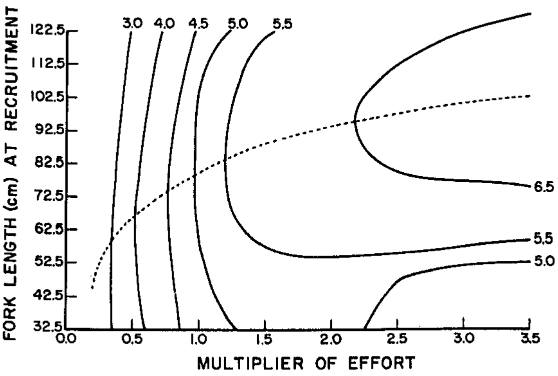

FIGURE 11.—Yield-per-recruit (kg) isopleths for the entire Atlantic yellowfin tuna fishery. Dotted curve is the line of eumetric fishing.

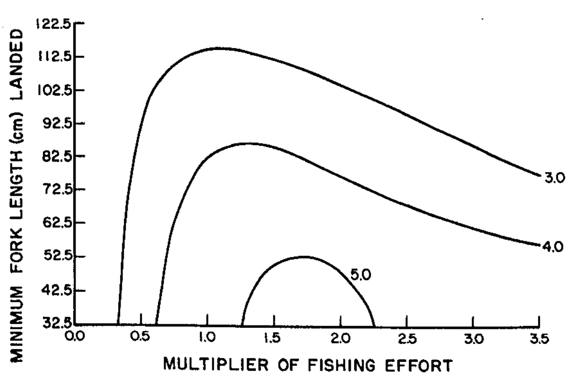

FIGURE 12.—Landings-per-recruit (kg) isopleths for Atlantic yellowfin tuna when all fish less than the minimum size that are caught are discarded dead.

TABLE 4.—Landings per recruit (kg) when M = 0.8, initial F = 0.2, growth curve of LeGuen and Sakagawa (1973) is used, and yellowfin less than the minimum size are caught and discarded dead.

BAIT BOATS

MINIMUM SIZE CM	MINIMUM SIZE KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.07	0.12	0.15	0.18	0.18	0.17	0.16	0.14	0.12	0.10
117.5	30.6	0.08	0.14	0.18	0.22	0.22	0.22	0.21	0.19	0.16	0.14
112.5	26.9	0.10	0.17	0.22	0.27	0.29	0.28	0.28	0.25	0.22	0.19
107.5	23.5	0.12	0.20	0.26	0.33	0.36	0.36	0.36	0.33	0.30	0.27
102.5	20.4	0.14	0.24	0.31	0.40	0.44	0.45	0.44	0.42	0.39	0.35
97.5	17.6	0.16	0.27	0.36	0.48	0.53	0.56	0.56	0.54	0.51	0.47
92.5	15.0	0.18	0.31	0.41	0.55	0.63	0.66	0.67	0.66	0.63	0.59
87.5	12.7	0.19	0.34	0.45	0.61	0.70	0.74	0.75	0.75	0.73	0.69
82.5	10.7	0.21	0.37	0.50	0.68	0.79	0.84	0.86	0.87	0.85	0.81
77.5	8.9	0.23	0.41	0.55	0.76	0.89	0.97	0.99	1.01	1.00	0.97
72.5	7.3	0.25	0.44	0.60	0.84	0.99	1.08	1.11	1.15	1.15	1.12
67.5	5.9	0.27	0.48	0.66	0.92	1.10	1.22	1.25	1.31	1.33	1.32
62.5	4.7	0.28	0.51	0.70	0.98	1.18	1.31	1.35	1.43	1.46	1.46
57.5	3.7	0.29	0.54	0.74	1.05	1.27	1.42	1.48	1.57	1.62	1.64
52.5	2.8	0.30	0.56	0.77	1.10	1.34	1.51	1.57	1.69	1.76	1.79
47.5	2.1	0.31	0.57	0.79	1.14	1.39	1.58	1.65	1.79	1.87	1.92
42.5	1.5	0.31	0.58	0.80	1.15	1.41	1.59	1.67	1.81	1.90	1.95
37.5	1.0	0.31	0.58	0.80	1.15	1.41	1.60	1.67	1.81	1.90	1.95
32.5	0.7	0.31	0.58	0.80	1.15	1.41	1.60	1.67	1.81	1.90	1.95

SMALL PURSE SEINERS

MINIMUM SIZE CM	MINIMUM SIZE KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.31	0.47	0.54	0.56	0.50	0.43	0.40	0.31	0.25	0.19
117.5	30.6	0.32	0.49	0.57	0.60	0.55	0.48	0.44	0.36	0.29	0.23
112.5	26.9	0.33	0.51	0.60	0.64	0.59	0.53	0.49	0.41	0.33	0.27
107.5	23.5	0.35	0.55	0.65	0.71	0.68	0.62	0.58	0.50	0.42	0.35
102.5	20.4	0.37	0.58	0.70	0.78	0.76	0.71	0.68	0.60	0.52	0.45
97.5	17.6	0.38	0.61	0.73	0.82	0.81	0.77	0.74	0.66	0.59	0.51
92.5	15.0	0.39	0.62	0.75	0.84	0.84	0.80	0.78	0.70	0.62	0.55
87.5	12.7	0.40	0.63	0.76	0.87	0.88	0.84	0.82	0.75	0.67	0.60
82.5	10.7	0.40	0.64	0.78	0.90	0.91	0.88	0.85	0.79	0.71	0.64
77.5	8.9	0.41	0.65	0.80	0.92	0.94	0.91	0.89	0.83	0.76	0.69
72.5	7.3	0.41	0.66	0.81	0.94	0.96	0.94	0.92	0.86	0.79	0.73
67.5	5.9	0.42	0.67	0.82	0.96	0.99	0.98	0.96	0.90	0.84	0.77
62.5	4.7	0.42	0.68	0.83	0.98	1.01	1.00	0.98	0.93	0.87	0.81
57.5	3.7	0.43	0.69	0.85	1.01	1.05	1.05	1.04	1.00	0.95	0.89
52.5	2.8	0.43	0.70	0.87	1.04	1.10	1.10	1.10	1.07	1.03	0.98
47.5	2.1	0.44	0.71	0.88	1.05	1.11	1.13	1.13	1.10	1.07	1.03
42.5	1.5	0.44	0.71	0.88	1.05	1.12	1.13	1.13	1.11	1.08	1.04
37.5	1.0	0.44	0.71	0.88	1.06	1.12	1.13	1.13	1.11	1.08	1.04
32.5	0.7	0.44	0.71	0.88	1.06	1.12	1.13	1.13	1.11	1.08	1.04

LARGE PURSE SEINERS

MINIMUM SIZE CM	MINIMUM SIZE KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.28	0.43	0.50	0.51	0.46	0.39	0.36	0.28	0.21	0.16
117.5	30.6	0.29	0.45	0.52	0.54	0.50	0.43	0.39	0.31	0.25	0.19
112.5	26.9	0.30	0.47	0.55	0.59	0.54	0.48	0.44	0.36	0.29	0.24
107.5	23.5	0.31	0.49	0.58	0.63	0.59	0.53	0.50	0.42	0.35	0.28
102.5	20.4	0.32	0.50	0.59	0.64	0.61	0.55	0.52	0.44	0.37	0.31
97.5	17.6	0.32	0.51	0.60	0.66	0.63	0.57	0.54	0.46	0.39	0.33
92.5	15.0	0.33	0.51	0.61	0.67	0.64	0.59	0.56	0.48	0.41	0.35
87.5	12.7	0.33	0.52	0.62	0.68	0.65	0.60	0.57	0.50	0.42	0.36
82.5	10.7	0.33	0.52	0.62	0.69	0.67	0.62	0.59	0.51	0.44	0.38
77.5	8.9	0.33	0.53	0.63	0.70	0.68	0.63	0.60	0.53	0.46	0.40
72.5	7.3	0.34	0.53	0.64	0.71	0.70	0.65	0.62	0.55	0.49	0.43
67.5	5.9	0.34	0.54	0.65	0.72	0.71	0.67	0.64	0.57	0.51	0.45
62.5	4.7	0.34	0.54	0.65	0.74	0.73	0.69	0.66	0.60	0.54	0.48
57.5	3.7	0.35	0.55	0.66	0.75	0.75	0.71	0.69	0.63	0.58	0.53
52.5	2.8	0.35	0.56	0.68	0.77	0.77	0.74	0.73	0.67	0.62	0.58
47.5	2.1	0.35	0.56	0.68	0.77	0.78	0.75	0.74	0.69	0.64	0.60
42.5	1.5	0.35	0.56	0.68	0.78	0.79	0.76	0.74	0.70	0.65	0.61
37.5	1.0	0.35	0.56	0.68	0.78	0.79	0.76	0.74	0.70	0.65	0.61
32.5	0.7	0.35	0.56	0.68	0.78	0.79	0.76	0.74	0.70	0.65	0.61

TABLE 4.—Landings per recruit (kg) when M = 0.8, initial F = 0.2, growth curve of LeGuen and Sakagawa (1973) is used, and yellowfin less than the minimum size are caught and discarded dead.—Continued.

