Considerations of stock structure of yellowfin tuna (*Thunnus albacares*) in the Indian Ocean based on fishery data

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ABSTRACT

Yellowfin stock structure in the Indian Ocean was studied by using industrial tuna longline fishery data. Three types of test variables were used to detect stock structure, i.e., CPUE, age-specific CPUE, and coefficient of variation for size. Time-series data of test variables were compiled for six sub-areas that were arranged by dividing the whole region systematically along longitude lines every 20 degrees. Then time-series data were smoothed by moving averages, and regressed by simple models. Patterns of time-series trends were graphically and statistically compared to classify homogeneous sub-area groups. Two assumptions were (a) that homogeneous stocks exist longitudinally and overlap in adjacent waters, and (b) that test variables within homogeneous sub-area groups are equally affected, and hence patterns of the time-series trends are similar. After graphical screening for significant sub-area groups, analysis of covariance was applied to test homogeneity of regression parameters representing patterns of the time-series trends. By classifying homogeneous sub-area groups, stock structures were determined at the $P < 0.05$ and $P < 0.50$ levels. The $P < 0.50$ level was recognized as a useful criterion for 'weak' test variables since masked or vague structures at the $P < 0.05$ level were likely cleared at this level in many cases. Results of this study and past stock structure studies were reviewed and compared. It was concluded that there are two major and two minor stocks of yellowfin tuna. The two major stocks (the western and the eastern) are located at 40°–90°E and 70°–130°E respectively. The minor stocks are the far western and the far eastern stocks (the latter possibly being a part of the Pacific stock), which are located westward of 40°E and eastward of 110°E respectively. Neighboring stocks are intermingled in adjacent waters.

Key words: Yellowfin tuna, Indian Ocean, tuna longline fishery, stock structure, CPUE, age-specific CPUE

INTRODUCTION

Concrete knowledge of fish stock structure is essential for policy makers to provide persuasive planning for resource management. Without it, there is no basis on which to estimate fundamental aspects of the stock, such as MSY and quotas, since they do not refer to any particular stock. Especially for highly migratory pelagic species, such as tuna and salmon, detailed information on population structure is a prerequisite for successful international fishery management.

In this paper, the stock structure of yellowfin tuna in the Indian Ocean is studied from available fishery data. Yellowfin tuna has been a commercially important species, and recently attention has been drawn to the necessity for management of this species (IPTP/Indo-Pacific Tuna Development and Management Programme, 1990). This attention came from the following background: (a) a continuous decreasing trend of the large yellowfin resources caught by the industrial longline fisheries since the start of the exploitation in 1952; (b) recent heavy exploitation by the industrial purse seine fisheries in the western Indian Ocean; and (c) fewer research activities being conducted in the Indian Ocean than in other oceans.

Therefore, the IPTP has two plans to deal with these problems in the near future, namely, a large-scale tagging experiment and a yellowfin stock assessment workshop (IPTP, 1990). Although the tagging experiment is the best method for elucidating the stock structure, the IPTP plan covers only the western part of the Indian Ocean. Furthermore, there are no other plans for stock structure studies in the entire Indian Ocean. Therefore, this study has attempted to estimate the yellowfin stock structure in the whole Indian Ocean through the longline fishery data. Although the use of fishery data for a stock structure study is considered to be a method inferior to other, more direct and effective approaches, it was realized that this kind of study was worthwhile at present for two reasons: (a) despite the fact that almost 40 years of longline fishery data covering the entire region have been accumulated, the latest study of this type was done 20 years ago by Morita and Koto (1970); and (b) from the management standpoint, the relevant information is urgently needed and cannot wait for accurate stock structure assessments made by more direct methods.

REVIEW

In the past, stock structure studies of tuna and similar species were made using various methods such as genetic studies, including electrophoresis, morphometrics, tagging, parasitology, and fishery data. Of these, tagging is the most effective approach because it provides a direct proof of movements, and hence of the boundaries of homogeneous stocks. Morphometric, electrophoretic, and parasitological approaches are secondarily favorable methods because they can identify stocks almost directly. The use of fishery data is the least satisfactory method because the data are not intentionally collected for racial studies, and hence some assumptions need to be set in the analysis.

