Potential tuna catches in the eastern Pacific Ocean from schools not associated with dolphins

Richard G. Punsly
Patrick K. Tomlinson
Ashley J. Mullen
Inter-American Tropical Tuna Commission
8604 La Jolla Shores Dr., La Jolla, CA 92037

Abstract.—The eastern Pacific purse-seine tuna fishery has historically been very productive, yielding up to 400,000 metric tons (t) per year of primarily yellowfin, *Thunnus albacares*, and skipjack, *Katsuwonus pelamis*. However, efforts to minimize dolphin (primarily spotted dolphin, *Stenella attenuata*, spinner dolphin, *S. longirostris*, and common dolphin, *Delphinus delphis*) mortality incidental to tuna seining in the eastern Pacific ocean have been increasing. Therefore, predictions of what the tuna catches will be in the future, if there is a ban or moratorium on catching dolphin-associated tuna, are useful. Based on recruitment levels, age-specific catchability coefficients for yellowfin tuna caught without dolphins, and average fishing effort observed during 1980-88, we predicted that yellowfin catches would be reduced by an average of about 25%. These results were verified by Monte Carlo simulations, by using average effort and randomly selected yellowfin recruitment and catchability coefficients from 1980 to 1988, which predicted a mean annual decrease of 55,563 t or 24.7% of yellowfin catch. The actual reduction in yellowfin catch might be greater because 1) fishing effort will probably decline, 2) the range of the fishery might be reduced to the traditional inshore non-dolphin regions, and 3) yellowfin recruitment could be reduced by the change in age structure and population size likely to result from a moratorium. Because skipjack seldom associate with dolphins, redirection of fishing effort to schools of tuna not associated with dolphins would probably result in increased skipjack catch rates. However, the magnitude of the increase is difficult to estimate, because the population dynamics of skipjack are poorly understood. Finally, this study predicted that the catches in the first years after a moratorium on dolphin sets would not necessarily reflect long-term catches.

Manuscript accepted 22 July 1993
Fishery Bulletin 92:132–143 (1994)

Since the late 1950's, purse-seine fishermen in the eastern Pacific Ocean (EPO), knowing that schools of yellowfin tuna (*Thunnus albacares*) often associate with dolphins (primarily spotted dolphins, *Stenella attenuata*, spinner dolphins, *S. longirostris*, and common dolphins, *Delphinus delphis*), have used the dolphins to help locate and capture yellowfin. Dolphins are relatively easy to detect, being larger and closer to the surface than yellowfin. In fact, the most efficient means of catching the 2- and 3-year-old yellowfin, which comprise the largest component of the tuna catch in the EPO, is purse-seine fishing for dolphin associated schools (Punsly and Deriso, 1991). Yellowfin remain associated with dolphins while the net is being set around the dolphin herds. The fishermen attempt to release all of the dolphins from the net; however, incidental mortality sometimes occurs through entanglement.

As a result of increasing public pressure to prevent mortality of dolphins incidental to tuna purse seining, elimination of setting on dolphin-associated tunas is being considered. Therefore, fishermen, biologists, and managers need to know the extent to which tuna catch in the EPO might be reduced by the elimination of sets on dolphin-associated fish. The objective of this study was to estimate this potential reduction in the catch. No such estimates have been published previously.

Tuna catches could be affected by a ban or moratorium on dolphin sets in six ways:

1 The overall catchability of yellowfin by purse seiners could be reduced.
2 The yield per recruit of yellowfin could decline because non-dolphin-associated yellowfin caught by purse seiners are mostly composed of fish younger than the optimum age of entry (Calkins, 1965; Allen, 1981).
3 The average age of yellowfin and mean biomass may be reduced by fishing on younger age groups. This might not only reduce the catch in weight, but also reduce the spawning potential and possibly the resulting recruitment.
4 Since the offshore EPO purse-seine fishery is directed primarily at dolphin-associated fish (Fig. 1, A and B), a moratorium on setting on dolphin herds could result in a contraction of the range of the fishery into inshore regions. The number of fish recruited to this new smaller area might be lower than the number recruited to the entire area. Lower effective recruitment would also result in lower catches.
5 If a moratorium on catching dolphin-associated tuna occurs,

some purse-seine fishermen may decide to move to other oceans or retire, which would reduce total fishing effort and hence the catch.

6 Since skipjack tuna (*Katsuwonus pelamis*), the only other primary target species in the fishery, seldom associate with dolphins, their catch may increase if effort remains at 1980–88 levels and is directed only toward tuna schools not associated with dolphins.

Because no relation between spawners and recruitment of yellowfin has been established (Bayliff, 1992, p. 62), the possible effects of reduced recruitment were not addressed in this study. Also, since the authors cannot predict how many seiners would leave the EPO, or how much the fishery would contract, these two factors were not considered. In other words, this study only attempted to estimate how much tuna catches might change due to changes in yellowfin catchability, yield per recruit, total biomass, and age structure.

To measure the possible effects of changing the mode of fishing from being directed toward primarily dolphin-associated schools of tuna ("dolphin sets," Allen, 1981) to one directed at exclusively free-swimming schools ("school sets") and floating-object-associated schools ("log sets," Greenblatt, 1979), we first estimated what the tuna catches would have been in previous years if dolphin sets had been replaced by non-dolphin sets. Then the estimates were compared with actual catches. Our method used non-dolphin-set catchability coefficients and total effort to estimate what the catches would have been during 1980–88 if there had been a moratorium on dolphin sets beginning in 1980. Other works in which catches were estimated for alter-