LONG LINERS

MINIMUM SIZE CM	KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.72	1.13	1.34	1.43	1.33	1.16	1.07	0.85	0.67	0.52
117.5	30.6	0.74	1.18	1.41	1.53	1.43	1.27	1.18	0.96	0.76	0.60
112.5	26.9	0.77	1.22	1.47	1.61	1.53	1.37	1.28	1.06	0.86	0.69
107.5	23.5	0.79	1.25	1.51	1.68	1.61	1.45	1.37	1.15	0.94	0.77
102.5	20.4	0.80	1.28	1.55	1.72	1.67	1.52	1.43	1.21	1.01	0.84
97.5	17.6	0.81	1.29	1.56	1.74	1.69	1.54	1.46	1.24	1.04	0.86
92.5	15.0	0.81	1.29	1.57	1.76	1.70	1.56	1.48	1.26	1.06	0.88
87.5	12.7	0.81	1.30	1.58	1.77	1.72	1.58	1.49	1.28	1.08	0.90
82.5	10.7	0.81	1.30	1.58	1.78	1.73	1.59	1.51	1.30	1.10	0.92
77.5	8.9	0.82	1.31	1.59	1.78	1.74	1.60	1.51	1.30	1.10	0.93
72.5	7.3	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.93
67.5	5.9	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94
62.5	4.7	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94
57.5	3.7	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94
52.5	2.8	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94
47.5	2.1	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94
42.5	1.5	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94
37.5	1.0	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94
32.5	0.7	0.82	1.31	1.59	1.78	1.74	1.60	1.52	1.31	1.11	0.94

occur. Therefore, if effort is constant the predicted gain with no dumping is greater than the possible loss through dumping if the minimum size were 55 cm, but at 77.5 cm the opposite is true. At both size limits we predict a greater gain with no dumping than possible loss through dumping if effort is doubled.

Assuming constant recruitment, yield per recruit per unit effort is a measure of fishing success. Table 5 presents the estimated yield per recruit per effort by gear assuming no dumping. Increasing the size at recruitment to 77.5 cm at the current level of effort would result in a 17% decrease for bait boats, a 9% increase for small purse seiners, a 12% increase for large purse seiners, and a 25% increase for longliners. Yield per recruit per effort would drop by about 35% for each of the gears if effort doubled and size at recruitment increased to 77.5 cm. If effort doubled and size at recruitment remained 32.5 cm, yield per recruit per effort would decrease by 30% for bait boats, 50% for purse seiners, and 60% for longliners.

Changes in the average weight of landings should be considered because average weight affects the values of landings particularly in light of size-specific changes in the value of yellowfin tuna. Table 6 presents estimates of the average weight of catches by gear. Figure 13 shows average weight isopleths for the entire fishery. If effort remained constant and size at recruitment increased to 77.5 cm, the average weight of the catch of the total fishery would increase from 17.7 kg to 30.3 kg. If effort doubled and size at recruitment increased to 77.5 cm, the average weight would increase to 24.2 kg.

Sensitivity of Results to Errors when Ageing Large Yellowfin

The growth curve used in this study was based on the use of modal progressions to age yellowfin. Unfortunately while this method is probably reasonably accurate for ageing yellowfin less than about 130 cm long, beyond this size it becomes increasingly difficult to separate modes, and there is a reasonable probability that ages are increasingly underestimated with increases in size. In addition, because tuna apparently spawn over a large portion of the year, the exact meaning of age is not always clear. Alternative methods, such as ageing by

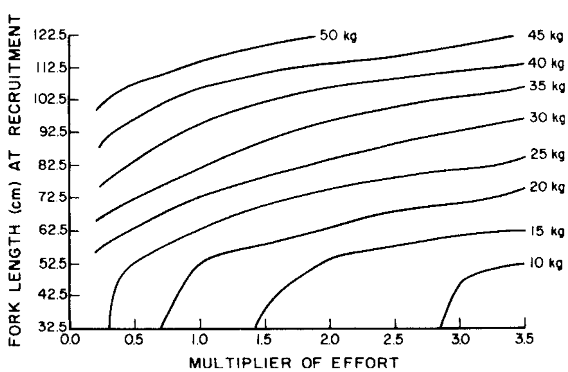

FIGURE 13.—Average weight (kg) isopleths for the entire Atlantic yellowfin tuna fishery.

TABLE 5.—Estimates of yield per recruit per effort (kg) when $M = 0.8$, initial $F = 0.2$, and growth curve of LeGuen and Sakagawa (1973) is used.

BAIT BOATS

MINIMUM SIZE		MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.40	0.37	0.35	0.31	0.28	0.25	0.24	0.22	0.21	0.19
117.5	30.6	0.47	0.43	0.40	0.36	0.33	0.30	0.29	0.26	0.24	0.23
112.5	26.9	0.55	0.51	0.48	0.43	0.39	0.36	0.35	0.32	0.30	0.28
107.5	23.5	0.64	0.60	0.56	0.50	0.45	0.42	0.40	0.37	0.34	0.32
102.5	20.4	0.73	0.68	0.64	0.57	0.52	0.48	0.46	0.42	0.39	0.36
97.5	17.6	0.84	0.78	0.74	0.66	0.61	0.56	0.54	0.50	0.46	0.43
92.5	15.0	0.94	0.88	0.83	0.75	0.69	0.64	0.61	0.57	0.53	0.49
87.5	12.7	1.01	0.95	0.90	0.81	0.74	0.69	0.66	0.61	0.56	0.53
82.5	10.7	1.09	1.03	0.97	0.88	0.80	0.74	0.72	0.66	0.61	0.57
77.5	8.9	1.19	1.12	1.06	0.95	0.87	0.81	0.78	0.71	0.66	0.61
72.5	7.3	1.28	1.20	1.13	1.02	0.93	0.85	0.82	0.75	0.69	0.64
67.5	5.9	1.37	1.28	1.21	1.08	0.98	0.90	0.86	0.78	0.71	0.66
62.5	4.7	1.43	1.34	1.25	1.12	1.01	0.92	0.88	0.79	0.72	0.66
57.5	3.7	1.49	1.39	1.30	1.15	1.02	0.92	0.88	0.78	0.70	0.64
52.5	2.8	1.54	1.42	1.32	1.15	1.02	0.91	0.86	0.75	0.67	0.60
47.5	2.1	1.57	1.44	1.33	1.15	1.01	0.90	0.84	0.74	0.65	0.57
42.5	1.5	1.57	1.44	1.33	1.15	1.01	0.89	0.84	0.73	0.64	0.56
37.5	1.0	1.57	1.44	1.33	1.15	1.01	0.89	0.84	0.72	0.63	0.56
32.5	0.7	1.57	1.44	1.33	1.15	1.01	0.89	0.84	0.72	0.63	0.56

