PRELIMINARY RESOURCE ASSESSMENT OF YELLOWFIN TUNA (*THUNNUS ALBACARES*) IN THE WESTERN INDIAN OCEAN BY THE STOCK-FISHERY DYNAMIC MODEL

T. Nishida

National Research Institute of Far Seas Fisheries
5-7-1, Orido
Shimizu, Shizuoka
424 Japan

INTRODUCTION

Yellowfin tuna (*Thunnus albacares,* YFT) in the Indian Ocean has been exploited for more than 200 years (Anderson and Hafiz, 1985), while official statistics are available for some 40 years. In this region, the YFT resource has been commercially important as a protein source for both developing and developed countries. Hence, it is essential to manage and conserve YFT resources properly for future generations. To this end, an assessment of the YFT stock is presented in this paper, in order to provide fundamental information for its management.

More than 80% of the YFT catch from the Indian Ocean comes from the western part (Figure 1), so this assessment is focused on that part. In this study, the stock structure of the Indian Ocean YFT is assumed to be two major (western and eastern) stocks and two minor stocks (far western and far eastern), as depicted in Figure 2a (Nishida, 1992). Hence, the assessment is focused to the western stock. The defined boundary of the western stock is depicted in Figure 2b; it is similar to FAO Area 51 (Figure 1) except for the western boundary.

For stock assessment analyses the stock-fishery dynamic model developed by Nishida and Kishino (1991) is used. This model describes the dynamics between the YFT stock and fisheries. In the model, the catches per unit effort (CPUEs) of longline fisheries for adult fish (age2+) are standardized using the Generalised Linear Model (GLM) and used for tuning. Other input information is the catch-at-age data (ages 0, 1 and 2+) of all fisheries, which are estimated from the available size and catch data for 7 gear types. With these estimated parameters, age-specific population sizes are estimated for 1970-92. Based on the estimated trends of the population, the status of the YFT population is discussed.

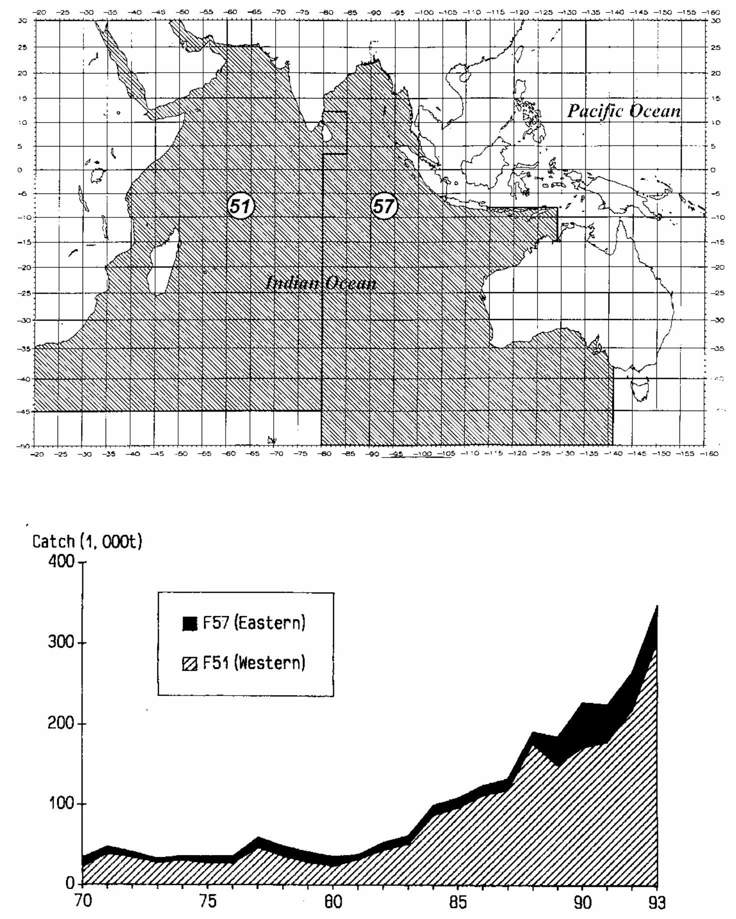
FISHERIES

In the western Indian Ocean various types of fisheries have been operated. Two different definitions are used to depict catch trends: scale of the fisheries (artisanal and industrial) and fishing depths (surface, sub-surface, and mid-water).

(1) Artisanal and industrial fisheries

If tuna fisheries are defined by their scale (small or large),

***Figure 1**. FAO statistical areas F51 and F57; Bottom: Annual catch trends in FAO statistical areas F51 (west) and F57 (east).*



they are classified into two types, artisanal (AF) and industrial fisheries. There are two major industrial fisheries, longline (LL) and purse seine (PS). Figure 3 depicts annual catch trends, in metric tons (t) and number, for AF, PS and LL. The lower panel of Figure 3 (number of fish) is based on the catch-at-age data estimated in this study (Section 4). This figure shows that the YFT catch has increased drastically since 1984, when the PS fishery started full-scale operations in the western Indian Ocean. This fishery exploits a large number of fish because it catches mainly young fish (age 0 and 1). Catches by AF and LL show gradual increases.

(2) Mid-water, sub-surface and surface fisheries

In terms of the depths of the waters fished (and hence the approximate size of the fish caught), the existing fisheries are classified into three groups: (a) surface fisheries (pole and line, troll, and PS: log school), (b) sub-surface fisheries (PS: free school, gillnet or gillnet-based combined gears), and (c) mid-water fisheries (LL and handline). Figure 4 shows the trends in annual catches for these three types of fisheries, in weight and number. The catches, in number and weight, by surface and sub-surface fisheries are almost the same throughout the 1970-92 period. The catches by mid-water fisheries in number are very small because they catch large YFT, but the catch in weight of the three types of fishery was almost the same after the PS fishery started in 1984; before then, the LL fishery dominated the YFT catches in weight.

DATA

Tables 1 to 3 summarize the types and sources of the information used in this paper for catch and effort, size and weight, and environmental data, respectively. The sources of fisheries data (catch, size, and weight) are from the Indo-Pacific Tuna Programme (IPTP) database and publications, the National Research Institute of Far Seas Fisheries (NRIFSF) and National Taiwan University, and the environmental data are from the U.S. National Oceanic and Atmospheric Administration, Hokkaido University and CSIRO/Fisheries (Australia). Appendix B lists annual catches (t) and available size data by gear type and country.

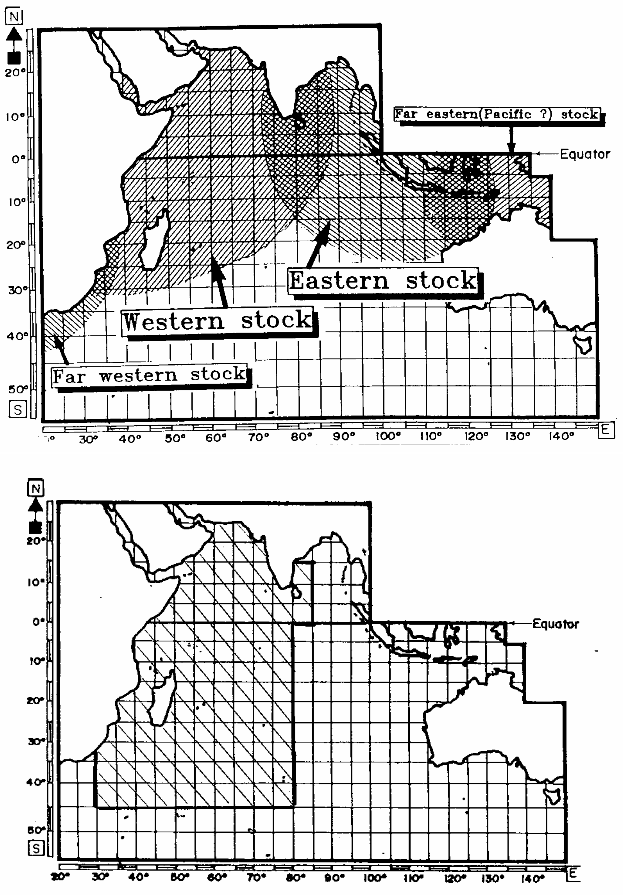
CATCH-AT-AGE

In the stock-fishery model, two types of input data are required: catch-at-age (age 0, 1 and 2+) and longline CPUE for adults (age 2+). In this section, the data processing steps required to estimate catch-at-age are described.