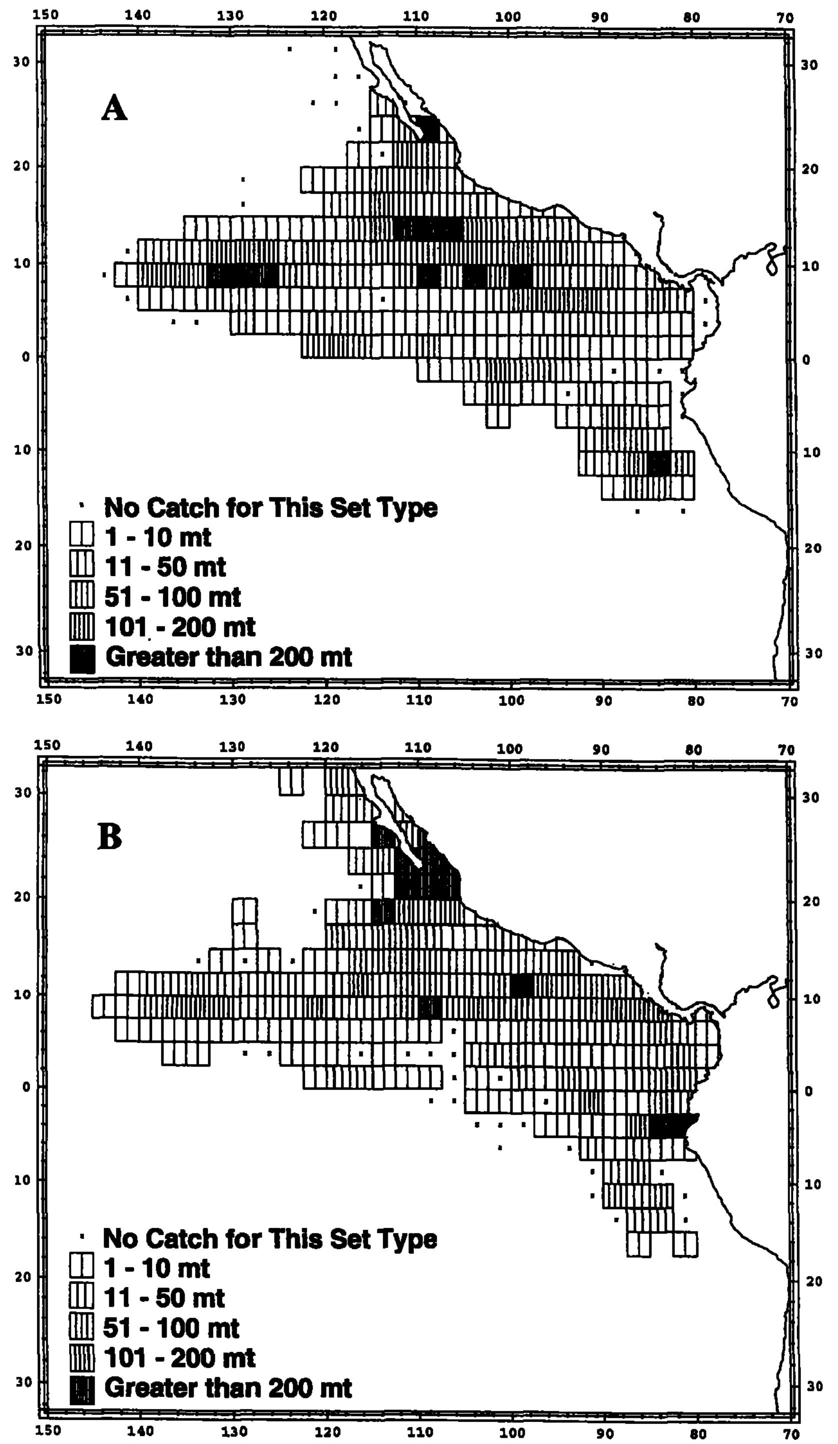

Figure 1

(**A**) Geographic distribution of average yellowfin tuna (*Thunnus albacares*) catch by purse seiners, during 1980–88, from schools associated with dolphins (Delphinidae). Catches are expressed in metric tons by 2.5–degree quadrangles. (**B**) Geographic distribution of average yellowfin catch by purse seiners, during 1980–88, from schools not associated with dolphins. Catches are expressed in metric tons by 2.5–degree quadrangles.

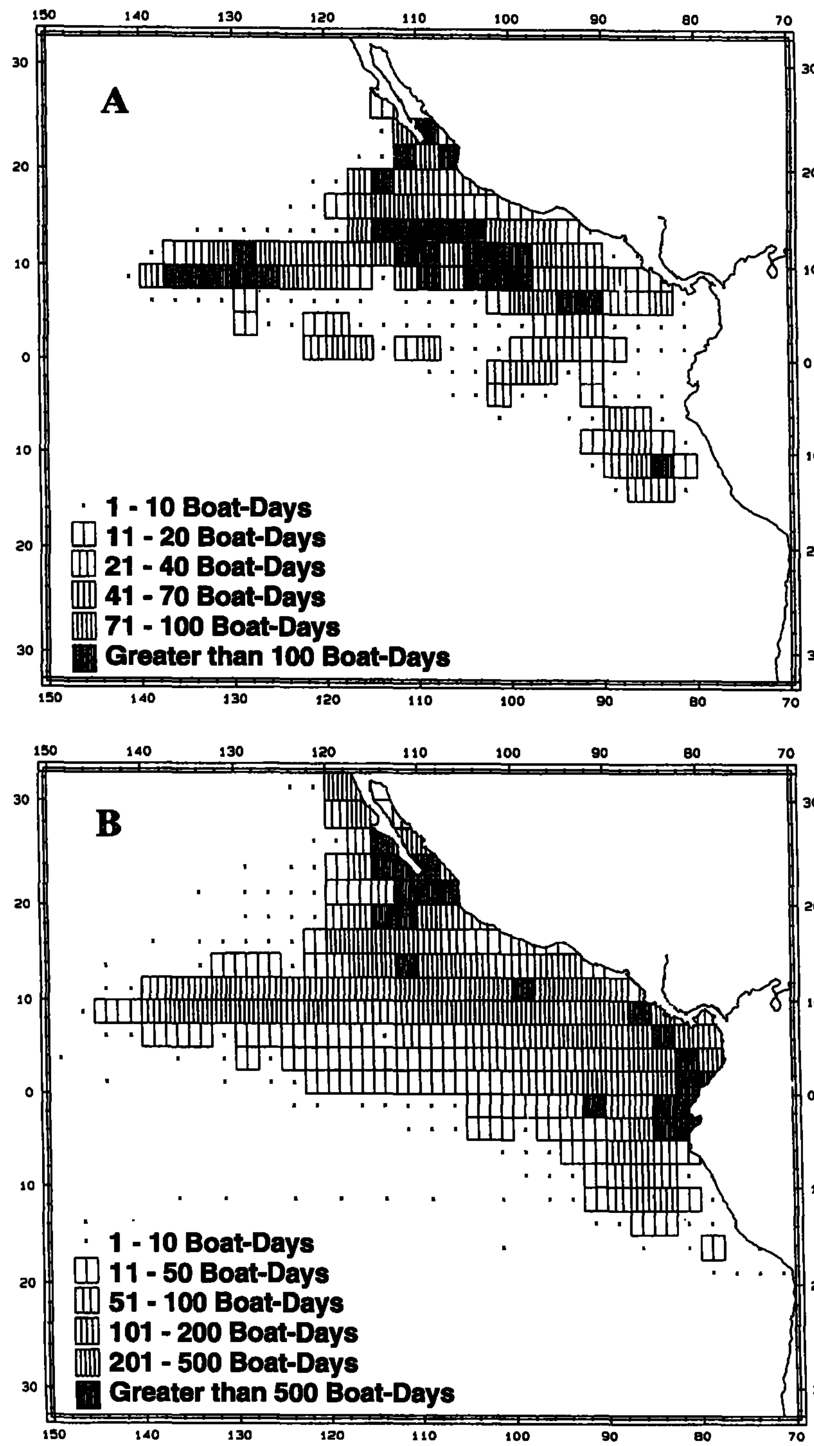

Figure 2

(**A**) Geographic distribution of total purse-seiner fishing effort during 1980–88 which lead to dolphin (Delphinidae) sets. Effort levels are expressed in boat-days of fishing by 2.5–degree quadrangles. (**B**) Geographic distribution of total purse-seiner fishing effort during 1980–88 which lead to non-dolphin sets. Effort levels are expressed in boat-days of fishing by 2.5–degree quadrangles.

native catchability coefficients include Holt (1958), Jones (1961), and Bartoo and Coan (1978).