In the Indian Ocean, stock structure studies have been done locally (Kurogane, 1960; BOBP, 1988; Cayre and Ramcharrun, 1990; IPTP, pers. commun.) as well as globally (Kurogane and Hiyama, 1958; Morita and Koto, 1970; Yano, 1991). The global studies are briefly reviewed here. Kurogane and Hiyama (1958) analyzed morphometric data collected from six different locations in the Indian Ocean and concluded that there were three stocks, i.e., one stock in the western Indian Ocean and two stocks in the eastern Indian Ocean (one in the Andaman Sea area of the central-eastern region and the other in the Lesser Sunda area of the far-eastern region). Morita and Koto (1970) analyzed the Japanese longline fishery data (1961–1965) and concluded there was a two-stock structure with western and eastern stocks separated at the approximate boundary of 100°E longitude. Yano (1991) reported results of the tagging experiments conducted by the RV *Nippon-Maru* of the Japan Marine Fishery Resources Research Center (JAMARC) during 1980–1990, which covered a large geographical area in the Indian Ocean. Despite the substantial tagging activities by the *Nippon-Maru* in past years, only two cases of long-distance movements from the central Indian Ocean to the western region were found. In addition, three more long-distance tag recoveries (from the Seychelles to the Maldives) were recently found (Yano, pers. commun.). These five cases confirmed an exchange of fish between the central and the western Indian Ocean.

Although the structure of two or three stocks appears to be plausible, no past papers on stock assessment utilized this information; instead, assessments have assumed only one stock (Miyabe and Koido, 1985; Marsac and Hallier, 1987; Wang and Tanaka, 1988; Miyabe and Suzuki, 1991). The major reason to use a one-stock hypothesis is probably that the heterogeneous stock hypothesis is still not strongly confirmed by tagging experiments and other direct methods. Another practical reason might be that a hypothesis of one-stock structure makes the analysis easier and simpler.

From studies and experiences in the other oceans, the yellowfin stock units are longitudinally formed, and they intermingle in adjacent waters with variations depending on season, year, and environmental conditions (Kamimura and Honma, 1963; Royce, 1964).

MATERIALS AND METHODS

The industrial longline fishery data of China (Taiwan), Japan, and Korea were used. Catch and effort data from 1967–1988 for China (Taiwan), 1952–1988 for Japan, and 1975–1987 for Korea were obtained from the IPTP database; i.e., monthly and 5 degrees (latitude) by 5 degrees (longitude) basis information. Fork length data (1952–1988) collected by the Japanese longline vessels were obtained from the National Research Institute of Far Seas Fisheries, Japan Fishery Agency. They are compiled by month and 10 degrees (latitude) by 20 degrees (longitude) areas.

Instead of establishing a hypothesis of a particular stock structure, the Indian Ocean is systematically divided by six sub-areas along longitudes with boundaries at every 20 degrees; i.e., 40°, 60°, 80°, 100°, and 120° East (Fig. 1). Three types of test variables are arranged to detect the stock structure: (i) catch-per-unit-effort (CPUE) for China (Taiwan), Japan, and Korea; (ii) age-specific CPUE (age-CPUE) for age 2–4; and (iii) coefficient of variation for size (CVS). The CPUE and age-CPUE variables are frequently used in stock assessment, but the CVS is not. The major reason for using CVS is that it includes two kinds of information (mean and standard deviation of size) in one variable. Therefore, CVS is considered to be a more effective and useful test variable than the mean.

Patterns of time-series trends of these test variables

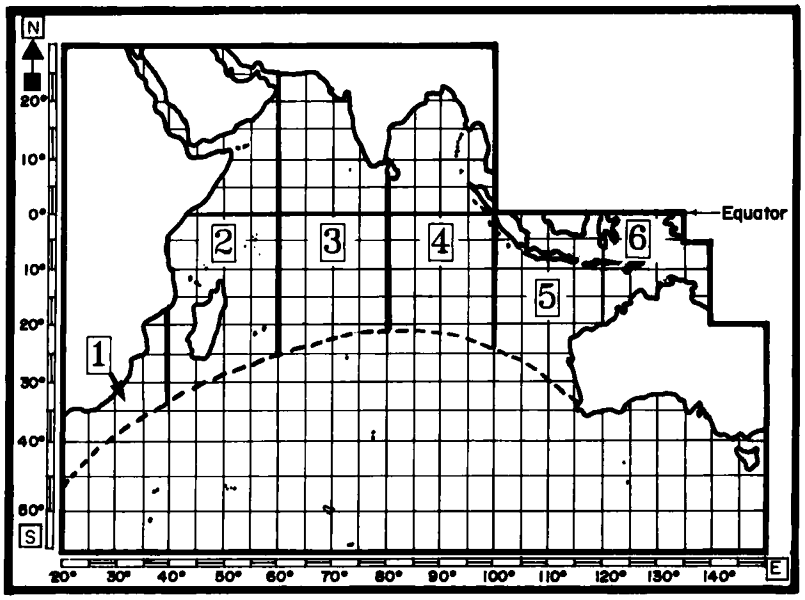


Figure 1. Six sub-areas used for the stock structure analysis of yellowfin tuna in the Indian Ocean.

Note 1: Map shows the whole area of the Indian Ocean defined by the IPTP.
2: The southern border (broken line) is an approximate boundary of the major habitat of yellowfin tuna.

among six sub-areas are graphically and statistically compared to classify homogeneous stocks. For the test variables CPUE and age-CPUE, standardized CPUE values are computed by dividing catch by effective effort for each sub-area and country. The effective effort is estimated by the Honma method (Honma, 1974).