(1) Gear types

To estimate accurate catch-at-age data, gear-specific catch-at-age needs to be estimated because age compositions are generally different among different gear types. In this study, gear types are classified into 9 categories by depth of fishing waters, (surface, sub-surface and mid-water) (Table 4).

***Figure 2**. Assumed stock structure of YFT in the Indian Ocean (Nishida, 1992); Bottom: Area of the western India Ocean covered in this study.*



(2) Separation of PS (free and log school) catch

PS catch data in the IPTP database are not separated by type of school (free or log) except France (1991-93) and Spain (1992-93). Because age compositions between free and log schools are significantly different, it is essential to separate the PS catch into two types to estimate reliable catch-at-age data. Table 5 shows the annual catch rates of the free- and log-school catch, based on IPTP/GEN/91/20 and the IPTP database. The PS catches, by free and log school, are then calculated by multiplying these rates by total PS catch. Appendix B shows the resultant PS statistics for free and log schools, by country.

(3) Conversion from size to age

***Figure 3**. Annual catch trends for YFT in the western Indian Ocean by AF, PS and LL in tonnes (upper) and in number of fish (lower).*

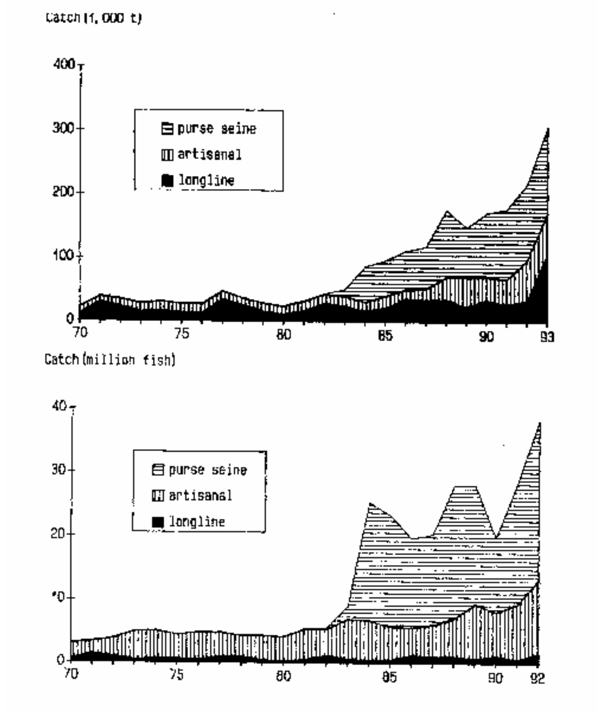
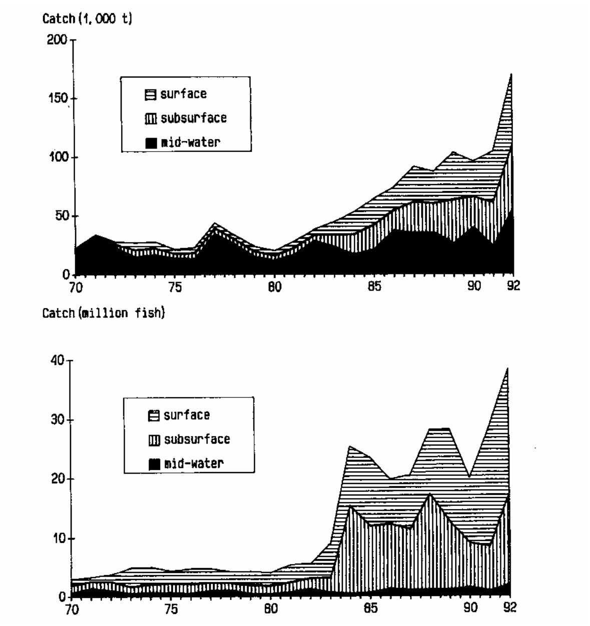


***Figure 4**. Annual catch trends for YFT in the western Indian Ocean by surface (pole and line, troll and PS: log), sub-surface (gillnet or gillnet-based combined gear, PS: free) and mid-water (LL and handline) fisheries, in tonnes (upper) and number of fish (lower).*



Size data (fork length (FL) and weight (W)) need to be converted to age to estimate the compositions for the catch-at-age. Fork-lengths (2 cm or 1 cm intervals) and weights (1 kg intervals) are converted to age using age-length and age-weight relationships. The age-length relationship is calculated based on Table 15 on page 53 of IPTP/91/GEN/20, 1991, which takes into account fast and slow growth rates. Appendix A-(1) shows in detail the steps to estimating the average age-length-weight key. Table 6 shows the results. Conversions from average length to weight are carried out using the following length-weight relationships (page 31, IPTP/91/GEN/20, 1991).

$FL <= 64$ cm: $W = 0.00005313 \times FL^{2.7536661}$
$FL > 64$ cm: $W = 0.00001585 \times FL^{3.044983}$

(4) Annual age composition

Annual age compositions are estimated by calculating annual percent age frequencies by gear type and country. If size data are not available, other available data within the same gear, country or year are substituted. Appendix B shows such substitution schemes. Those for longline fisheries are estimated by quarter and sub-area. The sub-areas are shown in Figure 5.

***Table. 1** Catch and effort data*

Type	*Countries*	*Year*	*Unit*	*Source*
Catch	Countries fishing YFT in FAO F51 area	1970-92	In tonnes, by year and country	TUNASTAT (IPTP database)
Catch and effort (longline: coarse-scale/5°x5° data)	China (Taiwan)	1970-92	Monthly and 5° x 5° Catch: ton; Effort: hooks	National Taiwan University
	Japan	1970-92	Monthly and 5° x 5° Catch: number; Effort: hooks	NRIFSF
	Korea	1975-87 & 92-93	Monthly and 5° x 5° Catch: ton; Effort hooks	IPTP database
		1988-91	Annual and 5° x 5° Catch: ton; Effort: hooks	
Catch and effort (longline: fine-scale/1°x1° data)	Japan	1971-92	Daily and 1° x 1° Catch: number	NRIFSF

Table.4 *Classification of gears*

Surface fisheries (small fish)	***Sub-surface***	***Mid-water fisheries (large fish)***
1. Pole & line	4. PS (free school)	8. Handline
2. Troll	5. Gillnet	9. LL
3. PS (log school)	Gillnet-based combined gear	
	6. Oman type (with handline)	
	7. Sri Lanka type (with troll, handline and LL)	

Table 5. **Annual PS catch rates on free & log schools, by country**

Year	*France (1)*		*Spain (2)*		*Japan (3)*		*Panama (4)*		*Mauritius (3)*		*Russia (5)*	
	free	***log***	***free***	***log***	***free***	***log***	***free***	***log***	***free***	***log***	***free***	***log***
1981	0.62	0.38	-	-	-	-	-	-	-	-	-	-
1982	0.62	0.38	-	-	-	-	-	-	-	-	-	-
1983	0.68	0.32	-	-	0.02	0.98	-	-	-	-	-	-
1984	0.81	0.19	0.84	0.16	0.02	0.98	0.82	0.18	0	1	-	-
1985	0.71	0.29	0.76	0.24	0.02	0.98	0.75	0.25	0	1	0.73	0.27
1986	0.77	0.23	0.81	0.19	0.02	0.98	0.68	0.32	0	1	0.77	0.23
1987	0.61	0.39	0.75	0.25	0.02	0.98	0.74	0.26	0	1	0.67	0.33
1988	0.83	0.17	0.80	0.20	0.02	0.98	0.86	0.14	0	1	0.82	0.18
1989	0.60	0.40	0.61	0.39	0.02	0.98	0.61	0.39	0	1	0.60	0.40
1990	0.77	0.23	0.84	0.16	0.02	0.98	0.77	0.23	0	1	0.79	0.21
1991	0.71	0.29	0.76	0.24	0.02	0.98	0.77	0.23	0	1	0.79	0.21
1992	0.64	0.36	0.68	0.32	0.02	0.98	0.77	0.23	0	1	0.79	0.21

Note: Rates for 1981-90 are based on Table 2 on page. 14 of IPTP/91/GEN/20.