Materials and methods

Data

The Inter-American Tropical Tuna Commission's (IATTC) logbook and length-frequency data bases were used in this study. The logbook data base, described in Orange and Calkins (1981), Punsly (1983; with emphasis on set types), and Punsly (1987; with emphasis on yellowfin catch rates), contains information on the fishing activities of about 90% of the purse seiners in the EPO. Total catches were estimated by multiplying the logbook catches by the ratio of the sum of the unloading weights to the sum of the logbook catches. Geographic distributions of the logbook data on catch and effort, during 1980–88, for both dolphin-associated and unassociated schools are shown in Figures 1 and 2. The length-frequency data base, described by Hennemuth (1957), Punsly and Deriso (1991), and Tomlinson et al. (1992), has information from samples of about 12–15% of the catch. Age-specific yellowfin abundances from cohort analysis (Pope, 1972; also called sequential computation of stock size in Ricker, 1975; and virtual population analysis in Gulland, 1965) were taken from Bayliff (1990).

Data from 1980 to 1988 were used in this study. Data before 1980 were not used because of the difficulty in modeling the closed seasons for yellowfin (Cole, 1980). Data after 1988 were not used because cohort analysis cannot produce accurate abundance estimates for cohorts which have not been in the fishery for a sufficient period of time.

Semi-annual age groups used in this study were described in detail in Bayliff (1992, p. 52). Monthly age compositions were estimated by combining 1-cm length-interval data into semi-annual age groups by fitting multinormal distributions to the data with the aid of the computer program NORMSEP, (Abramson, 1971), and constraining the fit to the growth parameters of Wild (1986). "X" and "Y" cohorts were defined as those fish reaching 30 cm, which correspond to the approximate age of first recruitment, during the fourth and second quarters of the year, respectively. Age groups in our study, 0.5 to 5.5 in 0.5 year increments, correspond to the Y0, X1, Y1 ... Y5 cohorts, respectively, in Table 21 of Bayliff (1992).

Estimates of fishing effort

The total monthly effort by purse seiners was estimated as

$$\hat{E}_{om} = f_{om} Y_{om} / y_{om},$$

where o, refers to the observed mixture of set types, Y_{om} is the yellowfin catch unloaded by purse seiners in month (m), y_{om} is the yellowfin catch reported in the IATTC logbooks and f_{om} is the effort, in boat-days of fishing, reported in the logbooks. Effort on non-dolphin sets for all purse seiners was estimated by

$$\hat{E}_{nm} = \sum_{cs} \sum \hat{f}_{nmcs} Y_{omcs} / \hat{y}_{omcs},$$

where $\hat{f}_{nmcs}$ is the fishing effort which lead to non-dolphin (n) sets by monitored vessels of size (s) from country (c), Y_{omcs} is the total catch of yellowfin from unloadings by size (s) vessels from country (c), and $\hat{y}_{omcs}$ is the total yellowfin catch by monitored vessels. These estimates were stratified by country and size of vessel because the proportion of dolphin sets is affected by these two factors.

Estimates of skipjack catches if all effort were non-dolphin

Skipjack are suspected to be mostly transient in the EPO (Joseph and Calkins, 1969), so we assumed that depletion is probably unimportant. Thus, the ratio of the total effort to the non-dolphin effort was used to estimate skipjack catches:

$$\hat{Y}_{pm}(SJ) = Y_{nm}(SJ) \hat{E}_{om} / \hat{E}_{nm},$$

where $\hat{Y}_{pm}(SJ)$ is the potential (p) non-dolphin, skipjack catch and $Y_{nm}(SJ)$ is the actual non-dolphin-set, skipjack catch. In essence, skipjack catches were estimated to be linear extrapolations of catch rates to higher levels of effort.

Estimation of yellowfin catches if all effort were non-dolphin

This method used age-specific, monthly catchability coefficients by fishing mode and allowed the future population structure to be affected by previous catches. First, age-specific catchability coefficients for non- dolphin sets (n) in each month (m) were estimated for each semi-annual age group (j):

$$\hat{q}_{nmj} = \hat{C}_{nmj} \Big/ \left(\hat{E}_{nm} \overline{N}_{mj} \right),$$

where $\hat{C}_{nmj}$ are the monthly, total, non-dolphin purse-seine catches (in numbers of fish) of semi-annual age group (j) and $\overline{N}_{mj}$ are the age-specific, monthly, average abundances estimated by the cohort analysis (Bayliff, 1990). Beginning with the population structure in January 1980, obtained from cohort analysis, we estimated what the catch in each month of each semi-annual age group would have been without dolphin sets; i.e.,

$$\hat{C}_{pmj} = \left[\left(\hat{N}_{mj} \hat{q}_{nmj} \hat{E}_{om} \right) \Big/ \left(\hat{q}_{nmj} \hat{E}_{om} + \overline{M}_j \right) \right] \left[1 - e^{-(\hat{q}_{nmj} \hat{E}_{om} + \overline{M}_j)} \right],$$

where $\overline{Mj}$ is the age-specific, instantaneous, monthly natural mortality (Bayliff, 1992, p. 52). Yield in weight was estimated by

$$\hat{Y}_{pmj} = \overline{W}_m(j) \hat{C}_{pmj},$$

where $\overline{W}(j)$ is the estimated mean weight of age (j) yellowfin in month m caught during 1980–88. The subsequent month's abundance of semi-annual age group (j) was estimated to be

$$\hat{N}_{m+1,j} = N_{mj} \, e^{-(\hat{q}_{nmj} \hat{E}_{om} + \overline{M}_j)},$$

except for the months of recruitment (May and January), when $\hat{N}_{JAN,2}$ and $\hat{N}_{MAY,3}$ were set equal to the historical recruitment previously estimated for that time period by cohort analysis. Yellowfin form the first semi-annual age group (those fish hatched in the middle of the current year) were not included in the analysis because they were not recruited until the next year, when they became semi-annual age group 3. Each January, the semi-annual age groups were graduated as follows:

$$\hat{N}_{JAN,j+2} = N_{DEC,J} \, e^{-\hat{q}_{nDECj} \hat{E}_{oDEC} + \overline{M}_j}.$$