SMALL PURSE SEINERS

MINIMUM SIZE		MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	1.72	1.46	1.26	0.97	0.78	0.65	0.60	0.50	0.43	0.38
117.5	30.6	1.77	1.50	1.29	0.99	0.79	0.66	0.61	0.51	0.43	0.38
112.5	26.9	1.82	1.54	1.31	1.01	0.80	0.67	0.61	0.51	0.44	0.38
107.5	23.5	1.91	1.61	1.38	1.06	0.85	0.71	0.66	0.55	0.48	0.42
102.5	20.4	1.99	1.69	1.45	1.12	0.90	0.76	0.70	0.59	0.52	0.46
97.5	17.6	2.05	1.73	1.48	1.14	0.93	0.78	0.72	0.61	0.53	0.47
92.5	15.0	2.07	1.74	1.49	1.15	0.93	0.77	0.72	0.60	0.52	0.46
87.5	12.7	2.10	1.76	1.51	1.16	0.93	0.78	0.72	0.60	0.52	0.46
82.5	10.7	2.12	1.78	1.52	1.16	0.93	0.77	0.71	0.60	0.51	0.45
77.5	8.9	2.13	1.78	1.52	1.15	0.92	0.76	0.70	0.58	0.50	0.43
72.5	7.3	2.14	1.79	1.52	1.14	0.91	0.74	0.68	0.56	0.48	0.41
67.5	5.9	2.15	1.79	1.51	1.13	0.89	0.72	0.66	0.54	0.45	0.39
62.5	4.7	2.16	1.78	1.50	1.11	0.87	0.70	0.64	0.52	0.43	0.37
57.5	3.7	2.17	1.79	1.50	1.10	0.85	0.68	0.62	0.50	0.41	0.35
52.5	2.8	2.19	1.79	1.49	1.08	0.83	0.66	0.60	0.48	0.39	0.33
47.5	2.1	2.19	1.78	1.48	1.06	0.81	0.64	0.58	0.45	0.37	0.31
42.5	1.5	2.19	1.78	1.47	1.06	0.80	0.63	0.57	0.45	0.36	0.30
37.5	1.0	2.19	1.78	1.47	1.06	0.80	0.63	0.57	0.44	0.36	0.30
32.5	0.7	2.19	1.78	1.47	1.06	0.80	0.63	0.57	0.44	0.36	0.30

LARGE PURSE SEINERS

MINIMUM SIZE		MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	1.57	1.34	1.16	0.89	0.71	0.58	0.53	0.44	0.37	0.32
117.5	30.6	1.61	1.37	1.18	0.90	0.72	0.59	0.54	0.44	0.37	0.32
112.5	26.9	1.66	1.41	1.21	0.92	0.74	0.60	0.55	0.46	0.39	0.33
107.5	23.5	1.71	1.44	1.24	0.94	0.75	0.61	0.56	0.46	0.39	0.34
102.5	20.4	1.72	1.44	1.23	0.93	0.73	0.59	0.54	0.44	0.37	0.32
97.5	17.6	1.73	1.45	1.23	0.92	0.72	0.58	0.53	0.43	0.35	0.30
92.5	15.0	1.74	1.45	1.22	0.91	0.71	0.57	0.51	0.41	0.34	0.29
87.5	12.7	1.74	1.45	1.22	0.90	0.69	0.56	0.50	0.40	0.33	0.28
82.5	10.7	1.74	1.44	1.21	0.89	0.68	0.54	0.49	0.39	0.32	0.27
77.5	8.9	1.75	1.44	1.20	0.88	0.67	0.53	0.47	0.37	0.30	0.25
72.5	7.3	1.75	1.44	1.20	0.86	0.65	0.51	0.46	0.36	0.29	0.24
67.5	5.9	1.75	1.43	1.19	0.85	0.64	0.49	0.44	0.34	0.27	0.23
62.5	4.7	1.76	1.43	1.18	0.84	0.62	0.48	0.43	0.33	0.27	0.22
57.5	3.7	1.76	1.42	1.17	0.82	0.60	0.46	0.41	0.32	0.25	0.20
52.5	2.8	1.76	1.42	1.15	0.80	0.59	0.45	0.40	0.30	0.24	0.19
47.5	2.1	1.76	1.40	1.14	0.78	0.57	0.43	0.38	0.29	0.22	0.18
42.5	1.5	1.76	1.40	1.14	0.78	0.56	0.42	0.37	0.28	0.22	0.18
37.5	1.0	1.76	1.40	1.14	0.78	0.56	0.42	0.37	0.28	0.22	0.17
32.5	0.7	1.76	1.40	1.14	0.78	0.56	0.42	0.37	0.28	0.22	0.17

TABLE 5.—Estimates of yield per recruit per effort (kg) when $M = 0.8$, initial $F = 0.2$, and growth curve of LeGuen and Sakagawa (1973) is used.—Continued.

LONG LINERS

MINIMUM SIZE		MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	4.00	3.51	3.10	2.49	2.05	1.74	1.61	1.35	1.16	1.02
117.5	30.6	4.12	3.60	3.17	2.53	2.07	1.75	1.61	1.35	1.16	1.01
112.5	26.9	4.21	3.66	3.21	2.54	2.07	1.73	1.60	1.33	1.13	0.98
107.5	23.5	4.27	3.69	3.22	2.52	2.03	1.68	1.54	1.27	1.07	0.92
102.5	20.4	4.31	3.70	3.21	2.49	1.99	1.63	1.49	1.21	1.01	0.86
97.5	17.6	4.31	3.68	3.17	2.43	1.92	1.56	1.42	1.14	0.94	0.79
92.5	15.0	4.30	3.66	3.14	2.38	1.87	1.50	1.36	1.08	0.89	0.74
87.5	12.7	4.30	3.64	3.11	2.34	1.82	1.46	1.31	1.04	0.84	0.69
82.5	10.7	4.29	3.61	3.08	2.29	1.77	1.40	1.26	0.98	0.79	0.64
77.5	8.9	4.27	3.57	3.03	2.23	1.70	1.33	1.19	0.92	0.72	0.58
72.5	7.3	4.24	3.53	2.98	2.17	1.63	1.26	1.12	0.85	0.66	0.53
67.5	5.9	4.21	3.49	2.91	2.09	1.55	1.19	1.05	0.78	0.60	0.47
62.5	4.7	4.19	3.45	2.86	2.03	1.49	1.13	0.99	0.73	0.55	0.42
57.5	3.7	4.15	3.39	2.79	1.95	1.40	1.04	0.91	0.65	0.49	0.36
52.5	2.8	4.12	3.33	2.72	1.86	1.32	0.96	0.83	0.58	0.42	0.31
47.5	2.1	4.09	3.29	2.67	1.81	1.26	0.91	0.78	0.54	0.39	0.28
42.5	1.5	4.08	3.27	2.65	1.79	1.25	0.89	0.76	0.53	0.37	0.27
37.5	1.0	4.08	3.27	2.65	1.78	1.24	0.89	0.76	0.52	0.37	0.27
32.5	0.7	4.08	3.27	2.65	1.78	1.24	0.89	0.76	0.52	0.37	0.27

ENTIRE FISHERY

MINIMUM SIZE		MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	7.70	6.68	5.86	4.65	3.82	3.22	2.98	2.51	2.17	1.91
117.5	30.6	7.97	6.90	6.04	4.78	3.91	3.29	3.05	2.57	2.21	1.94
112.5	26.9	8.25	7.12	6.22	4.90	4.00	3.36	3.11	2.61	2.25	1.97
107.5	23.5	8.53	7.34	6.40	5.02	4.08	3.42	3.16	2.65	2.27	1.99
102.5	20.4	8.75	7.51	6.53	5.10	4.14	3.46	3.19	2.67	2.28	2.00
97.5	17.6	8.92	7.64	6.62	5.16	4.17	3.48	3.20	2.67	2.28	1.99
92.5	15.0	9.04	7.73	6.69	5.19	4.19	3.48	3.21	2.67	2.27	1.98
87.5	12.7	9.14	7.80	6.74	5.21	4.19	3.48	3.20	2.65	2.26	1.96
82.5	10.7	9.24	7.86	6.78	5.22	4.18	3.46	3.18	2.62	2.22	1.92
77.5	8.9	9.34	7.92	6.81	5.22	4.16	3.42	3.14	2.58	2.18	1.88
72.5	7.3	9.42	7.96	6.82	5.19	4.12	3.38	3.09	2.52	2.12	1.82
67.5	5.9	9.49	7.99	6.82	5.15	4.06	3.30	3.01	2.44	2.04	1.74
62.5	4.7	9.54	7.99	6.80	5.10	4.00	3.23	2.94	2.37	1.97	1.66
57.5	3.7	9.58	7.98	6.75	5.01	3.88	3.11	2.81	2.25	1.84	1.55
52.5	2.8	9.60	7.95	6.68	4.90	3.75	2.98	2.68	2.11	1.71	1.42
47.5	2.1	9.61	7.91	6.61	4.81	3.65	2.87	2.58	2.01	1.62	1.33
42.5	1.5	9.60	7.90	6.59	4.78	3.62	2.84	2.54	1.98	1.59	1.31
37.5	1.0	9.60	7.89	6.59	4.77	3.61	2.83	2.53	1.97	1.58	1.30
32.5	0.7	9.60	7.89	6.59	4.77	3.61	2.83	2.53	1.97	1.58	1.30

the examination of hard parts, are extremely difficult and not easily interpreted for tropical species such as the yellowfin tuna.