Two major assumptions used in the analysis are (a) that homogeneous stocks exist longitudinally and intermingle in adjacent waters, and (b) that test variables within homogeneous sub-area groups are equally affected, hence patterns of time-series trends are similar within each homogeneous sub-area group. With these assumptions, an approximate population structure is determined for each test variable by grouping sub-areas forming similar patterns of time-series trends.

For the analysis of the time-series data, several steps are taken. First, a moving average is applied to time-series data to filter out and smooth noise because time-series fishery data usually contain various degrees of statistical noise caused by nature and human-related factors. In this way, intrinsic and robust time-series trends can be extracted and results of the analysis will become more reliable than those without smoothed data. However, there is one caution regarding smoothing; real information might be lost if too long a period of the average is applied. Hence, moving averages in optimal periods are arbitrarily selected for each type of test variable.

Second, patterns of smoothed time-series data are graphically and statistically compared. In the graphical (visual) comparison, sub-areas forming significantly different patterns from others are segregated and defined as different stocks. After graphical screening, the remaining sub-areas are compared by the analysis of covariance (ANCOVA). Prior to the use of ANCOVA, time-series data are regressed by simple mathematical functions such as straight line and exponential function. In the regression analysis, the last two digits of years are used as x-values; e.g., 52 for 1952, 75 for 1975, 80 for 1980, etc. The ANCOVA procedures are detailed in Zar (1984).

In this case, only the parameters representing slopes (or curvatures) are statistically examined. y-intercepts are not tested because (1) for CPUE, y-intercepts represent abundance of yellowfin resources, and hence they are not necessarily equivalent because yellowfin abundance varies in different sub-areas; and (2) for CVS (= mean size/standard deviation), mean sizes will increase when fish migrate from one sub-area to the next sub-area, hence y-intercepts will increase and are not necessarily equivalent as long as standard deviations remain the same within those sub-areas.

The initial procedure of ANCOVA tests the null hypothesis, "homogeneity of all slopes (or curvatures)." If it is not rejected, fish in all tested sub-areas are determined to be homogeneous. If the null hypothesis is rejected, then pair-wise comparisons of two slopes (curvatures) in adjacent sub-areas are conducted, i.e., comparisons between 1 vs. 2, 2 vs. 3, 3 vs. 4, 4 vs. 5, and 5 vs. 6. Then consecutive homogeneous sub-areas are pooled and classified as one independent stock. By repeating these procedures, the stock structure is determined for each test variable. For example, the stock structure for some test variable might be formed as | (1) | (2-3) | (4-5-6) |. Throughout all ANCOVA procedures, two levels of critical probability are used for decision, one for the $P < 0.05$ level and another for the $P < 0.50$ level. The $P < 0.05$ criterion is standard, but $P < 0.50$ is a less stringent level. The primary reason for using the $P < 0.50$ level is that some 'weak' or 'less effective' test variables might not be able to detect real stock structures at the $P < 0.05$ level; in such cases, it is expected that masked or vague structures at the $P < 0.05$ level might be effectively depicted at the $P < 0.50$ level. Finally, resultant structures determined by seven testing variables at two critical probability levels are compared with those of past studies and tagging experiments in the Indian Ocean to determine a final stock structure.

RESULTS

CPUE

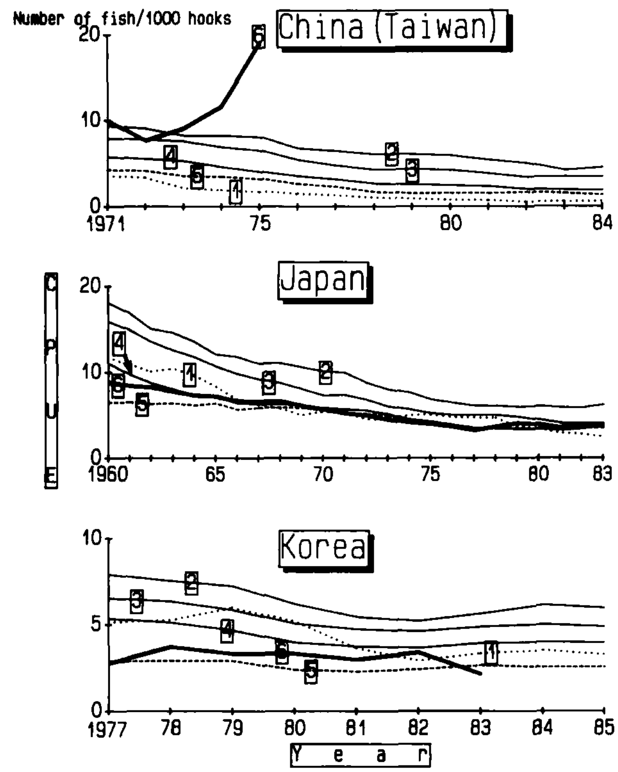
Standardized CPUE for China (Taiwan) (1967–1988), Japan (1957–1988), and Korea (1975–1987) were analyzed. Although Japanese 1952–1956 data were available, they were not used because CPUE values in those years were considered as probably too high and biased due to the starting exploitation period of virgin fishing grounds.