Monte Carlo simulation

The age-structure method produced catches specific to the observed time-series of recruitment and age-specific catchability coefficients during 1980– 88. Additional information can be gained by estimating what the trend in catches would be if the recruitment and catchability trends were different. In order to explore the range of resulting catches which might have occurred under various conditions, a Monte Carlo simulation was used. Paired simulations were performed for both the observed mixed-mode fishery and a fishery in which all effort was directed toward non-dolphin-associated tuna. Frequency distributions of differences between catches from the two simulated fisheries provide a more comprehensive estimate of future expectations.

The simulations used quarterly time steps and 1,000 replicates. At each quarter of each year in each replicate, a year between 1980 and 1988 was randomly selected with replacement (i.e., each year could be selected more than once). Pairs of quarterly catchability coefficients (one from the observed mixture of fishing modes and one for the non-dolphin sets only) estimated for the corresponding year, were used in the calculations during the time steps. Quarterly coefficients were calculated with the same equation as that for the monthly coefficients with months replaced by quarters. Quarterly fishing efforts were set to the 1980–88 averages. The same average total effort was applied to both the observed and non-dolphin fishing-mode models.

Recruitment was simulated to occur in the second and fourth quarter. For each year in each simulation, a randomly selected year was chosen. Recruitment pairs (X and Y) from the randomly selected year were used for both fishery models. Initial population sizes and age structures were also set to the 1980–88 averages.

One thousand differences between the simulated catches for the mixed- mode and non-dolphin only scenarios were generated for a time series of nine years. The 95% confidence intervals corresponded to the 50th and 950th highest differences from the 1,000 simulations. Because yellowfin usually live for less than 5 years (Fig. 3), results for the last (9th) year were unaffected by the initial age structure.

Table 1

Estimated annual tuna (Scombridae) catches by purse seiners in the eastern Pacific ocean, in thousands of metric tons.

Year	OYF	NYF	QYF	OSJ	NSJ	OT	QT	NT
1980	170	129	158	131	155	301	313	284
1981	190	152	146	120	151	310	297	303
1982	134	111	120	99	129	233	249	240
1983	104	96	98	58	73	162	171	169
1984	155	103	125	61	90	215	215	193
1985	227	132	169	49	99	276	268	231
1986	286	193	168	64	113	350	281	305
1987	285	243	195	62	120	347	314	363
1988	303	266	229	85	123	388	352	389
Mean	206	158	156	81	117	286	274	275

OYF = yellowfin tuna (*Thunnus albacares*) - observed mixture of set types.
NYF = yellowfin tuna - all effort directed at non-dolphin (Delphinidae) sets, using the observed monthly catchability coefficients for non-dolphin sets.
QYF = yellowfin tuna - all effort directed at non-dolphin sets, using the average, observed, quarterly catchability coefficients for non-dolphin sets.
OSJ = skipjack tuna (*Katsuwonus pelamis*) - observed mixture of set types.
NSJ = skipjack tuna - all effort directed at non-dolphin sets.
OT = yellowfin plus skipjack tuna - observed mixture of set types.
QT = yellowfin plus skipjack tuna - effort directed at non-dolphin sets, using quarterly average catchability coefficients.
NT = yellowfin plus skipjack tuna - all effort directed at non-dolphin sets, using monthly catchability coefficients.

Results

Deterministic approach

If trends in total effort, recruitment, and non-dolphin-set catchability coefficients had been the same as during 1980–88, with all effort directed at non-dolphin sets, yellowfin catches (Table 1, column NYF) were estimated to have averaged 77% of the observed catch (Table 1, column OYF). The range was from 58% in 1985 when dolphin-associated tuna fishing was good to 93% in 1983 when dolphin-associated tuna fishing was poor. The reasons why the ratio of estimated catch without dolphin sets to the observed catch varied annually can be seen in Figures 3–7. For example, the high estimated biomasses of 1.5-year-old yellowfin in 1988 (Fig. 4), coupled with their high non-dolphin-set catchability coefficients (Fig. 5), produced an estimated catch of 266,000 t for all effort directed at non-dolphin sets, which was almost as high as the 303,000 t catch estimated from the catchability coefficients for the observed mixture of set types (Fig. 6). Catchabilities could have increased in 1988 for a variety of reasons, including the use of deeper nets, the use of "bird radar" (relatively new radar used for detecting birds which commonly have tuna beneath them) or environmental factors, such as a shoaling of the thermocline (Green, 1967). For a given level of effort, catches depended on the age-specific abundances (Figs. 3 and 4) and catchability coefficients (Figs. 5 and 6). Consequently, the estimated catches if all effort were directed at non-dolphin sets approached

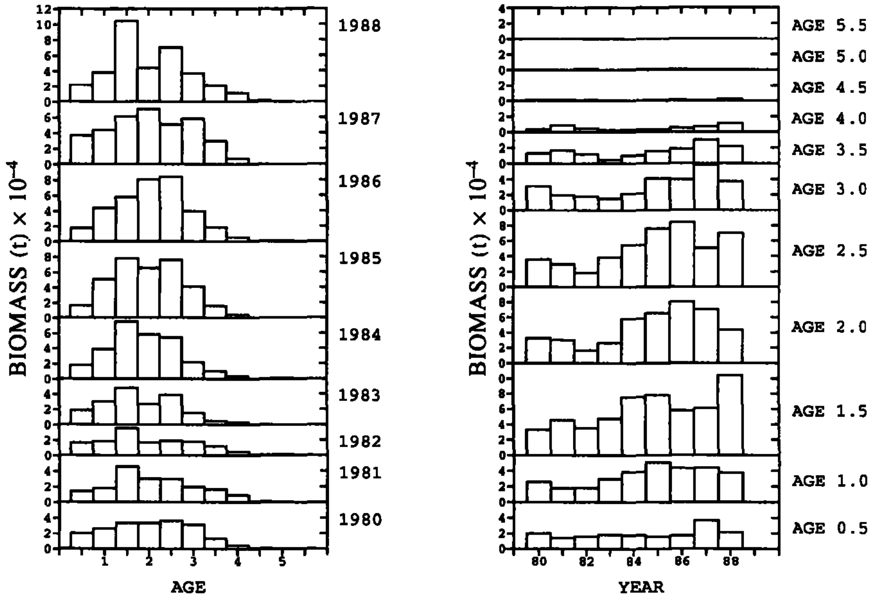

Figure 3

Estimated average annual biomasses (t) of yellowfin tuna (*Thunnus albacares*) by semi-annual age group for the observed mixture of set types. In the left panel, biomasses are summarized by age within year. In the right panel, biomasses are summarized by year within age group. Age refers to the age in years at the middle of the year.