The marked increase in estimates of size-specific F beyond 130 cm for the purse seine gears is a possible result of underestimating ages of older yellowfin. To examine this possibility, the growth curve of LeGuen and Sakagawa (1973) was modified. It was hypothetically assumed that the percentage of underestimation of the time interval within a size interval increased linearly from 0% at 135 cm to 100% at 180 cm. The resulting growth curve is compared to the original in Figure 14.

Values of size-specific F were then estimated as before with initial values of 0.2 and 0.8. The value of 0.2 gave the most reasonable results for reasons similar to those given before. Values of size specific F for each gear are shown in

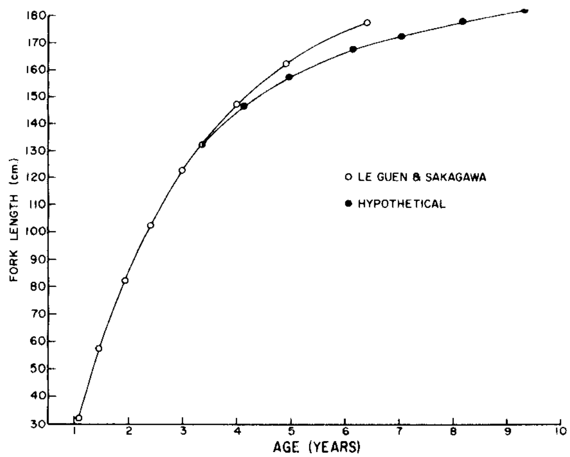

FIGURE 14.—Growth curves of Atlantic yellowfin tuna. Upper curve is from LeGuen and Sakagawa (1973). Lower curve is a modification of the upper curve (see text).

TABLE 6.—Estimates of average weight of catch (kg) when $M = 0.8$, initial $F = 0.2$, and growth curve of LeGuen and Sakagawa (1973) is used.

BAIT BOATS

MINIMUM SIZE CM	KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	48.87	47.71	46.73	45.18	44.03	43.14	42.78	42.01	41.41	40.91
117.5	30.6	45.55	44.47	43.56	42.12	41.06	40.24	39.90	39.19	38.61	38.14
112.5	26.9	41.63	40.64	39.80	38.47	37.49	36.72	36.40	35.71	35.15	34.68
107.5	23.5	38.03	37.10	36.32	35.08	34.15	33.42	33.10	32.43	31.87	31.40
102.5	20.4	34.67	33.80	33.07	31.91	31.02	30.31	30.01	29.35	28.79	28.31
97.5	17.6	31.19	30.39	29.71	28.63	27.80	27.12	26.83	26.19	25.65	25.19
92.5	15.0	28.34	27.59	26.96	25.95	25.16	24.53	24.25	23.64	23.12	22.67
87.5	12.7	26.21	25.51	24.91	23.95	23.19	22.58	22.31	21.72	21.21	20.77
82.5	10.7	23.80	23.13	22.57	21.65	20.93	20.34	20.08	19.50	19.00	18.57
77.5	8.9	21.12	20.51	19.98	19.12	18.44	17.87	17.62	17.06	16.58	16.16
72.5	7.3	18.89	18.31	17.82	17.00	16.35	15.81	15.57	15.03	14.56	14.16
67.5	5.9	16.57	16.04	15.58	14.81	14.20	13.68	13.45	12.93	12.48	12.09
62.5	4.7	15.08	14.57	14.13	13.39	12.80	12.29	12.07	11.57	11.13	10.75
57.5	3.7	13.31	12.82	12.40	11.70	11.13	10.64	10.42	9.93	9.50	9.13
52.5	2.8	11.97	11.50	11.10	10.41	9.85	9.37	9.16	8.67	8.25	7.88
47.5	2.1	10.87	10.42	10.02	9.35	8.80	8.33	8.11	7.63	7.21	6.85
42.5	1.5	10.57	10.13	9.73	9.07	8.51	8.04	7.83	7.35	6.93	6.56
37.5	1.0	10.51	10.07	9.67	9.01	8.46	7.98	7.77	7.29	6.87	6.50
32.5	0.7	10.51	10.06	9.67	9.00	8.45	7.98	7.76	7.28	6.86	6.50

SMALL PURSE SEINERS

MINIMUM SIZE CM	KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	63.08	60.94	58.99	55.67	53.02	50.93	50.04	48.20	46.76	45.59
117.5	30.6	60.95	58.69	56.65	53.18	50.44	48.28	47.36	45.47	43.98	42.78
112.5	26.9	58.62	56.24	54.09	50.47	47.62	45.38	44.44	42.48	40.94	39.69
107.5	23.5	54.53	51.97	49.68	45.87	42.91	40.61	39.65	37.65	36.10	34.85
102.5	20.4	50.69	48.01	45.65	41.78	38.82	36.55	35.61	33.67	32.18	31.00
97.5	17.6	48.15	45.42	43.03	39.15	36.22	33.99	33.07	31.19	29.74	28.60
92.5	15.0	46.71	43.96	41.55	37.66	34.74	32.53	31.61	29.75	28.32	27.19
87.5	12.7	44.78	41.99	39.57	35.67	32.76	30.55	29.64	27.79	26.37	25.24
82.5	10.7	42.99	40.17	37.73	33.82	30.92	28.72	27.82	25.97	24.55	23.43
77.5	8.9	41.01	38.17	35.71	31.79	28.89	26.71	25.81	23.97	22.55	21.41
72.5	7.3	39.22	36.35	33.88	29.96	27.07	24.89	24.00	22.16	20.74	19.60
67.5	5.9	37.02	34.12	31.65	27.73	24.86	22.69	21.80	19.97	18.55	17.41
62.5	4.7	35.35	32.44	29.96	26.06	23.20	21.05	20.16	18.34	16.93	15.79
57.5	3.7	31.69	28.79	26.34	22.51	19.73	17.65	16.79	15.04	13.68	12.59
52.5	2.8	27.97	25.13	22.75	19.09	16.46	14.52	13.72	12.10	10.86	9.88
47.5	2.1	26.14	23.35	21.02	17.47	14.93	13.07	12.31	10.77	9.60	8.67
42.5	1.5	25.72	22.94	20.63	17.10	14.59	12.74	11.99	10.47	9.31	8.39
37.5	1.0	25.62	22.84	20.54	17.01	14.50	12.66	11.91	10.39	9.23	8.32
32.5	0.7	25.61	22.84	20.53	17.00	14.50	12.65	11.90	10.39	9.23	8.32