1. Ivory Coast and Seychelles are assumed to have the same rate. Rates for 1991-92 are based on separate statistics available in the IPTP database.
2. Cayman Islands is assumed to be the same. 1992 rates are based on separate catch statistics available in the IPTP database; 1991 rate is the average of 1990 and 1992.
3. Based on IPTP/91/GEN/20
4. UK and Malta are assumed to have the same rate. 1991-92 rates are same as in 1990.
5. Rates are same as in 1990.

Table 2 **Size (fork length & weight) data**

Fisheries	*Gear*	*Country*	*Year*	*Interval*	*Area*	*Source*
Industrial	Longline	China (Taiwan)	1985-88	2 cm	5º x 5º	IPTP database
		Japan	1970-92	2 cm, 1 cm, or 1 kg	1º x 1º, 5º x 5º, 5ºx10º, 10ºx20	NRIFSF
		Korea	1983-85	2 cm	5º x 5º	IPTP database
	Purse seine	France	1982-91	2 cm	5º x 5º	IPTP database
		Japan	1988-89	2 cm	5º x 5º	IPTP/GEN/20
			1990		whole area	IPTP database
		Spain	1991	2 cm	5º x 5º	IPTP database
Artisanal	Pole & line	Maldives	1980-90	2 cm	Sampling sites	IPTP database
	Troll	Indonesia	1985 & 87	2 cm	Sampling sites	IPTP data record
	Gillnet	Pakistan	1987-92	2 cm	Sampling sites	IPTP database
	Gillnet based combined gear	Sri Lanka	1980-90	2 cm	Sampling sites	IPTP database
		Oman	1988	2 cm	Sampling sites	IPTP/GEN/20
	Handline	Maldives	1990	2 cm	Sampling sites	IPTP/GEN/20

Table.3 **Environmental data.**

Type	*Year*	*Unit*	*Source*
Sea-surface temperature (SST)	1979-92	in C by month and 2.5º x 2.5º area	Hokkaido University via NOAA
Southern Oscillation Index	1970-92	by month	CSIRO
West wind	1972-92	by month	CSIRO
Moon phase	1970-92	by month	CSIRO

(5) Catch-at-age matrix

Catch-at-age data (in t) by gear type and country (or country group) are estimated by multiplying the annual catch (t) by the annual age compositions. Catch-at-age data, in number, are then calculated by dividing catch-at-age (kg) by the average weight (kg) of the midpoint of each age (the weight at the end of 6 months of each age). Appendix A-(2) shows the estimation procedures used to evaluate the average weight. The basic data used in Appendix A-(2) are taken from Table 15 on page 53 of IPTP/91/GEN/ 20, 1991. In this procedure, average lengths are converted by the length-weight relationships described above; the summary results are shown in Table 7.

The results of catch-at-age (age 0, age 1 and age 2+) by fisheries type (surface, subsurface and mid-water) are depicted in Figure 6.

STANDARDIZATION OF CPUE (LONGLINE)

For the stock-fishery model analyses, longline CPUEs (age 2+) are used for input data as indices of abundance of the adult population and also for tuning the stock-fishery dynamic model. Intrinsic CPUE values are usually biased by various effects such as year, season, area, vessel characteristics (number of branches, bait and vessel size) and environmental factors, so unbiased or standardized CPUEs need to be estimated. For standardization, two different data sets were used: (a) coarse-scale (by month and 5°x5° area) data for China (Taiwan), Japan and Korea and (b) fine-scale (by day and 1°x1° area) data for Japan. According to Campbell *et. al.* (1995), CPUE standardized by fine-scale data is more reliable than CPUE standardized by coarse-scale data. However, in this paper both types of data set are used, and the results are compared in order to select the best CPUE index.

In standardizing the CPUE of longline fisheries, the log CPUE model has been widely used with the log-normal distribution model or the Gamma distribution model. However, zero CPUE due to zero catch has been problematic because it makes the log CPUE value negative infinity. To overcome this problem, the log(CPUE) model is converted to the C(catch) model (Nishida *et. al.*, 1994; Nishida and Hiramatsu, 1995).

The Poisson distribution (discrete model) is then applied to the C(catch) model. The analyses are conducted using the GLM with the GENMOD procedure available in the SAS/STAT statistical package software (version 6.09). The procedures and results for the two data sets are as follows:

(1) Coarse-scale data

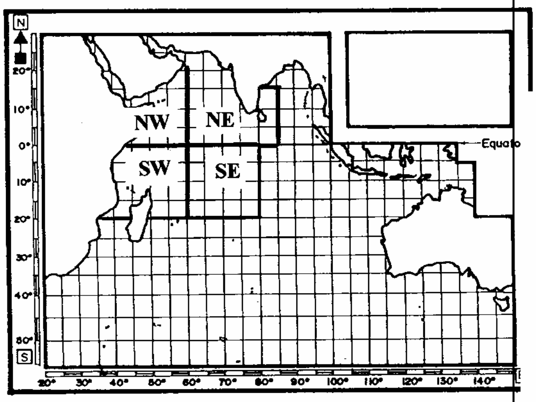
Table.6 **Average age-length and age-weight keys for YFT in the Indian Ocean (results from Appendix A-(1)).**

Age	*Age-length key (cm)*	*Age-weight key (kg)*
0	$FL < 54$	W< 3.1
1	$54 <= FL < 90$	3.1 <= W< 14.2
2	$90 <= FL < 122$	14.2 <= W< 35.7
3	122 <= FL < 143	35.7 <= W< 57.9
4	$143 <= FL < 157$	57.9 <= W< 77.0
5+	$157 <= FL$	77.0 <= W

Catch and effort data from the western Indian Ocean (Figure 2) for China (Taiwan), Korea and Japan from 1970-92 were used. For adult (age 2+) YFT, the following catch model was developed and applied using the factors of year, season (quarter), area, country and Southern Oscillation Index (SOI):

$$\log\left[E\left(CPUE_{yqac}\right)\right] = \mu_0 + Y + Q + A + C + SOI = f(\theta)$$

Figure 5. *Defined sub-areas for LL (used to standardise CPUE by GLM)*



$$E\left[CPUE_{yqac}\right] = E\left[(C/hook)_{yqa}\right] = e^{f(\theta)}$$

$$E\left[Catch_{yqac}\right] = hook_{yqa}\left[e^{f(\theta)}\right]$$

where

E : expectation

Table 8. **Summary of the GLM analyses for the coarse-scale data**

Source	*NDF*	*DDF*	*F*	*Pr>F*	*Chi-square*	*Pr>Chi*
YR	22	22E3	201.7041	.0000	4437.4910	0.0000
Q	3	22E3	423.3404	.0000	1270.0213	0.0000
AREA	3	22E3	508.9609	.0000	1526.8826	0.0000
C	2	22E3	979.7556	.0000	1959.5112	0.0000
SOI	1	22E3	17.6101	.0000	17.6101	0.0000

μ_0 : intercept

Y : factor Y (year)

Q: factor Q (quarter)

A : factor A (area) (see Figure 5)

C: country

y: y-th year

q : q-th quarter

a : a-th area

Figure 6. *Summary of estimated catch-at-age, presented by annual catch trends of surface, sub-surface and mid- water fisheries for age 0, age 1 and age 2+.*

Surface fisheries: pole & line, troll, PS: log;
Sub-surface fisheries: gillnet or combined gears, PS: free;
Mid-water fisheries: LL, handline)