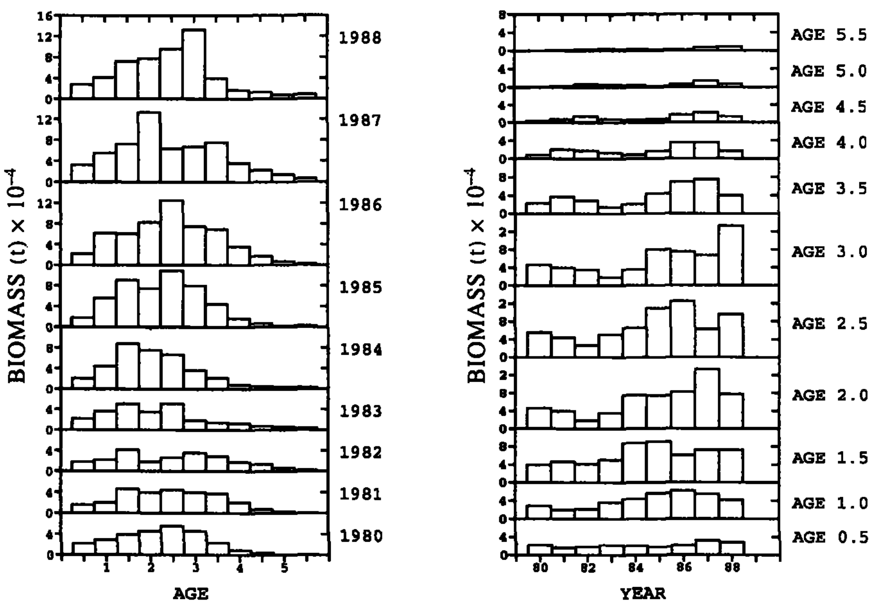

Figure 4

Estimated average annual biomasses (t) of yellowfin tuna (*Thunnus albacares*) by semi-annual age group for all effort directed at non-dolphin (Delphinidae) sets. In the left panel, biomasses are summarized by age within year. In the right panel, biomasses are summarized by year within age group. Age refers to the age in years at the middle of the year.

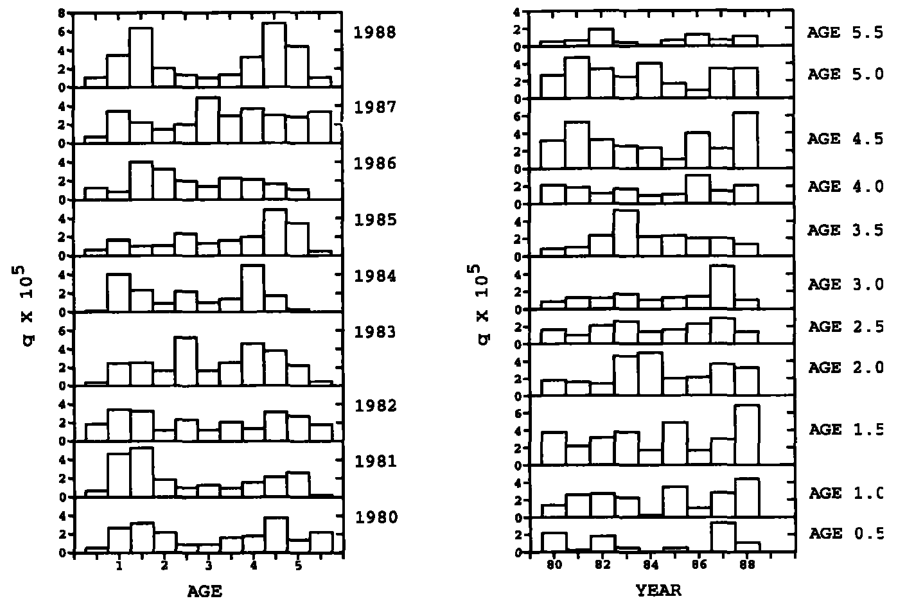

Figure 5

Average annual non-dolphin-set yellowfin tuna (*Thunnus albacares*) catchability coefficients (q in boat-days^{-1}) by semi-annual age group. In the left panel, coefficients are summarized by age within year. In the right panel, coefficients are summarized by year within age group. Annual catchability coefficients are estimated as the mean of the monthly coefficients. Age refers to the age in years at the middle of the year.

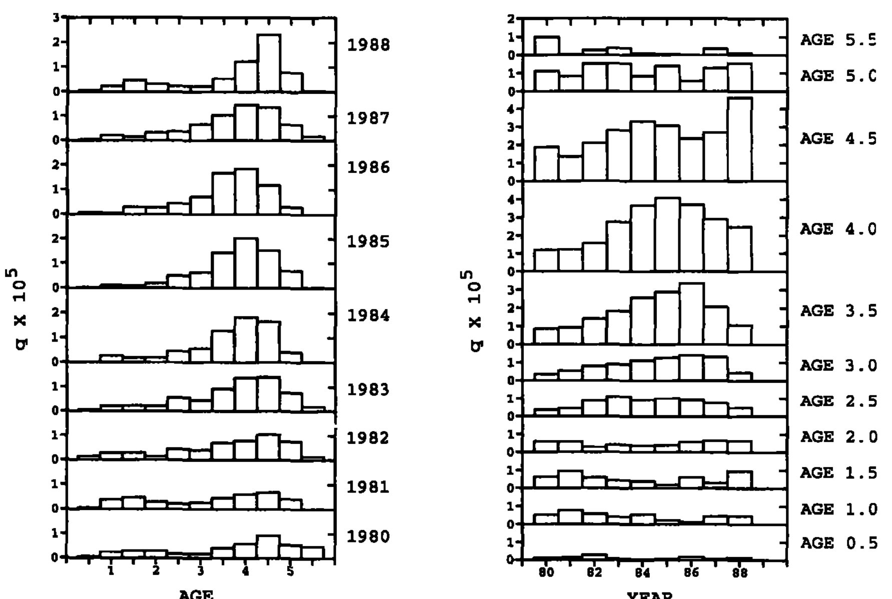

Figure 6

Average annual observed yellowfin tuna (*Thunnus albacares*) catchability coefficients (q in boat-days^{-1}) by semi-annual age group. In the left panel, coefficients are summarized by age within year. In the right panel, coefficients are summarized by year within age group. Annual catchability coefficients are estimated as the mean of the monthly coefficients. Age refers to the age in years at the middle of the year.