LARGE PURSE SEINERS

MINIMUM SIZE CM	KG	MULTIPLIER OF EFFORT 0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	63.26	61.49	59.84	56.92	54.48	52.45	51.57	49.68	48.15	46.90
117.5	30.6	61.30	59.40	57.62	54.49	51.88	49.72	48.78	46.77	45.16	43.83
112.5	26.9	58.69	56.61	54.69	51.30	48.50	46.19	45.19	43.07	41.37	39.98
107.5	23.5	55.99	53.75	51.68	48.07	45.11	42.70	41.66	39.47	37.72	36.31
102.5	20.4	54.78	52.46	50.33	46.62	43.59	41.13	40.07	37.84	36.07	34.63
97.5	17.6	53.40	51.00	48.79	44.96	41.84	39.30	38.21	35.92	34.10	32.62
92.5	15.0	52.39	49.92	47.65	43.73	40.53	37.94	36.83	34.48	32.62	31.10
87.5	12.7	51.41	48.87	46.54	42.52	39.24	36.59	35.45	33.05	31.13	29.57
82.5	10.7	50.10	47.48	45.07	40.91	37.54	34.80	33.63	31.15	29.16	27.54
77.5	8.9	48.65	45.92	43.43	39.13	35.64	32.82	31.61	29.05	27.00	25.32
72.5	7.3	46.62	43.77	41.16	36.69	33.07	30.15	28.90	26.27	24.16	22.45
67.5	5.9	44.46	41.48	38.78	34.14	30.43	27.44	26.17	23.50	21.38	19.66
62.5	4.7	41.92	38.81	36.01	31.24	27.46	24.46	23.18	20.53	18.44	16.77
57.5	3.7	38.35	35.12	32.23	27.39	23.62	20.67	19.44	16.90	14.94	13.40
52.5	2.8	34.39	31.08	28.17	23.39	19.74	16.96	15.82	13.50	11.75	10.41
47.5	2.1	32.91	29.60	26.69	21.96	18.39	15.68	14.58	12.35	10.69	9.42
42.5	1.5	31.85	28.53	25.64	20.94	17.43	14.78	13.70	11.54	9.93	8.71
37.5	1.0	31.52	28.21	25.31	20.63	17.13	14.50	13.43	11.29	9.70	8.49
32.5	0.7	31.52	28.20	25.31	20.62	17.13	14.50	13.43	11.29	9.70	8.49

TABLE 6.—Estimates of average weight of catch (kg) when $M = 0.8$, initial $F = 0.2$, and growth curve of LeGuen and Sakagawa (1973) is used.—Continued.

LONG LINERS

MINIMUM SIZE		MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	59.30	57.92	56.63	54.33	52.38	50.73	50.00	48.41	47.10	46.00
117.5	30.6	57.53	56.05	54.68	52.23	50.16	48.41	47.63	45.96	44.57	43.41
112.5	26.9	55.76	54.18	52.71	50.11	47.91	46.05	45.23	43.45	41.97	40.74
107.5	23.5	54.18	52.51	50.96	48.20	45.87	43.90	43.03	41.14	39.58	38.26
102.5	20.4	52.88	51.13	49.50	46.61	44.16	42.09	41.18	39.19	37.53	36.13
97.5	17.6	52.31	50.51	48.85	45.89	43.38	41.25	40.31	38.26	36.55	35.11
92.5	15.0	51.85	50.02	48.32	45.30	42.74	40.56	39.60	37.49	35.72	34.23
87.5	12.7	51.33	49.46	47.72	44.62	41.98	39.74	38.74	36.55	34.71	33.14
82.5	10.7	50.84	48.93	47.15	43.98	41.27	38.95	37.92	35.65	33.73	32.09
77.5	8.9	50.61	48.68	46.88	43.66	40.91	38.56	37.50	35.19	33.22	31.54
72.5	7.3	50.39	48.44	46.61	43.35	40.56	38.16	37.09	34.72	32.70	30.96
67.5	5.9	50.30	48.34	46.51	43.23	40.41	38.00	36.91	34.52	32.47	30.70
62.5	4.7	50.28	48.31	46.48	43.19	40.37	37.94	36.86	34.45	32.40	30.62
57.5	3.7	50.26	48.29	46.45	43.16	40.34	37.91	36.82	34.40	32.34	30.56
52.5	2.8	50.26	48.29	46.45	43.16	40.34	37.91	36.82	34.40	32.34	30.56
47.5	2.1	50.26	48.29	46.45	43.16	40.34	37.91	36.82	34.40	32.34	30.56
42.5	1.5	50.26	48.29	46.45	43.16	40.34	37.91	36.82	34.40	32.34	30.56
37.5	1.0	50.26	48.29	46.45	43.16	40.34	37.91	36.82	34.40	32.34	30.56
32.5	0.7	50.26	48.29	46.45	43.16	40.34	37.91	36.82	34.40	32.34	30.56

Figure 15. The values of F of large fish are relatively smaller than those estimated with the original growth curve.

Results of the yield-per-recruit calculations are shown in Table 7. The results indicate that if effort is held constant and size at recruitment is increased to the optimum, less than a 3% increase in yield per recruit would occur. If size at recruitment is constant and effort is doubled, yield per recruit would increase by about 28% which is considerably more than when the original growth curve is used. If size at recruitment is increased to 77.5 cm and effort doubled, a 44% increase in yield per recruit would occur.

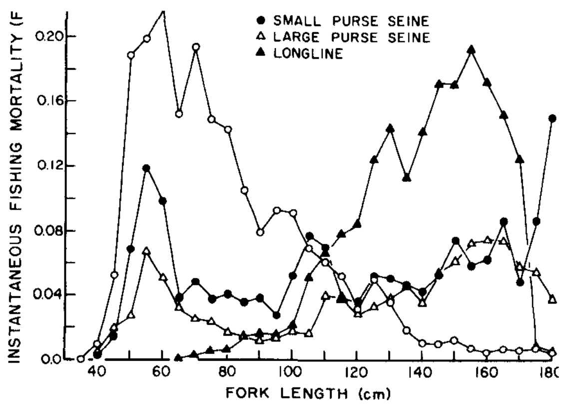

FIGURE 15.—Estimates of size-specific F when its initial value is 0.2 and using the modified growth curve.

TABLE 7.—Estimates of yield per recruit (kg) for the entire fishery when $M = 0.8$, initial $F = 0.2$, and hypothetical growth curve is used.

ENTIRE FISHERY

MINIMUM SIZE		MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.80	1.48	2.06	2.99	3.70	4.24	4.47	4.95	5.32	5.61
117.5	30.6	0.84	1.55	2.15	3.12	3.85	4.41	4.65	5.13	5.50	5.79
112.5	26.9	0.88	1.62	2.25	3.25	4.00	4.58	4.82	5.30	5.67	5.97
107.5	23.5	0.92	1.70	2.35	3.39	4.15	4.74	4.98	5.46	5.83	6.11
102.5	20.4	0.96	1.76	2.43	3.49	4.27	4.85	5.09	5.57	5.93	6.21
97.5	17.6	0.98	1.80	2.49	3.56	4.35	4.93	5.17	5.64	5.99	6.25
92.5	15.0	1.00	1.84	2.53	3.62	4.40	4.98	5.21	5.68	6.01	6.26
87.5	12.7	1.02	1.87	2.57	3.66	4.44	5.01	5.24	5.69	6.01	6.25
82.5	10.7	1.04	1.89	2.60	3.69	4.47	5.03	5.25	5.69	5.99	6.21
77.5	8.9	1.05	1.92	2.63	3.72	4.48	5.03	5.24	5.65	5.93	6.12
72.5	7.3	1.07	1.94	2.66	3.74	4.48	5.01	5.21	5.59	5.84	6.01
67.5	5.9	1.08	1.96	2.68	3.74	4.47	4.96	5.15	5.49	5.70	5.83
62.5	4.7	1.09	1.98	2.69	3.74	4.44	4.91	5.08	5.39	5.57	5.66
57.5	3.7	1.11	1.99	2.69	3.71	4.37	4.80	4.95	5.20	5.32	5.37
52.5	2.8	1.11	1.99	2.69	3.67	4.28	4.66	4.79	4.98	5.05	5.05
47.5	2.1	1.12	1.99	2.68	3.63	4.21	4.55	4.66	4.81	4.84	4.81
42.5	1.5	1.12	1.99	2.67	3.62	4.18	4.51	4.61	4.75	4.77	4.73
37.5	1.0	1.12	1.99	2.67	3.61	4.18	4.50	4.60	4.73	4.75	4.71
32.5	0.7	1.12	1.99	2.67	3.61	4.17	4.50	4.60	4.73	4.75	4.70

Sensitivity of Results to Errors in Estimates of Natural Mortality

Size-specific values of F were estimated using values of M of 0.6 and 1.0 and an initial value of $F = 0.2$. The results are compared to size-specific F when $M = 0.8$ in Figure 16. Although the absolute values differ considerably, the same general trends appear in each curve. The ratio of F/M varies about threefold.