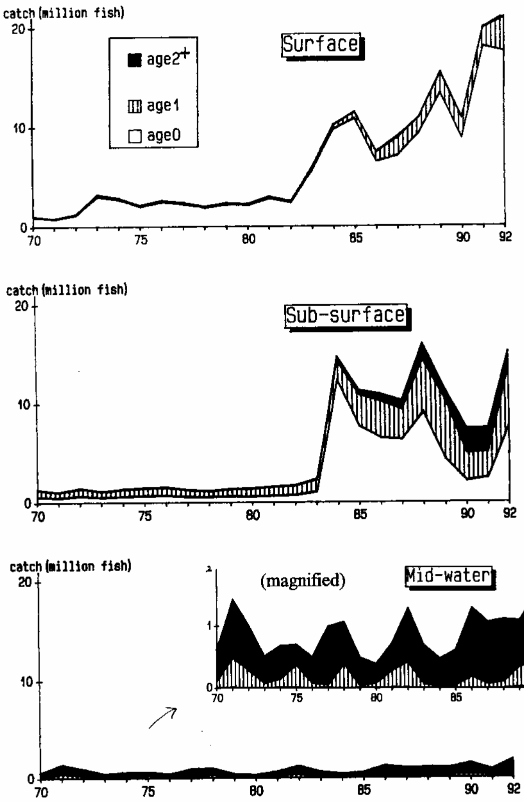


Table 9. **Summary of the GLM analyses using the fine-scale data**

Source	*NDF*	*DDF*	*F*	*Pr>F*	*Chi-square*	*Pr>Chi*
YR	13	64E3	111.5022	.0000	1449.5287	0.0000
Q	3	64E3	638.8019	.0000	1916.4056	0.0000
AREA	3	64E3	805.5203	.0000	2416.5608	0.0000
BAIT	1	64E3	29.9384	.0000	29.9384	0.0000
VS	1	64E3	34.3825	.0000	34.3825	0.0000
B	1	64E3	0.1664	.6833	0.1664	0.6833
ALB	1	64E3	21.4685	.0000	21.4685	0.0000
BIG	1	64E3	545.4079	.0000	545.4079	0.0000
SWO	1	64E3	54.7362	.0000	54.7362	0.0000
MLS	1	64E3	12.1435	.0005	12.1435	0.0005
BLM	1	64E3	181.9980	.0000	181.9980	0.0000
BUM	1	64E3	49.0702	.0000	49.0702	0.0000
SAI	1	64E3	76.9745	.0000	76.9745	0.0000
SKJ	1	64E3	1.5781	.2090	1.5781	0.2090
SHK	1	64E3	3.8895	.0486	3.8895	0.0486
MP	1	64E3	22.5354	.0000	22.5354	0.0000
SOI	1	64E3	95.5580	.0000	95.5580	0.0000
SOI2	1	64E3	178.9637	.0000	178.9637	0.0000
SST	1	64E3	0.7641	.3820	0.7641	0.3820
SST2	1	64E3	1.5525	.2128	1.5525	0.2128
WIND	1	64E3	6.7131	.0096	6.7131	0.0096
WIND2	1	64E3	3.5825	.0584	3.5825	0.0584

Table 7. *Average age-length and age-weight key at the midpoint of each age for YFT in the Indian Ocean (summary from Appendix A-(2))*

Age	***Age-length key (cm)***	***Age-weight key (kg)***
0	$FL = 41$	$W = 1.49$
1	$FL = 73$	$W = 7.40$
2	$FL = 107$	$W = 24.1$
3	$FL = 134$	$W = 47.8$
4	$FL = 151$	$W = 68.0$
5+	FL = 179	$W = 115$

c : c-th country

SOI : Southern Oscillation Index

$hook_{yqa}$: effort(hooks) is defined as an offset variable

In this model, natural logarithm is used as a link function. It is assumed that Catch_{yqac} follows the Poisson distribution, including the scale parameters. With estimated parameters, CPUEs are calculated using the following
equation:

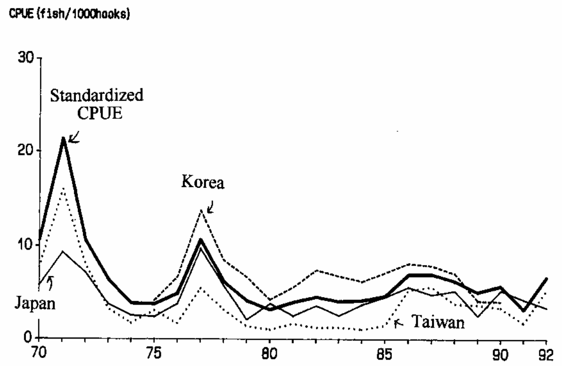
$$\hat{CPUE}_y = \left(\left(\sum_q\left(\sum_a\left(\sum_c e^{\mu+Y+Q+A+C+SOI}\right)/c\right)/a\right)/q\right)$$

Appendix C-(1) lists the computer outputs of the analyses including estimated parameters. Table 8 shows the ANOVA-type table that explains the degrees of effect of all factors. According to Table 8, all 5 factors are statistically significant. The most effective factors, in descending order of importance, are 'country', 'area', 'season', 'year' and 'SOI'. Figure 7 shows annual trends of raw CPUE for three countries and estimated CPUE.

(2) Fine-scale data

CPUE standardization for the fine-scale data is conducted similarly to that for the coarse-scale data. In this case only Japanese data are available. In addition to year, season, area, and SOI factors, 'vessel- related factors', 'bycatch factors', and 'environmental factors' can be included in the model because these factors are on a daily basis and the fine scale data are also on a daily basis. Hence, more concrete factors affecting raw CPUE can be examined than with the coarse-scale data. Because SST data (monthly averages based on 2.5° x 2.5° areas) are available only from 1979-92, the data set for the GLM were adjusted for those years. The GLM is expressed as follows:

Figure 7. *Comparison of annual CPUE trends of raw data for Korea, Japan and Taiwan, and estimated CPUE.*



$$\log\left[E\left(CPUE_{yqac}\right)\right] = \mu_0 + Y + Q + (vessel) + (bycatch) + (env.factors) = f(\theta)$$

$$E\left[CPUE_{yqac}\right] = E\left[(C/hook)_{yqa}\right] = e^{f(\theta)}$$

***Figure 8**. Annual trends of raw and standardized CPUE using fine-scale data.*

$$E\left[Catch_{yqac}\right] = hook_{yqa} * \left[e^{f(\theta)}\right]$$

where

E : expectation

μ_0 : intercept

Y : factor Y (year)

Q : factor Q (quarter)

A : factor A (area): see Figure 5.

y : y-th year

q : q-th quarter

a : a-th area

Vessel factors:

B (number of branches)

VS (vessel size),

BAIT (bait type: saury, squid, live)

Bycatch (number):

BET, ALB, SWO, MLS, BLM, BUM, SAI, SKJ, SHK

Environmental factors:

SOI (Southern Oscillation Index)

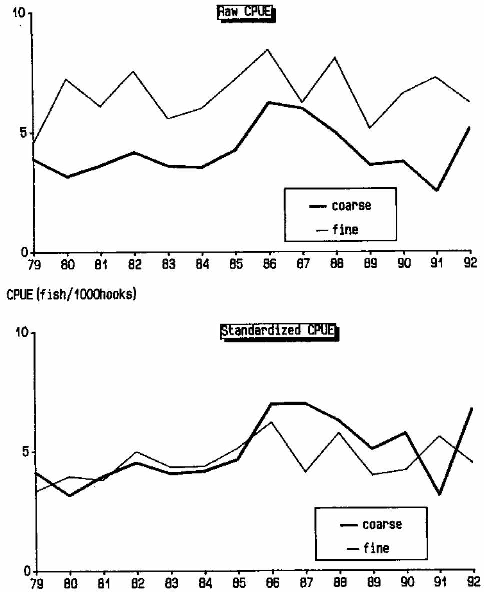
SST (sea-surface temperature),

MP (moon phase)

WWWI (westerly wind index)

$hook_{yqa}$: effort(hooks) is defined as an offset variable

***Figure 9**. Comparisons of CPUE trends from fine-scale (Japan) and coarse-scale (Korea, Japan and Taiwan combined) data: raw CPUE (upper), standardized CPUE (lower).*



In this model, natural logarithm is used as a link function. It is assumed that $Catch_{yqa}$ follows the Poisson distribution, including scale parameters. With the estimated parameters, CPUE is calculated with the following equation:

$$C\hat{PUE}_y = \left(\left(\sum_q\left(\sum_a e^{\mu+Y+Q+A+vessel+bycatch+env.factors}\right)/a\right)/q\right)$$

Appendix C-(2) lists the computer outputs of the analyses, including estimated parameters. Table 9 shows the ANOVA-type table that explains the degrees of effect of all factors. According to Table 9, all factors except branch, bycatch(skipjack) and SST2 are statistically significant. The most effective factors (F>100) are 'area', 'season', 'bycatch(bigeye)', 'bycatch(blue marlin)', 'SOI2' and 'year'. Figure 8 shows annual trends of raw and estimated CPUE. As in the case of southern bluefin tuna, the standardized CPUE has much lower values, but both trends are similar.