For the initial step of the analysis, 9 years of a moving average were arbitrarily selected to filter out and smooth noise. Figure 2 shows the smoothed time-series trends for China (Taiwan), Japan, and Korea. In the graphical comparisons, the time-series trend of sub-area 6 of China (Taiwan) showed behavior unique from the others, and thus it was classified as an independent stock. Judging from the shapes of the time-series trends, the negative exponential function CPUE = $Ae^{-B(yr)}$ was considered to be a suitable model. For fitting to the smoothed data, this model was linearized by taking the logarithm for both sides, i.e., log(CPUE) = log(A) − B(yr), where A and B were parameters representing the simple straight line. Results of the estimated regression parameters are given in Tables 1–3. Then the ANCOVA was conducted to compare curvatures (parameter B). The null hypothesis of homogeneity of all curvatures (slopes) was rejected at the $P < 0.05$ level except for Korea, for which it was rejected at the $P < 0.50$ level. Finally, pair-wise comparisons for two curvatures in adjacent sub-areas were conducted, and the results are summarized in Tables 1–3.

Age-specific CPUE (age-CPUE)

Standardized CPUE and fork length data from Japan (1957–1988) were used to estimate age-CPUE. Data

Figure 2. Smoothed time series trends of CPUE by 9 years of moving average for China (Taiwan), Japan, and Korea. Number flags correspond to sub-area numbers.



for 1952–1956 were not used for the reason previously given. Fork lengths were initially converted to age by the age-length relation (von Bertalanffy curve), which was estimated based on the information from Romanov and Korotkova (1988). The resulting equation was $L(t) = 197.3\,[1 - e^{-0.2753\,(t + 0.006877)}]$. Table 4 lists conversions between length and age. After size data were converted to age, annual percent age-compositions were computed and age-CPUE for major age groups 2, 3, and 4 were estimated by multiplying the annual CPUE by annual percent age-compositions for each sub-area. Finally, time-series data were smoothed by a moving average of 15 years (arbitrarily selected) and plotted (Fig. 3). In the graphical comparison, no sub-areas forming unique patterns were found. Then, six time-series data sets were regressed, also by the negative exponential function, and the homogeneity of curvatures was examined by the ANCOVA. Results of estimated regressions are given in Tables 5–7. The null hypothesis of homogeneity of all curvatures (parameter B) was rejected at $P < 0.05$, except for age 2, which was not rejected at $P < 0.50$. Then parameter B in adjacent sub-areas was pair-wise compared; the results are summarized in Tables 5–7.

Table 1. Summary of estimated parameters of the regression and results of analysis of covariance for test variable, CPUE of China (Taiwan).

A. Estimated parameters of the regression, CPUE = $Ae^{-B(yr)}$

Sub-area	1	2	3	4	5	6
A	122,400	673.4	1660	5438	4424	(G)
B	0.9605	0.9657	0.9548	0.09626	0.09799	(G)
n	14	14	14	14	14	5
r	0.9800	0.9827	0.9771	0.9885	0.9537	(G)

Note: (G) Not estimated because fish in sub-area 6 formed an independent stock by the graphical analysis.

B. Results of analysis of covariance

1. Homogeneity of 5 parameters of *B* was rejected. (*Pr* <0.05).
2. Results of pair-wise comparisons of parameter *B* between adjacent sub-areas are as depicted below:
   (a) *P* <0.05 level
   1 – – (*) – – 2 – – – – – 3 – – – – – – – 4 – – – – – 5 – (G) – 6
   (b) *P* <0.50 level
   1 – – (*) – – 2 – – – – – 3 – – (*) – – 4 – – – – – 5 – (G) – 6

Note: 1,2,3,4,5,6 are sub-area numbers.
(*) Homogeneity is rejected.
– – – Homogeneity is accepted.
(G) see above for explanation.

Table 2. Summary of estimated parameters of the regression and results of analysis of covariance for test variable, CPUE of Japan.

A. Estimated parameters of the regression, CPUE = $Ae^{-B(yr)}$

Sub-area	1	2	3	4	5	6
A	399.3	372.2	599.2	200.8	58.26	126.0
B	0.0599	0.0519	0.0619	0.0509	0.0349	0.0446
n	24	24	24	24	24	24
r	0.9598	0.9785	0.9897	0.9712	0.9572	0.9582

B. Results of analysis of covariance

1. Homogeneity of 6 parameters of *B* was rejected. (*Pr* <0.05).
2. Results of pair-wise comparisons of parameter *B* between adjacent sub-areas are as depicted below:
   (a) *P* <0.05 level
   1 – – – – – – 2 – – – – – – 3 – – – – – – 4 – – (*) – – 5 – – – – – – 6
   (b) *P* <0.50 level
   1 – – (*) – – 2 – – (*) – – 3 – – (*) – – 4 – – (*) – – 5 – – (*) – – 6

See Note (Table 1) on abbreviations.