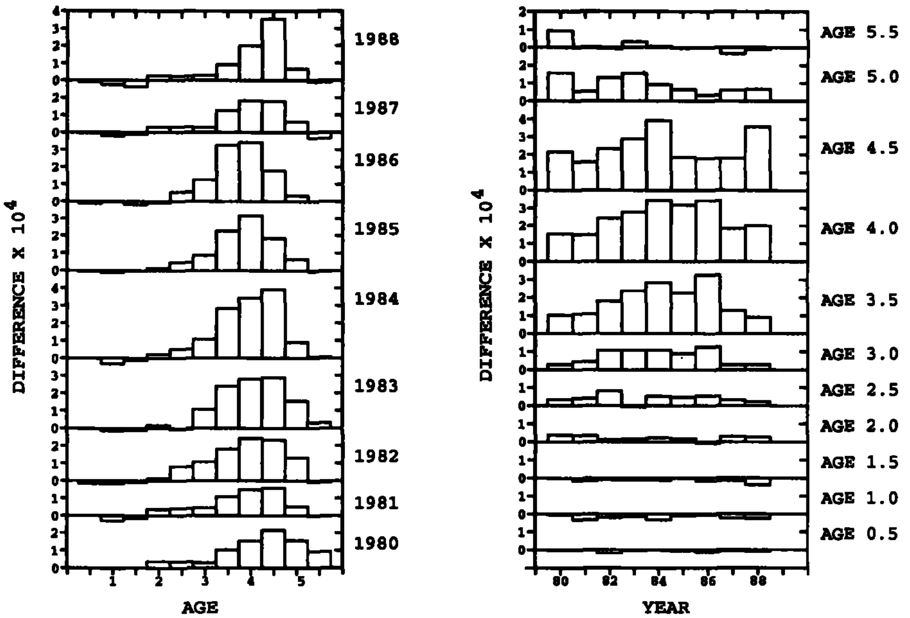

Figure 7

Average annual differences between the observed and non-dolphin (Delphinidae) catchability coefficients (boat-days^{-1}). In the left panel, differences are summarized by age within year. In the right panel, differences are summarized by year within age group. Age refers to the age in years at the middle of the year. Negative values (those pointing down) indicate that those non-dolphin-set catchability coefficients were greater than the observed coefficients.

the observed levels when the non-dolphin-set catchability coefficients were greater than or equal to the observed overall catchability coefficients (Fig. 7, negative values) for the age groups of the greatest biomass (Figs. 3 and 4). Estimated total yellowfin plus skipjack catches, if all effort were directed at non-dolphin sets, ranged from 84% during 1985 to 104% in 1983.

Estimates (Table 1, column QYF) of what the catches would have been without dolphin sets, using the quarterly average (over years) non-dolphin-set catchability coefficients for 1980–88, indicate that yellowfin catchabilities on non-dolphin sets increased in the late 1980's. Average quarterly catchability coefficients produced noticeably higher catches than the observed non-dolphin-set monthly coefficients in 1983–85 when the observed coefficients on small fish were low. On the other hand, average quarterly catchability coefficients produced lower catches during 1986–88, when the observed non-dolphin-set coefficients were high.

Monte Carlo simulation

The Monte Carlo simulations (Table 2) predicted that, if total effort, recruitment, and non-dolphin-set catchability coefficients had varied randomly throughout their 1980–88 distributions, and current levels of effort and recruitment had been maintained, changing to a fishery with all effort directed toward non-dolphin sets would have resulted in an average reduction of 55,563 t (24.7%) of yellowfin catch per year. The 95% confidence interval, based on the 50th and 950th highest simulated differences was 24,000 to 91,000 t (10%–42%). The entire frequency distribution of the differences between the two fishing-mode models in the 9th year is shown in Figure 8. Simulated recruitment estimates were selected from the observed values during 1980–88. Thus, average recruitment used in the simulations was higher than the mean actual recruitment to the initial 1980 population structure, which was partly a result of the poor recruitment during 1978 and 1979. Consequently, simulated catches were higher for both the observed mixed mode fishery (229,000 t per year) and the non-dolphin-set only fishery (175,000 t).

Yield per recruit

Estimated yellowfin catches from both the deterministic approach (Table 1) and the Monte Carlo simu-

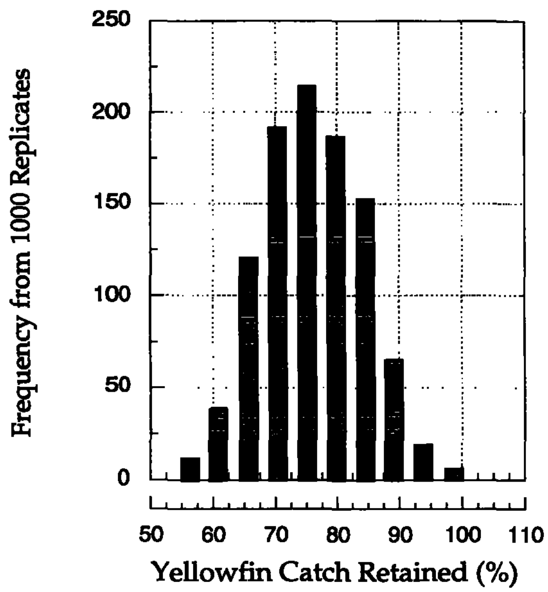

Figure 8

Frequency distribution of the percent of the yellowfin tuna (*Thunnus albacares*) catch in weight retained in the ninth year of a ban on dolphin (Delphinidae) sets, from 1,000 Monte Carlo simulated replicates. The percent of catch retained is calculated as 100× (the catch if all effort were directed at non-dolphin sets) / (the catch from the observed mixture of set types).

lations (Table 2) were heavily influenced by the recruitment and fishing effort levels used. Recruitment in the future may be different from that of past, because of changes in population size, age structure, and environmental factors. Therefore, actual future catches could be different from what we estimated. For these reasons, results in terms of reduction in yield per recruit are of interest. We estimated that the change to non-dolphin sets only would result in the reduction of the yield per recruit of yellowfin from the observed value of 2.8 kg per recruit to 2.1 kg as shown in Figure 9. In addition, effort levels could change in the future, perhaps as a reaction to the moratorium. Therefore, estimates of yield per recruit for various levels of effort might be useful. If effort levels change in the future, the multipliers on the X-axis in Fig. 9 could be used to estimate the potential yellowfin catch.