(3) Selection of CPUE for tuning

It has been reported that CPUE estimates based on fine-scale data are more reliable and unbiased than those based on coarse-scale data. In this study it was found that CPUE is most affected by country (Table 8) because the magnitudes of CPUE among the three countries are different, although the trends are similar (Figure 7). Hence, it is necessary to use all three countries' CPUE data. For the fine-scale CPUE, only Japanese data is used, and the fishing areas of the Japanese longline fleet have been reduced in recent years. Thus, it is difficult for the

Table 10. **Notations/terms and their meanings/definitions in the stock-fishery dynamic model.**

Notation/term	*Meaning/definition*
adult	Age 2 or older
F	Instantaneous fishing mortality for adults
m	Instantaneous natural mortality for adults
S_0, S_1, S_2+	Annual survival rate for age 0, age 1, and age2+ (adults)
P_0, P_1, P_2+	Population (in number) for age 0, age I and age 2+ (adult)
q	Catchability coefficient of longline fisheries for adult fish
E	Fishing effort of longline fisheries (millions of hooks)
$CPUE$	Adult CPUE of longline fisheries
m	Magnitude of recruitment is assumed to be m times of the adult population, *i.e.*, mP will be recruited to age 0 vulnerable size fish.
R	Recruitment to age 2+ group
t	Time (years)
C_0, C_1, C_2+	Age 0, 1 and 2+ catch (all fisheries combined)

Japanese CPUE to express real CPUE trends. The ideal would be to have fine-scale data for the two other countries. This can be seen from Figure 9, which depicts annual trends of raw and standardized CPUE by fine- and coarse-scale data: CPUE trends using the Japanese fine-scale data are different from those from coarse-scale data. Hence, standardized CPUE by coarse-scale data will be used as a tuning index in the stock-fishery dynamic model.

STOCK-FISHERY MODEL ANALYSES

The stock-fishery model (Nishida, 1991) is used to estimate population parameters. This model explains the dynamics between stock (population) and fisheries (catch) by formulating the relationship between immature and adult YFT. It is assumed that adult fish are age 2 or older and that the adult population is proportional to the adult CPUE of longline fisheries. This model is explained by Figure 10 and in the following equations. The notation and definitions are listed in Table 10.

Figure10 depicts the mechanism of the model. $P_{2+}(t)$ (adult population in year t) is simply the sum of A and B. A is the recruitment to the adult group, which comes from the cohort of year *(t-2)*; B is the surviving adults (age 3+) from year *(t-1)*. This mechanism in Figure 10 is expressed as follows:

$$\hat{P}_{2+}(t) = \hat{A} + \hat{B} \qquad (1)$$

where,

$$\hat{A} = \left(\left\{\hat{m}\hat{P}_{2+}(t-2) - C_0(t-1)\right\}\hat{S}_0 - C_1(t)\right)\hat{S}_1 \qquad (2)$$

$$\hat{B} = \left(\hat{P}_{2+}(t-1) - C_{2+}(t-1)\right)\hat{S}_{2+} \qquad (3)$$

By assuming $P_{2+}(t)=CPUE(t)/q$ and substituting it into equations (1)-(3), these equations become:

$$CPUE(t) = \left(\hat{A} + \hat{B}\right)(t)\hat{q} \qquad (1)'$$

$$\hat{A} = \left[\left\{\hat{m}CPUE(t-2) - C_0(t-1)\right\}\hat{S}_0 - C_1(t)\right]\hat{S}_1 \qquad (2)'$$

$$\hat{B} = \left\{CPUE(t-1)\hat{q} - C_{2+}(t-1)\right\}\hat{S}_{2+} \qquad (3)'$$

In these relationships, five parameters (S_0, S_1, S_2, m and q) need to be estimated. To estimate parameters, the nonlinear least-squares method is applied to evaluate optimum parameters when the sum of squares (SS) of equation (1)' is minimized:

$$SS = \sum\left\{(A+B)(t)*q - CPUE(t)\right\}^2 \qquad (4)$$

From equations (1)'-(3)', six input data sets need to be prepared: *CPUE(t-2), CPUE(t-1), CPUE(t), C0(t-2), C1(t-1)* and *C2(t-1)*. Table 11 lists the input data.

To avoid the problem of colinearity, S_2+ and q are

***Figure 10**. Mechanism of the stock-fishery dynamic model:*
$P_2+(t) = A+B$

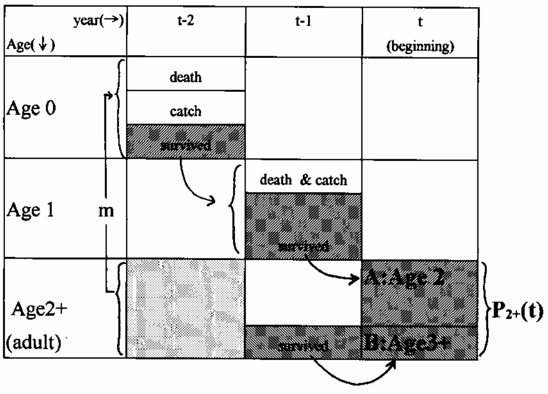
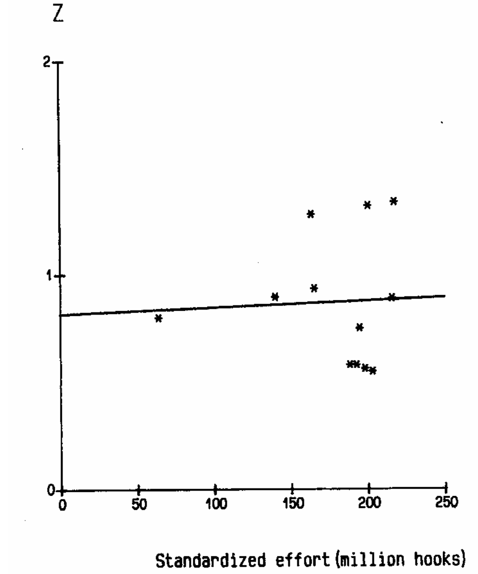


Figure 11. *Simple regression of Z vs. standardized effort (in million hooks). Z is estimated by Heincke's method. Because Z = qE+M, q= 0.322 x 10^{-9} hooks and M = -0.8164, hence S_2+ = exp(-0.8164) = 0.4420 is the estimated value.*



estimated separately, using the method developed by Heincke (1913), because of experience in a previous study (Nishida 1991).