Coefficient of variation for size (CVS)

Japanese fork length data (1952–1988) were analyzed. An annual coefficient of variation for size was computed by dividing the annual standard deviation of size by its mean for each sub-area. This was multiplied by 100 in order to represent CVS as a percentage of mean values. Then, time-series data were smoothed by a moving average of 15 years (arbitrarily selected) and depicted in Fig. 4. In the graphical comparison, no sub-areas forming unique patterns were found. For the regression, simple straight lines were applied because trends of six lines showed more likely linear trends. Then ANCOVA was applied. The null hypothesis of homogeneity of six slopes was rejected at the *P* <0.05

Table 3. Summary of estimated parameters of the regression and results of analysis of covariance for test variable, CPUE of Korea.

A. Estimated parameters of the regression, CPUE = $Ae^{-B(yr)}$

Sub-area	1	2	3	4	5	6
A	2535	159.0	116.3	100.6	10.34	65.57
B	0.0793	0.0398	0.0382	0.0391	0.0171	0.0383
n	9	9	9	9	9	7
r	0.8211	0.7393	0.8073	0.7734	0.5069	0.4483

B. Results of analysis of covariance

1. Homogeneity of 6 parameters of B was accepted. ($Pr < 0.05$), but rejected at $Pr < 0.50$.
2. Results of pair-wise comparisons of parameter B between adjacent sub-areas are as depicted below:
   (a) $P < 0.05$ level
   1 – – – – – – 2 – – – – – – 3 – – – – – – 4 – – – – – – 5 – – – – – – 6
   (b) $P < 0.50$ level
   1 – – (*) – – 2 – – – – – – 3 – – – – – – 4 – – – – – – 5 – – – – – – 6

See Note (Table 1) on abbreviations.

Table 4. List of age-length conversion of yellowfin tuna based on Romanov and Korotkova (1988).

Age	L: Fork length (cm)
0	$L \leq 49.9$
1	$49.9 < L \leq 85.0$
2	$85.0 < L \leq 111.8$
3	$111.8 < L \leq 132.2$
4	$132.2 < L \leq 147.7$
5	$147.7 < L \leq 159.6$
6	$159.6 < L \leq 168.6$
7	$168.6 < L \leq 175.4$
8	$175.4 < L$

level. Finally, homogeneity of two slopes in adjacent waters was tested pair-wise; the results are summarized in Table 8.

DISCUSSION AND CONCLUSIONS

Results in this study are reviewed and compared with those from past studies and tagging experiments in order to provide a concrete conclusion about the yellowfin stock structure in the Indian Ocean.

Results of this study are summarized in Fig. 5. It can be seen from this figure that each test variable forms 2–4 groups except in three cases: the CPUE (Japan, $P < 0.50$), the CPUE (Korea, $P < 0.05$), and the age-CPUE (age 2, both probability levels). Structures created by the latter three variables seem to be unrealistic, and these structures are significantly different from

Figure 3. Smoothed time-series trends of age-specific CPUE for Japanese data by 15 years of moving average for ages 2, 3, and 4. Number flags correspond to sub-area numbers.

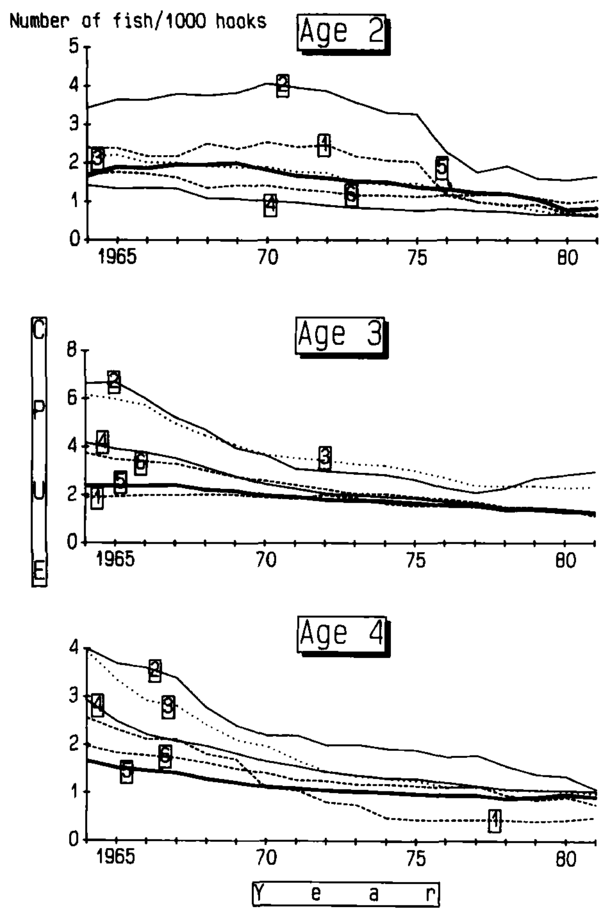


Table 5. Summary of estimated parameters of the regression and results of analysis of covariance for test variable, age-specific CPUE of Age 2.