Discussion

In order to predict what the tuna catches might be in the future if there were a moratorium on dolphin sets, we estimated what the tuna catches would have been during 1980–88, had there been a moratorium on dolphin sets beginning in 1980. Using these estimates to predict future catches required the following assumptions:

1 Age-specific, non-dolphin catchability coefficients will be the same in the future as during 1980–88.
2 Fishing effort will remain at 1980–88 levels.
3 The geographic distribution of effort will be the same as during 1980–1988 (Fig. 2, A and B combined).
4 Recruitment will be at 1980–88 levels.
5 Natural mortality will not change in the future.
6 Skipjack abundance will not significantly change.

Table 2

Monte-Carlo simulated annual yellowfin tuna (*Thunnus albacares*) catches, in thousands of tons, from 1980–88, quarterly, average catchability coefficients.

YEAR	OYFM	OYFL	OYFU	NYFM	NYFL	NYFU	PCM	PCL	PCU
1	202	184	229	150	121	186	72	61	83
2	215	183	247	164	127	205	76	62	89
3	227	183	276	170	129	217	76	59	91
4	229	183	283	175	131	223	70	68	88
5	236	188	286	181	139	230	76	59	91
6	245	195	302	187	138	241	76	61	91
7	237	189	294	180	138	229	75	59	90
8	231	182	281	176	134	228	76	58	91
9	229	181	279	174	131	222	75	58	90

OYFM = mean yellowfin tuna catch for the observed mixture of set types.
OYFL = OYFM lower 95% confidence interval.
OYFU = OYFM upper 95% confidence interval.
NYFM = mean yellowfin tuna catch using total effort and non-dolphin catchability coefficients.
NYFL = NYFM lower 95% confidence interval.
NYFU = NYFM upper 95% confidence interval.
PCM = mean percent of catch retained (100 x NYFM/OYFM).
PCL = PCM lower 95% confidence interval.
PCU = PCM upper 95% confidence interval.

Significant deviations from these assumptions could make our estimates less valid. Therefore, the potential ramifications of deviations from the assumptions are discussed in detail below.

Major changes in the vulnerability of non-dolphin-associated yellowfin to purse seiners could result in significantly different catches than we estimated. Allen and Punsly (1984) showed that both environmental and vessel efficiency factors affect the catchability of yellowfin by purse seiners in the EPO. Improvements in vessel efficiency could increase future catchability coefficients; whereas, environmental factors could produce either higher or lower catchability coefficients than those observed during 1980–88. Environmental factors affecting catchability could conceivably mask the effects of a moratorium on dolphin sets for several years. For example, if a moratorium on dolphin sets had been imposed at the beginning of 1983, the low catch in 1983 would have made it appear that the decline resulted from the moratorium. However, we predicted that a moratorium would have had the smallest effect in 1983 (Table 1). Fishermen, biologists, and managers should be aware that catches during the first year after a moratorium starts may not be indicative of long-term averages. However, since 9 years of data were used, our long-term average estimates should only be affected by long-term changes in catchability.

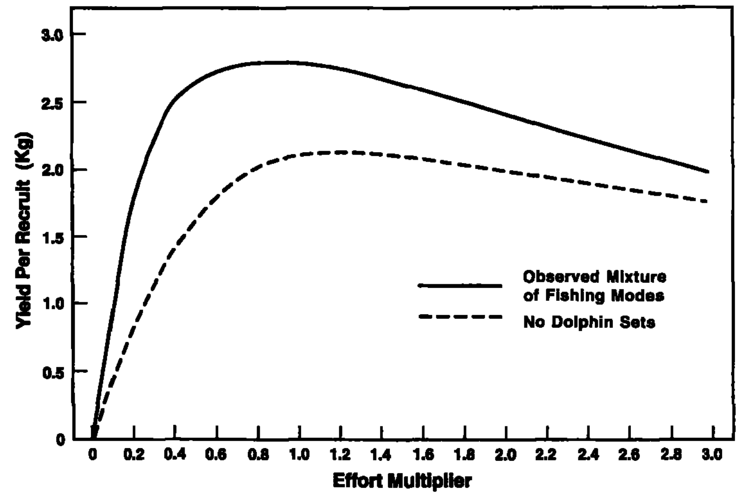

Figure 9

Yield per recruit of yellowfin tuna (*Thunnus albacares*) (kg) for the observed 1980–88 fishery (solid line) and a fishery with all effort directed at non-dolphin (Delphinidae) sets (dashed line). An effort multiplier of 1.0 refers to the 1980–88 average effort.

An assumption that effort will be lower in the future may be more realistic than our assumption that effort will remain at 1980–88 levels. However, we could not predict the extent to which effort might be reduced because it is affected by ex-vessel tuna prices at canneries all over the world, the prices of other foods, and the cost of fuel. Nevertheless, if we could estimate what the effort reductions would be in the future, the effort multipliers in the the yield-per-recruit estimates in Fig. 9 could still be used.

If the fishery contracted into the traditional inshore school- and log-set areas after a moratorium on dolphin sets, then catches may be lower than we estimated them to be. For example, if the area fished were smaller, and mixing between the fish inside and outside the area were incomplete, then the new fishing area would encompass fewer fish than the total area. Therefore, all of the population sizes of yellowfin used in the equations in the methods section would be overestimated. Recruitment estimates, which are estimates of the number of 30-cm yellowfin, would also be overestimated. In addition, if fishing effort remained high, but the range contracted, then a gear- competition effect might lower the catch of both yellowfin and skipjack. However, since effort levels are expected to decline after a moratorium, localized depletion of tuna due to a contracted fishery is unlikely.

We assumed that yellowfin recruitment in the future would not be affected by the changes in population size and age structure which might result from re-directing effort toward smaller fish, because a relationship between yellowfin spawning biomass and recruitment has not yet been demonstrated. However, a spawner-recruit relationship for yellowfin may be discovered in the future, because better estimates of yellowfin fecundity by size of fish, season, and area are currently being developed at IATTC. When this work is completed we may be able to predict recruitment levels and their resulting catches more accurately in the future. If future recruitment levels could be estimated, the future catches could be derived by multiplying the recruitment estimates by the yield per recruit shown in Figure 9.

Environmental factors have long been suspected of having significant effects on yellowfin recruitment. For example, favorable conditions in the late 1980's may have contributed to the large number of recruits (Bayliff, 1992). In 1987, the number of recruits was so large that the effect of a moratorium in 1988 would have been masked by a high catch of 1.5 year old yellowfin, first recruited during 1987. In 1988, the high abundance of 1.5 year old fish (Fig. 4) coupled with their high catchability for non-dolphin sets (Fig. 5) caused the estimated yellowfin catch if all effort were directed at non-dolphin sets to be almost as high as the estimated actual catch.