Results of yield-per-recruit calculations are shown in Tables 8 and 9 and Figures 17 and 18. There is a steeper horizontal gradient when $M = 1.0$ and a steeper vertical gradient when $M = 0.6$ than when $M = 0.8$. That is, yield per recruit is more sensitive to changes in effort

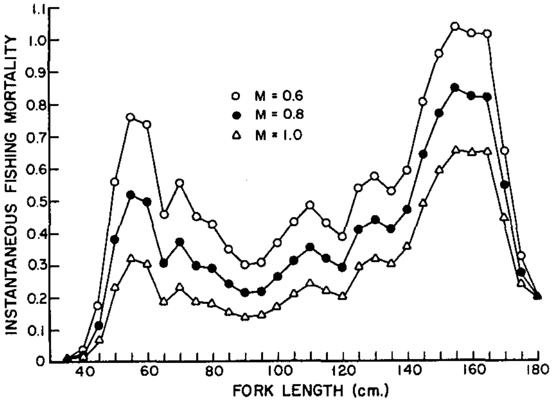

FIGURE 16.—Estimates of size-specific F when its initial value is 0.2 and using values for M of 0.6, 0.8, and 1.0.

TABLE 8.—Estimates of yield per recruit (kg) for the entire fishery when $M = 0.6$, initial $F = 0.2$, and growth curve of LeGuen and Sakagawa (1973) is used.

MINIMUM SIZE		ENTIRE FISHERY MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	3.52	5.82	7.34	9.07	9.93	10.39	10.55	10.81	10.98	11.10
117.5	30.6	3.61	5.94	7.47	9.18	10.00	10.43	10.58	10.81	10.95	11.04
112.5	26.9	3.70	6.06	7.58	9.26	10.04	10.44	10.56	10.76	10.86	10.92
107.5	23.5	3.79	6.16	7.68	9.30	10.03	10.38	10.48	10.63	10.70	10.72
102.5	20.4	3.85	6.24	7.74	9.31	9.98	10.28	10.36	10.47	10.49	10.48
97.5	17.6	3.90	6.28	7.77	9.28	9.91	10.16	10.22	10.28	10.27	10.22
92.5	15.0	3.93	6.31	7.77	9.24	9.82	10.03	10.07	10.09	10.04	9.97
87.5	12.7	3.95	6.33	7.77	9.18	9.70	9.87	9.90	9.87	9.79	9.68
82.5	10.7	3.97	6.33	7.74	9.09	9.55	9.66	9.66	9.58	9.45	9.31
77.5	8.9	3.99	6.33	7.70	8.95	9.33	9.38	9.35	9.20	9.01	8.82
72.5	7.3	4.00	6.31	7.63	8.79	9.08	9.06	8.99	8.78	8.54	8.30
67.5	5.9	4.01	6.27	7.53	8.57	8.75	8.64	8.54	8.25	7.94	7.65
62.5	4.7	4.01	6.23	7.44	8.37	8.47	8.29	8.16	7.80	7.45	7.13
57.5	3.7	4.00	6.15	7.28	8.05	8.01	7.73	7.55	7.11	6.70	6.33
52.5	2.8	3.98	6.06	7.10	7.70	7.54	7.16	6.95	6.43	5.97	5.56
47.5	2.1	3.96	5.99	6.96	7.45	7.20	6.75	6.52	5.95	5.46	5.04
42.5	1.5	3.95	5.96	6.92	7.37	7.09	6.62	6.38	5.80	5.30	4.87
37.5	1.0	3.95	5.96	6.90	7.35	7.06	6.59	6.35	5.77	5.26	4.83
32.5	0.7	3.95	5.96	6.90	7.34	7.06	6.59	6.34	5.76	5.26	4.83

TABLE 9.—Estimates of yield per recruit (kg) for the entire fishery when $M = 1.0$, initial $F = 0.2$, and growth curve of LeGuen and Sakagawa (1973) is used.

MINIMUM SIZE		ENTIRE FISHERY MULTIPLIER OF EFFORT									
CM	KG	0.2	0.4	0.6	1.0	1.4	1.8	2.0	2.5	3.0	3.5
122.5	34.6	0.66	1.18	1.62	2.26	2.72	3.06	3.19	3.47	3.67	3.84
117.5	30.6	0.69	1.24	1.68	2.36	2.83	3.18	3.32	3.60	3.81	3.98
112.5	26.9	0.72	1.29	1.76	2.45	2.94	3.30	3.45	3.74	3.96	4.13
107.5	23.5	0.75	1.35	1.83	2.55	3.06	3.42	3.57	3.87	4.09	4.27
102.5	20.4	0.77	1.39	1.89	2.63	3.15	3.52	3.67	3.97	4.20	4.37
97.5	17.6	0.79	1.43	1.93	2.69	3.21	3.59	3.74	4.04	4.27	4.44
92.5	15.0	0.81	1.45	1.97	2.73	3.26	3.64	3.79	4.09	4.31	4.48
87.5	12.7	0.82	1.47	1.99	2.76	3.29	3.67	3.82	4.12	4.34	4.50
82.5	10.7	0.83	1.49	2.02	2.79	3.32	3.70	3.85	4.14	4.35	4.51
77.5	8.9	0.85	1.51	2.05	2.82	3.35	3.72	3.86	4.14	4.34	4.49
72.5	7.3	0.86	1.53	2.07	2.84	3.36	3.72	3.86	4.13	4.32	4.45
67.5	5.9	0.87	1.55	2.09	2.86	3.37	3.72	3.85	4.10	4.27	4.38
62.5	4.7	0.88	1.56	2.10	2.86	3.36	3.70	3.82	4.06	4.21	4.31
57.5	3.7	0.89	1.57	2.11	2.86	3.34	3.65	3.76	3.97	4.09	4.16
52.5	2.8	0.90	1.58	2.11	2.84	3.30	3.58	3.68	3.85	3.94	3.99
47.5	2.1	0.90	1.58	2.11	2.82	3.26	3.52	3.61	3.76	3.83	3.85
42.5	1.5	0.90	1.58	2.10	2.81	3.24	3.50	3.59	3.73	3.79	3.80
37.5	1.0	0.90	1.58	2.10	2.81	3.24	3.50	3.58	3.72	3.78	3.79
32.5	0.7	0.90	1.58	2.10	2.81	3.24	3.50	3.58	3.72	3.78	3.79

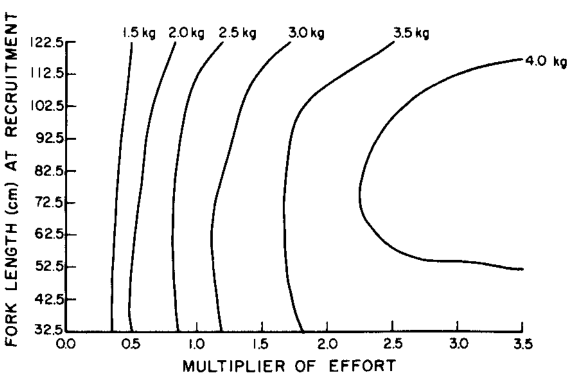

FIGURE 17.—Yield-per-recruit isopleths for the entire Atlantic yellowfin tuna fishery with $M = 1.0$.