A. Estimated parameters of the regression, CPUE = $Ae^{-B(yr)}$

Sub-area	1	2	3	4	5	6
A	130.6	183.6	265.9	35.49	48.44	57.00
B	0.0591	0.0573	0.0722	0.0504	0.0483	0.0533
n	18	18	18	18	18	18
r	0.8570	0.8365	0.9765	0.9658	0.9168	0.9785

B. Results of analysis of covariance

1. Homogeneity of 6 parameters of B was not rejected. (*Pr* <0.50).

   1 – – – – – – – 2 – – – – – – 3 – – – – – – 4 – – – – – – 5 – – – – – – 6

See Note (Table 1) on abbreviations.

Table 6. Summary of estimated parameters of the regression and results of analysis of covariance for test variable, age-specific CPUE of Age 3.

A. Estimated parameters of the regression, CPUE = $Ae^{-B(yr)}$

Sub-area	1	2	3	4	5	6
A	13.58	285.9	314.5	482.5	35.56	281.9
B	0.0286	0.0609	0.0621	0.0744	0.0411	0.0670
n	18	18	18	18	18	18
r	0.9050	0.8770	0.9815	0.9924	0.9880	0.9939

B. Results of analysis of covariance

1. Homogeneity of 6 parameters of B was rejected. (*Pr* <0.05).
2. Results of pair-wise comparisons of parameter B between adjacent sub-areas are as depicted below:
   (a) *P* <0.05 level

   1 – – (*) – – 2 – – – – – 3 – – – – – – – 4 – – (*) – – 5 – – (*) – – 6

   (b) *P* <0.50 level

   1 – – (*) – – 2 – – – – – 3 – – (*) – – 4 – – (*) – – 5 – – (*) – – 6

See Note (Table 1) on abbreviations.

Table 7. Summary of estimated parameters of the regression and results of analysis of covariance for test variable, age-specific CPUE of Age 4.

A. Estimated parameters of the regression, CPUE = $Ae^{-B(yr)}$

Sub-area	1	2	3	4	5	6
A	2535	159.0	116.3	100.6	10.34	65.57
B	0.1233	0.0673	0.0813	0.0582	0.0343	0.0503
n	18	18	18	18	18	18
r	0.9473	0.9765	0.9694	0.9786	0.9428	0.9834

B. Results of analysis of covariance

1. Homogeneity of 6 parameters of B was rejected. (*Pr* <0.05).
2. Results of pair-wise comparisons of parameter B between adjacent sub-areas are as depicted below:
   (a) *P* <0.05 level

   1 – – (*) – – 2 – – – – – – – 3 – – – – – – – 4 – – – – – – 5 – – – – – – – 6

   (b) *P* <0.50 level

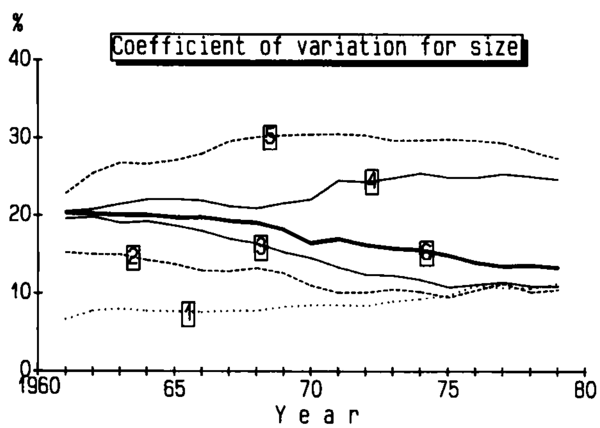
   1 – – (*) – – 2 – – – – – – – 3 – – (*) – – 4 – – (*) – – 5 – – – – – – – 6

See Note (Table 1) on abbreviations.

those using other test variables. Thus, these three particular variables are excluded from further consideration.

In the remaining structures shown in Fig. 5, the most clearly separated groups are fish in sub-areas 1 and 6. From a geographical point of view, fish in sub-area 6 seem to be part of the Pacific stock. The next most clearly defined group includes fish in sub-areas 2 and 3, which are likely to be one unit because the majority of variables show strong ties between these two sub-areas. However, the group (2-3) extends into sub-area 4 and forms one group (2-3-4) in a few cases. This implies that the core group of (2-3) is likely intermingled with the neighboring stock in the adjacent sub-area 4. Fish in the remaining sub-areas 4 and 5 are also likely one group, but they do not seem to be strongly tied because sub-area 4 is also associated at times with the (2-3) group, and sub-area 5 is associated with sub-area 6 to form a (5-6) group in some cases. Therefore, fish in sub-area (4-5) likely overlap with both neighboring groups in adjacent waters.