In order to predict future recruitment, the IATTC is currently studying the relationship between the environment and yellowfin recruitment. If they are successful the yield-per-recruit estimates in Figure 9 could be multiplied by the recruitment estimates to better predict future yellowfin catches.

Little is known about the rate of natural mortality of yellowfin. However, there is no reason to believe this rate will change. But, if it does change, a reasonable assumption would be that if natural mortality goes up, catch will go down and vice versa.

Little is known about skipjack population dynamics. We assumed that local depletion is negligible for skipjack. However, since skipjack are primarily caught in association with floating objects, if the amount of effort per floating object increases as a result of effort being re-directed from dolphin-associated tunas to floating objects, then the chances of depletion is certainly possible. If this occurs, our estimates of skipjack catch rates will be too high. This effect could be compounded during years in which floating objects are scarce, because the number of sets per floating object would increase. Since the skipjack catches have been increasing in the western Pacific Ocean, their abundance and catch in the eastern Pacific could be lower than our estimates.

A moratorium on dolphin sets is likely to result in reduced catchability, yield per recruit, average age, and total biomass of yellowfin. The catch of yellowfin, based on these factors only, was predicted to decline by approximately 55,600 t (25%). On the other hand, skipjack catches could increase, making the reduction in total tuna catches much smaller (4%). The effects of reductions in fishing effort, the range of the fishery, and recruitment were not analyzed in this study because they are currently unpredictable; however, all three would result in an additional decrease in total tuna catches. If better predictions of effort levels and yellowfin recruitment are made, the yield-per-recruit estimates in Figure 9 could be used in conjunction with them to better predict yellowfin catches. The results of our analysis indicate that catches in the first years after a moratorium begins may not be indicative of the long-term catches. Fishermen, biologists, and managers should not consider these first-year catches as indices of future catches, because recruitment and catchability vary annually. On the other hand, our estimates of future average catches should be useful unless there are long-term changes in catchability or recruitment.

Acknowledgments

We would like to thank James Joseph, director of investigations of the Inter-American Tropical Tuna Commission for suggesting the need for this research, Richard B. Deriso for his many methodological suggestions, Alejandro Anganuzzi for his reviews and for sharing his knowledge about about dolphins, and William H. Bayliff for his extensive editorial reviews of this manuscript.

Literature cited

Abramson, N. J.
1971. Computer programs for fish stock assessment. F.A.O. Fish. Tech. Pap. 101, 154 p.

Allen, R. L.
1981. Dolphins and the purse-seine fishery for yellowfin tuna. I.A.T.T.C. Int. Rep. 16, 23 p.

Allen, R. L., and R. G. Punsly.
1984. Catch rates as indices of abundance of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean. I.A.T.T.C. Bull. 18(4):301–379.

Bartoo, N. W., and A. L. Coan.
1978. Changes in yield per recruit of yellowfin tuna (*Thunnus albacares*) under the ICCAT minimum size regulation. I.C.C.A.T. Col. Vol. Sci. Pap. 8(1):120–183.

Bayliff, W. H. (ed.)
1990. Annual report of the Inter-American Tropical Tuna Commission 1989, 288 p.
1992. Annual report of the Inter-American Tropical Tuna Commission 1991, 271 p.

Calkins, T. P.
1965. Variation in size of yellowfin tuna within individual purse-seine sets. I.A.T.T.C. Bull. 10(8):463–524.

Cole, J. S.
1980. Synopsis of biological data on the yellowfin tuna, *Thunnus albacares* (Bonnaterre, 1788), in the Pacific Ocean. I.A.T.T.C. Special Rep. 2:71–150.

Green, R. E.
1967. Relationship of the thermocline to success of purse seining for tuna. Am. Fish. Soc., Trans. 96(2):126–130.

Greenblatt, P. R.
1979. Association of tuna with flotsam in the eastern tropical Pacific. Fish. Bull. 77(1):147–155.

Gulland, J. A.
1965. Estimation of mortality rates. Annex to Rep. Arctic Fish. Working Group, Int. Counc. Explor. Sea C.M. 1965(3), 9 p.

Hennemuth, R. C.
1957. Analysis of methods of sampling to determine the size composition of commercial landings of yellowfin tuna (*Neothunnus macropterus*) and skipjack (*Katsuwonus pelamis*). I.A.T.T.C. Bull. 2(5):174–243.

Holt, S. J.
1958. A note on the simple assessment of a proposal for mesh regultaion. I.C.N.A.F. Annual Proc. 8(4):82–83.

Jones, R.
1961. The assesment of the long term effects of changes in gear selectivity and fishing effort. Mar. Res. Scot. 1961(2), 19 p.

Joseph, J., and T. P. Calkins.
1969. Population dynamics of the skipjack tuna (*Katsuwonis pelamis*) of the eastern Pacific Ocean. I.A.T.T.C. Bull. 13(1), 273 p.

Orange, C. J., and T. P. Calkins.
1981. Geographical distribution of yellowfin and skipjack tuna catches in the eastern Pacific Ocean, and fleet and total catch statistics 1975–1978. I.A.T.T.C. Bull. 18(1):1–120.

Pope, J. G.
1972. An investigation of the accuracy of virtual population analysis using cohort analysis. Int. Comm. Northwest Atl. Fish. Res., Bull. 9:65–74.

Punsly, R. G.
1983. Estimation of the number of purse-seiner sets on tuna associated with dolphins in the eastern Pacific Ocean during 1959-1980. I.A.T.T.C. Bull. 18(3):227–299.

1987. Estimation of the relative annual abundance of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean during 1970–1985. I.A.T.T.C. Bull. 19(3):263–306.

Punsly, R. G., and R. B. Deriso.
1991. Estimation of the abundance of yellowfin tuna, *Thunnus albacares*, by age groups and regions within the eastern Pacific Ocean. I.A.T.T.C. Bull. 20(2):98–131.

Ricker, W. E.
1975. Computation and interpretation of biological statistics of fish populations. Fish. Res. Board Can., Bull. 191, 382 p.

Tomlinson, P. K., S. Tsuji, and T. P. Calkins.
1992. Length frequency estimation for yellowfin tuna. I.A.T.T.C. Bull. 20(6):357–398.

Wild, A.
1986. Growth of yellowfin tuna, *Thunnus albacares*, in the eastern Pacific Ocean based on otolith increments. I.A.T.T.C. Bull. 18(6):423–482.