(1) Heincke's method (estimation of S_{2+} and q)

According to Heincke (1913), *Z* (instantaneous total mortality) is estimated by:

$$Z(t) = -\log\left\{\sum_{i=1}^{\infty} N(t+1,i) / \sum_{i=1}^{\infty} N(t+1,i)\right\} \tag{5}$$

For the longline YFT data, adult population size is assumed to be proportional to CPUE (age 2+), thus equation (5) will be represented by:

$$\begin{aligned} Z(t) &= -\log\left\{\sum_{i=1}^{\infty} CPUE(t+1,i) / \sum_{i=1}^{\infty} CPUE(t+1,i)\right\} \\ &= -\log\left[\frac{CPUE(t+1,age1)+\cdots CPUE(t+1,age5+)}{CPUE(t,age0)+CPUE(t,age1)+\cdots CPUE(t,age5+)}\right] \end{aligned} \tag{6}$$

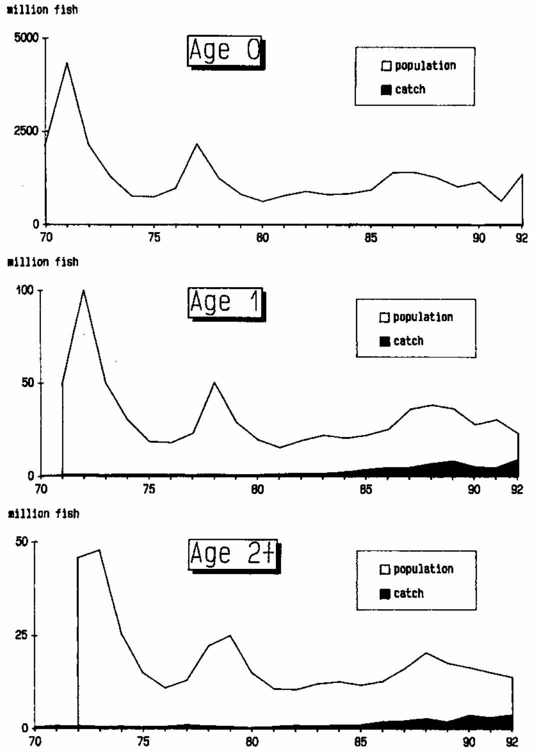
Because the longline fisheries exploit adult YFT, CPUE (age 0 and age 1) need to be excluded. Equation (6) then becomes:

$$\hat{Z}(t) = -\log\left(\frac{\sum_{i=3}^{5+} CPUE(t+1,i)}{\sum_{2}^{5+} CPUE(t,i)}\right)$$

Because Korean effort data for 1970-1975 are not available, these data and their outliers are not used to estimate Z. With the

following relation,

Figure13*. Annual trend of estimated population size and catch, in number, for age-0 (upper), age-1 (middle) and age-2+ fish (lower).*



$$\hat{Z} = \hat{F} + \hat{M} = q * E + M$$

q and M are estimated by a simple regression of Z *vs.* E (effort:hooks). Figure 11 shows the plot of Z *vs.* E (millions of hooks). Effort (Japan, Korea and Taiwan combined) is standardized by (Catch)/(standardized CPUE from GLM).

(2) Estimation of other parameters

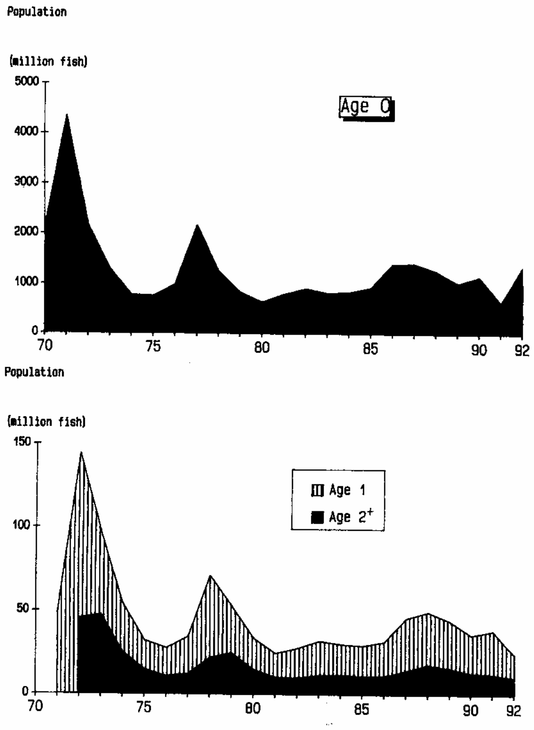
Using estimated S_2+ and q, other parameters (S_0, S_1 and m) are estimated using equation (4). The non-linear least-squares method is used that searches for the parameter values which minimise the *SS* value of the equation(4). The NLIN PROC procedure available in SAS/STAT for workstations (HP9000/735) is used for the parameter search. The estimated parameters are as follows:

$$S_0 = 0.02287 (M_0 = 1.475), S_1 = 0.3381 (M_1 = 1.084), m = 65.5$$

(3) Estimation of population size

Using estimated parameters, the population sizes of age 0, 1 and 2+ fish were evaluated. Figure 12 shows the trend in annual population sizes for age-0, age-1 and age-2+ fish. Figure 13 depicts annual trends in population size and also catch for age-0, age-1 and age-2+ fish.

***Figure 12**. Annual trend of estimated population size, in number, for age-0 ((upper) and age-1 and age-2+ fish (lower).*



DISCUSSION

Data

It is an advantage to have the detailed fisheries statistics collected by IPTP for stock assessment. Although IPTP's efforts are much appreciated, if the following points were improved, more reliable and accurate assessments could be made.

- Separation of historical PS catch/size into free- and log-school categories.
- Size-frequency data for all types of fisheries need to be collected, especially from the fisheries that recorded large catches in recent years, such as those in Yemen, Oman, and Iran (gillnet), to improve the accuracy of the catch-at-age matrices.
- Complete historical catch/effort data, by 5° x 5° area, for the Taiwanese and Korean fleets.
- Although it might be difficult, fine-scale data need to be collected from longline nations so that more accurate CPUE standardization can be carried out.
- Unknown LL catches need to be specified.

Catch-at-age

Table 11. **Input data for the stock-fishery dynamic model.**

Year	*CPUE (t)*	*CPUE (t-1)*	*CPUE (t-2)*	*Age_0(t-2)*	*Age_1(t-1)*	*Age_2(t-1)*
70	10.6034	-	-	-	-	-
71	21.4263	10.6034	-	-	0.84900	0.61552
72	10.6751	21.4263	10.6034	1.6359	1.07941	1.02455
73	6.4244	10.6751	21.4263	1.3234	1.10681	0.83146
74	3.8594	6.4244	10.6751	1.9178	0.86467	0.52486
75	3.7806	3.8594	6.4244	3.6157	1.03127	0.65032
76	4.9144	3.7806	3.8594	3.4114	1.27994	0.44645
77	10.7355	4.9144	3.7806	2.7822	1.04238	0.53879
78	6.2097	10.7355	4.9144	3.2710	0.86165	1.05086
79	4.1435	6.2097	10.7355	2.9220	1.10407	0.75124
80	3.1816	4.1435	6.2097	2.5024	0.88982	0.56264
81	3.9659	3.1816	4.1435	2.9168	1.01461	0.37094
82	4.5368	3.9659	3.1816	2.7842	1.36923	0.53416
83	4.0719	4.5368	3.9659	3.5795	1.52410	0.99002
84	4.1690	4.0719	4.5368	3.1875	1.64084	0.81237
85	4.6621	4.1690	4.0719	6.7184	2.36188	1.02494
86	6.9519	4.6621	4.1690	22.0536	3.82174	1.11199
87	6.9909	6.9519	4.6621	18.5590	4.81262	1.95027
88	6.2686	6.9909	6.9519	13.0854	4.82920	2.13673
89	5.0744	6.2686	6.9909	13.5136	6.90929	2.80236
90	5.7329	5.0744	6.2686	18.4724	8.35571	1.95065
91	3.1784	5.7329	5.0744	17.8768	5.27360	3.70138
92	6.7196	3.1784	5.7329	11.0404	-	-

Because complete annual size data are not always available, various substitutions were attempted as shown in Appendix B. In addition, nine different gear groups were used to estimate accurate catch-at-age matrices. Because each gear group has similar age compositions, estimated size-at-age data are probably realistic. As mentioned previously, more extensive size-data collection, covering all types of gear, is essential for the age-structure based stock assessment. From the estimated catch-at-age matrix, a recent sharp increase of catch for all types of gears can be clearly observed. In particular, a considerable amount of age-0 and age-1 fish have been exploited since 1984 by surface and sub-surface fisheries.

CPUE standardization

Problems with zero CPUE were resolved by converting the log CPUE to the C(catch) model and by applying the Poisson distribution model in the GLM analyses.