Figure 4. Smoothed time-series trends of coefficient of variation for size by 15 years of moving average. Number flags correspond to sub-area numbers.



Other relevant information from past studies is briefly reviewed in terms of sub-area numbers used in this study, as follows:

(a) The morphometric study of Kurogane and Hiyama (1958) implies a 3-stock structure, | (2-3) | (4) | (5) |, with strong intermingling trends in sub-area 4.

(b) The study by Morita and Koto (1970) concluded that there was a 2-stock structure of | (1-2-3-4) |

Figure 5. Estimated stock structure by test variable and critical probability level.

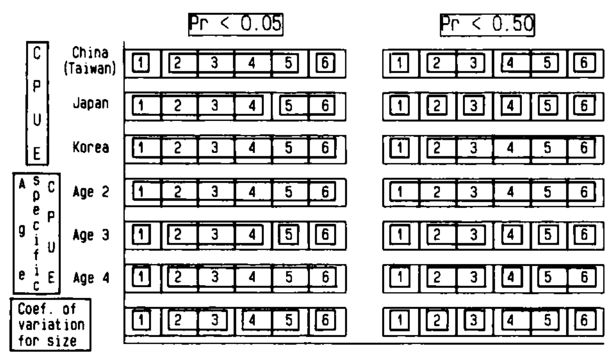


Table 8. Summary of estimated parameters of the regression and results of analysis of covariance for test variable, coefficient of variation for size.

A. Estimated parameters of the regression, CVS = A + B(yr)

Sub-area	1	2	3	4	5	6
A	−7.753	34.07	56.39	2.931	13.58	48.57
B	0.2217	−0.3515	−0.5926	0.2884	0.2141	0.4474
n	20	20	20	20	20	20
r	0.9282	0.9016	0.9741	0.8902	0.5816	0.9781

B. Results of analysis of covariance

1. Homogeneity of 6 parameters of B was rejected. ($Pr < 0.05$).
2. Results of pair-wise comparisons of parameter B between adjacent sub-areas are as depicted below:
   (a) $P < 0.05$ level

   1 – – (*) – – 2 – – – – – – – – 3 – – – – – – – 4 – – (*) – – 5 – – (*) – – 6

   (b) $P < 0.50$ level

   1 – – (*) – – 2 – – – – – – – 3 – – (*) – – 4 – – (*) – – 5 – – (*) – – 6

See Note (Table 1) on abbreviations.

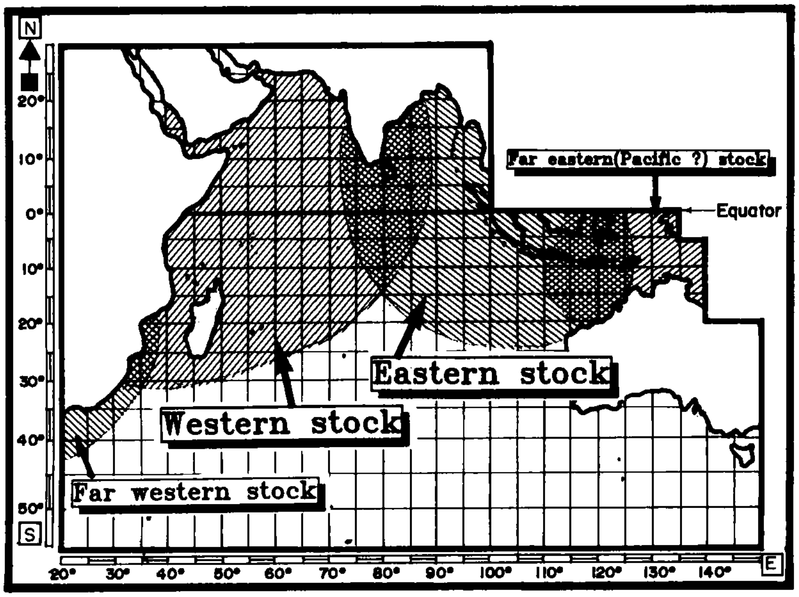


Figure 6. Estimated stock structure of yellowfin tuna in the Indian Ocean.

(5-6) |, with possible mixture of two stocks in each adjacent water mass.

(c) The JAMARC tagging experiments proved there was an exchange of fish between sub-areas 2 and 3.

(d) The IPTP tagging experiments proved there were movements from the Maldives to Sri Lanka (IPTP, pers. commun.); thus, movements from sub-areas 3 to 4 within their boundary waters are confirmed.