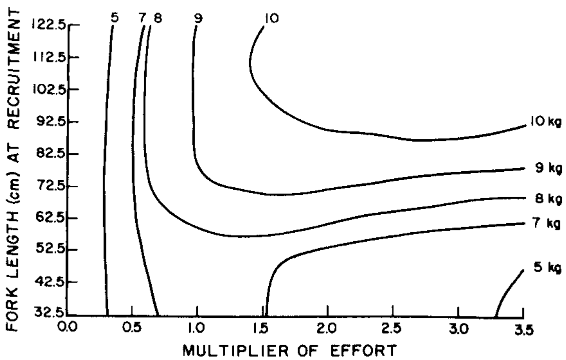

FIGURE 18.—Yield-per-recruit isopleths for the entire Atlantic yellowfin tuna fishery with $M = 0.6$.

when $M = 1.0$ and more sensitive to changes in size at recruitment when $M = 0.6$ than when $M = 0.8$. When $M = 1.0$ and effort is constant an increase in size at recruitment to 77.5 cm does not change yield per recruit. However, when $M = 0.6$, the same change in size at recruitment causes a 22% increase in yield per recruit. When $M = 1.0$ and size at recruitment is held constant, a doubling of effort causes a 29% increase in yield per recruit. When $M = 0.6$, the same change causes a 14% decrease in yield per recruit. When $M = 1.0$ and size at recruitment is increased to 77.5 cm, a doubling of effort causes a 39% increase in yield per recruit. When $M = 0.6$, the same changes cause a 27% increase in yield per recruit.

DISCUSSION

The use of results of our study must be based on three further assumptions: (1) the composition of the fleet will not change; (2) either the gear is currently dispersed so that all qualitative characteristics of the population are available to capture by each gear, or that the dispersal of gear as it now stands will not change; and (3) recruitment is constant.

Relation Between Composition of Fleet and Optimum Size at Recruitment

The preceding text has assumed that the composition of the fleet remains constant. The history of the fishery reveals that the composition has been a very dynamic process and there is no reason to believe that it will not continue to be. Since each fishing gear has a different curve of size-specific F, changes in the fleet composition will cause changes in size-specific F for the entire fleet. These changes will cause changes in the yield-per-recruit isopleths.

To illustrate the influence of changes in fleet composition on management strategy, the optimum size at recruitment was estimated for 441 combinations of baitboat and longline effort. For simplicity, effort of purse seiners is not included, i.e., we excluded two variables—small and large purse seiners. Multipliers of effort for each gear ranged from 0 to 2.0 with increments of 0.1.

The results (Table 10) show a considerable range in the estimates of optimum size at recruitment and that minimum size regulations must be adjusted to changes in the composition of the fleet to maintain maximum yield per recruit. As an example, with a 1.0 level of effort by both gears, the minimum size should be about 72.5 cm. If this were instituted as a minimum size regulation, the bait boat effort might decline to about 0.2 because of the extreme loss of catch. The minimum size, therefore, should be lowered to 67.5 cm. Now the longline effort might increase by about 80% due to the decrease in competition from bait boats—the minimum size should be increased to 77.5 cm. Finally, suppose an innovation occurs in bait fishing such that non-nominal effort again increases to about 0.7—the minimum size should be raised further to about 82.5 cm. These changes could occur slowly allowing for a smooth transition of the minimum size regulations. When economics are involved, however, the changes might be precipitous causing the confusion in the above example. If the possible changes in

TABLE 10.—Optimum size (cm) at recruitment for 441 combinations of multipliers of effort by bait boats and longliners.

Longline multiplier	Bait boat multiplier 0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	1.6	1.7	1.8	1.9	2.0
0	32.5	32.5	32.5	32.5	32.5	32.5	37.5	37.5	42.5	42.5	42.5	42.5	47.5	47.5	47.5	47.5	52.5	52.5	52.5	52.5	52.5
0.1	32.5	32.5	32.5	37.5	37.5	42.5	42.5	42.5	47.5	47.5	47.5	47.5	52.5	52.5	52.5	52.5	52.5	52.5	57.5	57.5	57.5
0.2	32.5	37.5	42.5	42.5	42.5	47.5	47.5	47.5	47.5	52.5	52.5	52.5	52.5	52.5	57.5	57.5	57.5	57.5	57.5	57.5	57.5
0.3	32.5	42.5	47.5	47.5	47.5	47.5	52.5	52.5	52.5	52.5	52.5	57.5	57.5	57.5	57.5	57.5	57.5	57.5	62.5	62.5	62.5
0.4	32.5	47.5	52.5	52.5	52.5	52.5	52.5	57.5	57.5	57.5	57.5	57.5	57.5	57.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5
0.5	32.5	52.5	52.5	52.5	57.5	57.5	57.5	57.5	57.5	57.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	67.5	67.5	67.5
0.6	32.5	57.5	57.5	57.5	57.5	57.5	57.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5
0.7	32.5	57.5	57.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	62.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5
0.8	62.5	62.5	62.5	62.5	62.5	62.5	62.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	72.5	72.5	72.5	72.5
0.9	62.5	62.5	62.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5
1.0	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	67.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5
1.1	67.5	67.5	67.5	67.5	67.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	77.5	77.5	77.5
1.2	67.5	67.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
1.3	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	72.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
1.4	72.5	72.5	72.5	72.5	72.5	72.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5
1.5	72.5	72.5	72.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	82.5	82.5
1.6	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	82.5	82.5	82.5	82.5	82.5	82.5
1.7	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	77.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5
1.8	77.5	77.5	77.5	77.5	77.5	77.5	77.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5
1.9	77.5	77.5	77.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5
2.0	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5	82.5

composition of both small and large purse seiners are included, the attempts to achieve some reason in the minimum size regulation based on maximum yield per recruit can become quite unwieldly.

Dispersion of Gear and Yield Per Recruit

The second assumption could be important. For example, in the eastern Pacific yellowfin tuna fishery effort has expanded farther offshore. Evidence suggests that larger fish were farther offshore and were not previously fully available to the fishery. A possible consequence of this phenomenon is a change in yield per recruit. Upon analysis of the data, the Inter-American Tropical Tuna Commission concluded, however, that the possible increase is minor (Joseph, pers. commun.). The surface gears have been fishing quite close to shore in the Atlantic. The possibility of offshore dispersal of the surface fleets and the effects of such a change on yield per recruit are unknown.

Interaction Between Minimum Size and Catch Quota Regulations

If recruitment is not constant, then the interaction between minimum size and catch quota regulations should be examined. Catch quotas are frequently based on assessments of the maximum sustainable average yield (MSAY), usually through a production model type analysis. The shape of the total yield curve, however, may be strongly dependent on the age at recruitment, t_r'. Therefore, the interaction between the two types of regulation should be examined before a singular action is taken. As an illustration, consider a population consisting of six age-groups with the growth curve and natural mortality coefficient ($M = 0.8$) similar to that of the Atlantic yellowfin tuna fishery, and assume also that recruitment is knife-edged at 19 mo. Figure 19 (lower curve) shows the total annual yield as a function of fishing mortality with an assumed arbitrary stock-recruitment function. Assume further that the fishery is operating at an $F = 1.0$. The yield per recruit at $F = 1.0$ and $t_r' = 19$ mo is 5.39, but the maximum yield per recruit is 6.11 at $t_r' = 27$ mo. If singular action were taken to increase t_r' to 27 mo, the upper total yield curve in Figure 19 would result. Not only did the yield per recruit increase, but so did the total yield at $F = 1.0$. In addition, the MSAY increased, but occurs at a much higher value for F. A phenomenon such as this may have occurred inadvertantly in the eastern tropical Pacific with the introduction of purse seiners which gave a better yield per recruit than the existing bait boats (Joseph, 1970).

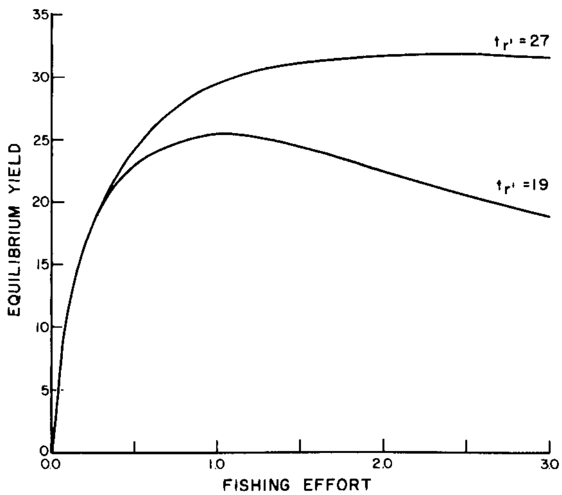

FIGURE 19.—Annual equilibrium yield as a function of fishing effort at two different ages at recruitment, t_r'.