In the coarse-scale standardization, magnitudes of raw CPUE are generally different among the three countries, although the trends are similar. It is assumed that the Korean CPUE is more realistic because Korean LL mainly target YFT, while Japanese LL target both bigeye and YFT and Taiwanese LL focuses more on albacore. It is assumed that these different targeting strategies account for the differences in catchability among the three countries. Therefore, CPUE values for Korea appear higher than those of Japan and Taiwan. CPUE values for Japan are higher than those of Taiwan because Taiwan operates in the higher latitudes for albacore, and thus catches less YFT. This method is therefore optimum for standardizing the CPUEs of all three countries. As a result, the standardized CPUE series fall in the middle of CPUE series of the three countries.

It has been reported that CPUEs standardized by fine-scale data are more reliable and unbiased than those standardized by coarse-scale data. However, in this paper CPUE series standardized by the coarse-scale data are used for the stock-fishery dynamic model for the following two reasons: (a) only Japanese data are used for the fine-scale CPUE, and the fishing grounds of the Japanese longline fisheries have been reduced in recent years. Thus, it is probably difficult for the Japanese CPUE to express realistic CPUE trends. Ideally, fine-scale data for the two other countries would be available. (b) In this study, it was found that CPUE is significantly affected by country (Tables 8 and 9). Hence, it is necessary to use all three countries' CPUE series standardized by the coarse-scale data.

Factors affecting CPUE

The factor most affecting raw CPUE is 'country' (in the case of coarse-scale data), followed by 'area' and 'season' (for both fine- and coarse-scale data). The 'area' and 'season' effects are understood from the fact that YFT longline fisheries have fishing seasons by area, and thus change fishing grounds by season. For the fine-scale data, it was found that bycatch (bigeye and black marlin) significantly affect raw CPUE for YFT. This is because

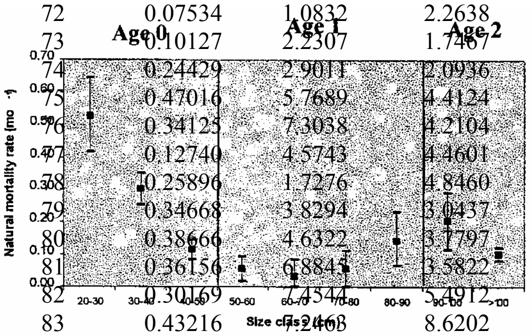


***Figure 14.** Estimated natural mortality rates of YFT, by size class (after SPC, 1995).*

***Table 12.** Exploitation rates (%) by age group.*

Year	*Age 0*	*Age 1*	*Age 2+*
72	0.07534	1.0832	2.2638
73	0.10127	2.2307	1.7467
74	0.24429	2.9011	2.0936
75	0.47016	5.7689	4.4124
76	0.34125	7.3038	4.2104
77	0.12740	4.5743	4.4601
78	0.25896	1.7276	4.8460
79	0.34668	3.8294	3.0437
80	0.38666	4.6322	3.1797
81	0.36156	6.8845	3.5822
82	0.30169	7.4544	5.4912
83	0.43216	7.2463	8.6202
84	0.37587	8.7328	6.8922
85	0.70843	12.5031	9.4693
86	1.55952	17.9726	10.1065
87	1.30508	15.0198	13.6929
88	1.02620	14.9912	11.9689
89	1.30919	24.0408	17.6012
90	1.58404	36.0193	15.0105
91	2.76500	19.9624	30.1082
92	0.80771	33.9750	29.8848

bigeye is caught in the deeper waters, hence when deep longlines are used, YFT catch (CPUE) becomes lower. Thus, it is likely that the relationship between YFT and bigeye catch (CPUE) is negatively proportional. The relationship with black marlin is under investigation.

It was also found that environmental factors do not affect raw CPUE to a large degree except SOI, which is unlike the case with southern bluefin tuna. This is because tropical environments are more or less constant and steady, thus it is likely that CPUE is generally less sensitive to SST and wind. It was found that moon phase is also not significantly related to YFT catch (CPUE).

Heincke's method and estimation of q & M_{2+}

Heincke's method assumes that the CPUE data utilized applies to fully-exploited age classes. However, in this analysis data for age-2 or older fish are used, although not all age-2 fish are fully exploited by longline fisheries. Hence, it is considered that the original data set includes some degree of uncertainty. Unreliable data sets were therefore excluded before and after Heincke's method was applied, and also during the regression analyses for $Z=qE+M$, *i.e.*, data sets including negative Z, data sets with increasing cohort (CPUE) and outliers. Upon removing the unrealistic data, reasonable parameters (q and M_{2+}) are estimated by a simple regression.

Stock-fishery dynamic model

Because of problems of uncertain quality of the data and under-reporting data in earlier years (1970s), parameters were not easily searched. Convergence was not obtained in the initial parameter search, and could be obtained when only new data from 1980-92 were used. However, local convergence was frequently obtained. To avoid estimating fault parameters in local minimum points, the following constraints were set for each parameter: $0<S_0<0.2$, $0<S_1<0.4$ and $0<m<100$. Reasonable parameter values could then be found. Nishida (1991) reported the same situation, *i.e.*, if newer data sets are used, less standard errors (SE) are obtained, and thus better fits for the model. Hence, in the Indian Ocean YFT stock assessment, it is suggested that the new data (post-1980) need to be used unless the quality of the pre-1980 data is significantly improved. This will also reduce the problem of heterogeneity of catchability between the old and new fishing periods.

Because this model is not based on the logistic population growth model, MSY is not estimated. However, it is considered that it can express realistic dynamics because no equilibrium conditions are required. Hence, once parameters are estimated, desired population levels can be set by controlling the effort.

Population size

The estimates of the population of age-0 (20-50 cm) fish are high, ranging from 0.6 to 4.2 billion fish, while the population estimates for age-1 and age-2+ fish are reasonable, ranging from 10 to 100 million fish. Such a large age-0 population seems unrealistic, because 65 times the adult population would be recruited as age-0 fish. The estimated survival rate for age-0 fish is 0.023, but natural mortality rates differ greatly within age 0, *i.e.*, M may be much higher for smaller fish and lower for large fish, as depicted in Figure 14 (Hampton, 1995). Thus, the actual population of large age-0 fish is much smaller, and a majority of the age-0 population consists of smaller fish (< 20 cm). If this is so, age-0 populations based on two or three size groups need to be estimated for more meaningful and realistic assessment in the future.

Wang and Tanaka (1988) estimated an adult population of about 5 million for 1977, and Nishida (1991) estimated about 4 million for the same year, while in this study the estimate was 10 million fish. The difference is because the first two studies used data up to 1988, but since that year catches in all fisheries (LL, PS and AF) have increased considerably. In particular, the LL and PS catches have more than doubled in the last 10 years. Similarly, after the PS fishery started, the recorded PS catch has been twice or three times the MSY level estimated by production models using LL data only (Marcille, 1986). This implies that when higher catches are recorded, it is likely that a larger population will be estimated, because the parameters probably tend to be affected by the higher level of catch. It is therefore necessary to monitor population levels frequently to see if the estimations have stabilized and become robust whenever a new data set is compiled. Only in this way is it possible to confirm that population assessments are robust and accurate.

Exploitation rates

Table 12 shows exploitation rates for each age group, calculated using estimated parameters. It is likely that age-0 YFT can be exploited by surface and sub-surface fisheries as much as possible in the current situation because a large number of fish are expected to be recruited every year; exploitation rates in recent years were 1.0-2.8%. However, the mortality rates are different by size within the age-0 group, as discussed above. Hence, size-specific population assessments for age-0 fish need to be investigated because the population of large age-0 fish (40-50 cm) might be much smaller and the exploitation rates might be much higher. Caution is needed at this point. Since the PS fishery started in 1985 the exploitation rates for age-1 fish have been more than 10%, and jumped to 20-36% in the 1990s. Caution is also needed for the age-1 catch, especially by sub-surface fisheries (PS: free school and gillnet), because of these recent high exploitation rates. For age-2+ fish, after 1986 the exploitation rate has been more than 10%, and in recent years has jumped to the 20-30% level. Hence, as for age 1, prudent catch levels need to be observed in mid-water fisheries (LL and handline).