With this relevant information, a stock structure of two major and two minor yellowfin stocks is finally concluded, as depicted in Fig. 6. The two major stocks are the western and the eastern stock. The core western stock is located approximately in and around sub-areas 2 and 3 (40°–80°E) and partly extending into sub-area 4, while the core eastern stock is found approximately in and around sub-areas 4 and 5 (80°–120°E) and also extending to both neighboring sub-areas 3 and 6. Two minor stocks are the far western stock and the far eastern stock, which are located in and around sub-areas 1 and 6 respectively. The stock in sub-area 6 might be a part of the western Pacific stock, which also extends to the adjacent water (sub-area 5), and intermingles with the eastern stock.

This study shows that fishery data can provide a realistic picture of the yellowfin stock structure since results of this study, past studies, and tagging experiments are similar. But, as explained at the beginning of this paper, the use of fishery data is not a direct approach for racial studies, and therefore results of this study need to be confirmed in the future by more direct approaches and by biological features such as maturity and spawning.

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REFERENCES

BOBP/Bay of Bengal Programme (1988) Studies of the tuna resources in the EEZs of Maldives & Sri Lanka. *FAO/BOBP/REP* **41**:143 pp.

Cayre, P., and Ramcharrun, B. (1990) Results of the tagging operations conducted within the regional tuna project (Indian Ocean Commission) in 1988 and 1989. *FAO/IPTP/TRW/90* **61**:10 pp.

Honma, M. (1974) Estimation of overall effective fishing intensity of tuna longline. *Bull. Far Seas Fish. Res. Lab.* **10**:63–85.

Honma, M., and Suzuki, Z. (1972) Stock assessment of yellowfin tuna exploited by longline fishery in the Indian Ocean, 1959–69. *Bull. Far Seas Fish. Res. Lab.* **7**:1–25.

IPTP/Indo-Pacific Tuna Development and Management Programme (1990) Report of the expert consultation on stock assessment of tuna in the Indian Ocean, *FAO/IPTP/90/GEN* **18**:96 pp.

Kamimura, T., and Honma, M. (1963) Distribution of the yellowfin tuna in the tuna longline fishing ground of the Pacific Ocean. *Rep. of Nansei Fish. Res. Lab.* **17**:131–153.

Kurogane, K. (1960) Morphometric comparisons of the yellowfin tuna from the Banda Sea and its adjacent waters. *Records of Oceanographic Works in Japan.* **5**(20):105–119.

Kurogane, K., and Hiyama, Y. (1958) Morphometric comparison of the yellowfin tuna from six grounds in the Indian Ocean. *Bull. Jap. Soc. Sci. Fish.* **24**:487–494.

Marsac, F., and Hallier, J. P. (1987) Preliminary yield per recruit analysis of the Indian Ocean yellowfin and big-eye fisheries. *FAO/IPTP Collective Volume of Working Documents* **2**(TWS/86/33):58–72.

Miyabe, N., and Koido, T. (1985) Production model analysis of bigeye and yellowfin tuna based on Japanese longline fishery data. *FAO/IPTP Collective Volume of Working Documents* **1**(TWS/85/27):71–83.

Miyabe, N., and Suzuki, Z. (1991) Stock analysis of bigeye and yellowfin tunas based on longline fishery data. *FAO/IPTP Collective Volume of Working Documents Vol.* **4** TWS/90/59: (In press).

Morita, Y., and Koto, T. (1970) Some consideration on the population structure of yellowfin tuna in the Indian Ocean based on the longline fishery data. *Bull. Far Seas Fish. Res. Lab.* **4**:125–140.

Romanov, E. V., and Korotkova, L. P. (1988) Age and growth rates of the yellowfin tuna (*Thunnus albacares*) (Bonnaterre, 1788) (Pisces, Scombridae) in the northern part of the Indian Ocean, determined by counting the rings of vertebrae. *FAO/IPTP Collective Volume of Working Documents* **3** (TWS/88/38):68–73.

Royce, W. F. (1964) A morphometric study of yellowfin tuna *Thunnus albacores* (Bonnaterre). *Fish. Bull.* **63**:395–443.

Shung, S. H. (1973) The sexual activity of yellowfin tuna caught by the longline fishery in the Indian Ocean based on the examination of ovaries. *Bull. Far Seas Fish. Lab.* **9**:123–142.

Wang, C-H., and Tanaka, S. (1988) Development of a multicohort analysis method and its application to the Indian Ocean yellowfin tuna length composition. *Bull. Far Seas Fish. Lab.* **25**:1–72.

Yano, K. (1991) An interim analysis of the data on tuna tagging collected by R/V Nippon Maru in the Indian Ocean, 1980–90. *FAO/IPTP/SEAC/90/***17**:107–124.

Zar, J. H. (1984) Biostatistical analysis. U.S.A.: Prentice-Hall Inc., pp. 292–304.