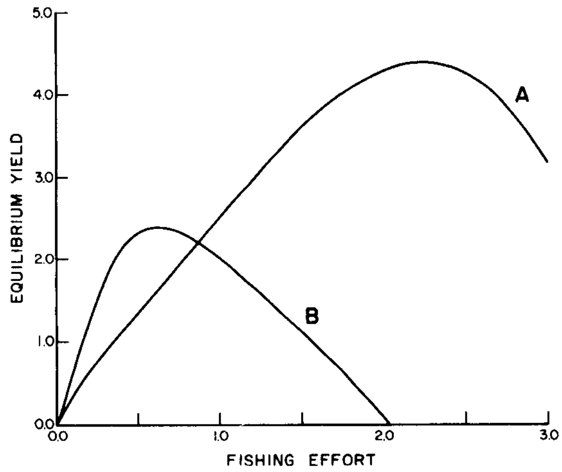

FIGURE 20.—Annual equilibrium yield as a function of fishing effort at two different ages at recruitment (see text).

The above result of singular action on the minimum size regulation resulted in a fortuitous increase in total yield and MSAY. This result may not always occur, however. Consider that if the fishery were operating with t_r' at 27 mo and $F = 0.2$, then the yield per recruit would be 2.77. The optimal yield per recruit is 3.02 at a t_r' of 19 mo. If singular action were taken to lower the t_r' to 19 mo, a slight loss of total yield would occur even with the improved yield per recruit. Even more disconcerting would be the loss in potential MSAY of 28%. The fishery would be suboptimized in a sense. Since the MSAY is usually estimated from a time series of catch and effort data, the actual potential which could have been realized had t_r' remained at 27 mo would likely be underestimated. It is likely that yield per recruit studies would continue as the fishery developed effort beyond $F = 0.2$, such that eventually the upper curve might be attained; this is because the optimal age at recruitment increases asymptotically as F increases. The low initial forecasts of MSAY, however, could hamper development of the fishery.

An even worse consequence of singular action on yield per recruit is illustrated in Figure 20. Assume the fishery is operating at about 0.6 unit of effort with an age at recruitment such to obtain curve A, but the yield per recruit is adjusted to maximal for the age at recruitment giving curve B. The actual MSAY of curve A might never be realized since the maximum equilibrium yield in curve B is also at 0.6 unit of fishing effort. This case represents true suboptimization.

CONCLUSIONS

Although there are some uncertainties in our knowledge of the parameters that enter into calculations of yield per recruit of yellowfin in the Atlantic, it is possible to come to some conclusions from our results.

The least amount of data and assumptions is involved in the simplified Beverton and Holt method. Results from this method (Table 1) show that, in all but a few extreme cases in a wide range of growth and mortality parameter values, an increase in the effective minimum size would result in an increase in yield per recruit. However, our most reasonable estimates of the parameters indicated that at the current level of fishing, an increase in the effective minimum size could only result in about an 8% increase in yield per recruit. We conclude that even if the quality of our data is poor an increase, probably minor, in yield per recruit of Atlantic yellowfin would occur if the effective minimum size is increased and if it is assumed that small yellowfin tuna were not dumped.

We next assumed that our most reasonable estimate of growth, constant Z, and effective minimum size are correct and constructed yield-per-recruit isopleths with the Ricker method for several values of natural mortality. The results (Figures 1-3) indicated that yield per recruit would increase from 0 to 20% if effective minimum size is increased and effort remains constant. Again, our most reasonable estimate of the increase is only 8%. The results also indicate that little if any increase in yield per recruit would occur if fishing effort is doubled and effective minimum size is unchanged. However, if the effective minimum size is increased and effort is doubled, a modest (20 to 40%) increase in yield per recruit could occur. All these results again assume that there would be no dumping of small yellowfin tuna.

We finally assumed that the available data are accurate enough to also make reasonably accurate estimates of size-specific F. When using our most reasonable parameter estimates and holding effort constant, an increase in size at recruitment to 55 cm (3.2 kg) would obtain a 3.9% increase in yield per recruit and to 77.5 cm (8.9 kg) would cause less than a 10% increase in yield per recruit. Increasing the size at recruitment to 55 cm with $M = 0.6$ would cause a 7% increase in yield per recruit, but with $M = 1.0$ only a 1% increase would occur. Increasing the size at recruitment to 77.5 cm with $M = 0.6$ would increase yield per recruit by 22%, but with $M = 1.0$ no increase would occur. When size at recruitment is held constant and fishing effort is doubled, our best estimate of the change in yield per recruit is a 6% increase. Our estimates ranged from a 14% decrease to a 29% increase. It seems safe to agree with the report of the Abidjan meeting that if conditions remain constant, there is little to be gained on a yield-per-recruit basis from increases in fishing effort. With a doubling of fishing effort and an increase in size of recruitment to 55 cm, our most reasonable estimate is a 15% increase in yield per recruit, with a range of a 1% decrease to a 35% increase. When size at recruitment is increased to 77.5 cm and fishing effort is doubled, our most reasonable estimate of the change in yield per recruit is a 30% gain; however, the estimates range from 27 to 44%. Thus it appears that if it is possible to increase the size at recruitment, a doubling of effort would produce a modest increase in yield per recruit. These results, it must be noted, assume that small yellowfin tuna are not dumped.

It is interesting to note that the same general conclusions would be made using either the knife-edged recruitment or size-specific F approaches. The size-specific F approach, in addition, allows us to examine more precisely the effects of an absolute minimum size regulation and the effects on each gear. The general conclusions from both aspects of this study also agree fairly well with those of Joseph and Tomlinson (1972, see footnote 4). It is not surprising, however, that results from the size-specific F approach agree with theirs because they used similar methodology and data. Both estimates suggest that under present conditions the fishery is near the point of maximum yield per recruit.

Specifically addressing the recommendations outlined in the introduction section of this paper for considering a minimum size between 3.2 and 10 kg, we offer the following results based on our most reasonable parameter estimates:

1. Minimum size limit 55 cm (3.2 kg):
   a) Current levels of fishing mortality:
      i) No dumping results in a 4% increase in landed yield per recruit
      ii) 100% dumping results in a 3% decrease in landed yield per recruit
   b) Doubling fishing mortality:
      i) No dumping results in a 15% increase in landed yield per recruit
      ii) 100% dumping results in a 1% increase in landed yield per recruit

2. Minimum size limit 77.5 cm (8.9 kg):
   a) Current levels of fishing mortality:
      i) No dumping results in a 9% increase in landed yield per recruit
      ii) 100% dumping results in a 13% decrease in landed yield per recruit
   b. Doubling fishing mortality:
      i) No dumping results in a 31% increase in landed yield per recruit
      ii) 100% dumping results in a 16% decrease in landed yield per recruit.

The 55-cm (3.2 kg) minimum size limit would likely be of more benefit to the tuna fishery than the larger minimum size limit of 77.5 cm (8.9 kg) since less dumping would occur. Therefore, there would likely be, on the average, an increase in landed yield per recruit at the current or greater levels of fishing mortality; whereas, if a larger size limit were adopted, there would likely be, on the average, a decrease in landed yield per recruit at current levels of fishing mortality and less of an increase (perhaps even a decrease) in landed yield per recruit than with the 55-cm (3.2 kg) minimum size and an increase in fishing mortality.

The results of this paper were obtained using reasonable assumptions and all available data on Atlantic yellowfin tuna. As we increased the number of assumptions we increased the number of conclusions. We think that it is unlikely that use of tecnhiques not used in this paper would result in conclusions that are significantly different from ours. That is, an increase in effective minimum size would result in a minor increase in yield per recruit, an increase in effort without increasing effective minimum size would not appreciably increase yield per recruit, and an increase in effective minimum size and effort would result in modest gains in yield per recruit. We wish to emphasize that these conclusions are based on a number of assumptions. We consider the assumptions reasonable, but because they are assumptions any management decisions, including the decision of taking no action, should be followed with careful evaluation of the results.

ACKNOWLEDGMENTS

We are indebted to James Joseph and Patrick Tomlinson of the Inter-American Tropical Tuna Commission for their useful comments on this paper. This study would not have been possible without the many valuable contributions of data and ideas by scientists of the nations that participate in the International Commission for the Conservation of Atlantic Tunas.

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