ACKNOWLEDGMENTS

The author sincerely thanks Mr. D. Ardill (IPTP), who provided a large quantity of the YFT fisheries data used in this paper and also helped promptly with a number of questions. Prof. H. Kishino (Tokyo University) and Dr. K. Hiramatsu (NRIFSF) suggested constructive ideas to improve this paper. Prof. S. Saitoh (Hokkaido University) processed SST data and Dr. R. Campbell (CSIRO) provided other environmental data. Their kind contributions are much appreciated.

REFERENCES

ANDERSON, R. C., AND A. HAFIZ (1985) The status of Maldivian tuna stocks: analyses of catch and effort data and estimation of maximum sustainable yields. Marine Research Section, Ministry of Fisheries, Maldives: 21pp.

CAMPBELL, R., G. TUCK AND T. NISHIDA (1995) Indices of abundance for southern bluefin tuna from analyses of fine-scale catch and effort data (SBFWS/95/14):65 pp.

HEINCKE, F. (1913) Investigation on the plaice. General report 1. The plaice fishery and protective regulations. Part I. Rapp.P.-V.Reun.-CIEM, 17A, 153 pp.

IPTP (1991) Report of the workshop on stock assessment of yellowfin tuna in the Indian Ocean (IPTP/91/GEN/20):90pp.

IPTP (1994) Tuna catches for the Indian Ocean and western Pacific adjacent to Southeast Asia (TunaStat PC) with 3.5 inch diskette: 26pp.

MARCILLE, J. (1986) Interaction between longline and surface fisheries for yellowfin tuna (IPTP/TWS/85/35):217-229

NISHIDA, T. (1991) Some consideration on stock structure of yellowfin tuna (Thunnus albacares) in the Indian Ocean based on fishery data, Fisheries Oceanography, 1(2):143-152

NISHIDA, T. (1992) Development of the stock-fishery dynamic model for yellowfin tuna (Thunnus albacares) in the Indian Ocean, Bull. Japan. Soc. Fish. Oceangr. 56(3): 263-270

NISHIDA, T. , Y. ISHIZUKA AND H. KISHINO (1994) Estimation of catch rate of Japanese longline fisheries for southern bluefin tuna (*Thunnus maccoyii*) (SBFWS/94/11): 30pp.

NISHIDA, T. AND K. HIRAMATSU (1995) Estimation of catch rate indices of Japanese longline fisheries for southern bluefin tuna (Thunnus maccoyii) (SBFWS/95/16):30pp.

SAS INSTITUTE (1993) The GENMOD procedure, SAS technical report (P-243):88 pp.

SPC (1995) Oceanic fisheries programme. Work programme review (1994-95) and work plan (1995-96), Working paper 5 (Eighth standing committee on tuna and billfish):44 pp.

WANG, C. H. AND S. TANAKA (1988) Development of a multi-cohort analysis method and its application to the Indian Ocean yellowfin tuna length composition. Bull. Far. Seas Fish. Lab., 25:72 pp.

Appendix A: *Age-length-weight keys*

To state average age-length-weight keys at the end and middle of each age, Table 15 (IPTP/GEN/20) is used, which considers slow and fast growth. Weight is computed by the length-weight relation (see p.9). Steps are shown in the tables below.

(1) Estimation of the average age-length-weight key at the end of each age.

unit: size (cm) and weight (kg)

Age	*0*		*1*		*2*		*3*		*4*		*5*	
Growth type	*slow*	*fast*	*slow*	*fast*	*slow*	*fast*	*slow*	*fast*	*slow*	*fast*	*slow*	*fast*
Size range	30-61	44-80	62-105	81-113	106-135	114-134	136-153	135-149	154-165	150-158	166-	159-
Average size	45.5	62.0	83.5	97.0	120.5	124.0	144.5	142.0	159.5	154.0		
Average size of ages	54		90		122		143		157			
Average weight of ages	3.1		14.1		35.7		57.9		77.0			

(2) Estimation of the average age-length-weight key at the middle of each age.

unit: size (cm) and weight (kg)

Age	*0*		*1*		*2*		*3*		*4*		*5*	
Growth type	*slow*	*fast*	*slow*	*fast*	*slow*	*fast*	*slow*	*fast*	*slow*	*fast*	*slow*	*fast*
Size range	30-49	25-61	50-81	62-98	82-123	98-125	124-145	126-145	146-159	143-155	160-200	156-200
Average size	39.5	43.0	65.5	80.0	102.5	111.5	134.5	134.0	152.5	149.0	180-	178-
Average size of ages	41		73		107		134		151		179	
Average weight of ages	1.49		7.40		24.1		47.8		68.0		114.5	

Appendix B: *Catch and available size data by gear type and country.*

(Substitution scheme of the size data are indicated)

Pole & Line

Catch (t)

	Madagascar		*Maldives*		*Mozambique*		*Seychelles*		*Sri Lanka*	
Year	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*
1970	0		1,799	(1)	0		0		0	
1971	0		1,081	(1)	0		0		0	
1972	0		1,940	(1)	0		0		0	
1973	550	(1)	5,234	(1)	0		0		0	
1974	1,160	(1)	3,868	(1)	0		0		0	
1975	180	(1)	3,512	(1)	0		0		0	
1976	0		4,481	(1)	0		0		0	
1977	0		4,123	(1)	0		0		0	
1978	0		3,214	(1)	0		0		0	
1979	0		3,692	(1)	0		0		0	
1980	0		3,647	(A)(2)	0		0	0	0	
1981	0		4,740	(A)(2)	0		363	(1)	0	
1982	0		3,770	(A)(2)	0		*55*	(1)	418	(1)
1983	0		5,984	(A)	15	(1)	0	0	452	(1)
1984	0		6,893	(A)	11	(1)	0	0	258	(1)
1985	0		5,797	(A)	15	(1)	0	0	27	(1)
1986	0		5,200	(A)	0		0	0	2	(1)
1987	0		6,531	(A)	0		0	0	2	(1)
1988	0		6,378	(A)	0		0	0	2	(1)
1989	0		5,831	(A)	0		0	0	1	(1)
1990	0		5,230	(A)	0		0	0	0	
1991	0		7,654	(1)	0		0	0	0	
1992	0		8,414	(1)	0		0	0	0	

Notes:

(A): Size (fork length) data are available, which are used to estimate annual age composition.

(1): Average percent size frequency distributions of Maldives (1983-90) are substituted to estimate annual age composition.

(2): Percent length frequency distributions for 1980-82 (based on the IPTP database) are identical.

Appendix B *(.. Continued)*

Troll

Catch (t)

Year	*Comoros* *Catch*	*Size*	*France* *Catch*	*Size*	*Maldives* *Catch*	*Size*	*Mauritius* *Catch*	*Size*	*Seychelles* *Catch*	*Size*
1970	0		79	(1)	190	(1)	0		0	
1971	0		395	(1)	146	(1)	0		0	
1972	0		395	(1)	136	(1)	0		0	
1973	0		316	(1)	241	(1)	0		0	
1974	0		381	(1)	260	(1)	0		0	
1975	0		284	(1)	262	(1)	0		0	
1976	0		303	(1)	410	(1)	0		0	
1977	0		255	(1)	350	(1)	0		0	
1978	0		352	(1)	370	(1)	0		0	
1979	0		312	(1)	597	(1)	0		0	
1980	0		260	(1)	582	(1)	0		0	
1981	0		244	(1)	544	(1)	0		0	
1982	0		190	(1)	234	(1)	0		0	
1983	0		183	(1)	257	(1)	0		0	
1984	0		174	(1)	229	(1)	50	(1)	0	
1985	0		144	(1)	242	(1)	0		7	(1)
1986	0		151	(1)	121	(1)	0		4	(1)
1987	0		170	(1)	137	(1)	0		3	(1)
1988	0		209	(1)	154	(1)	0		1	(1)
1989	1,206	(1)	198	(1)	245	(1)	0		0	
1990	1,206	(1)	198	(1)	50	(1)	0		1	(1)
1991	1,206	(1)	244	(1)	55	(1)	0		1	(1)
1992	3,412	(1)	317	(1)	278	(1)	0		0	

Notes:

(1): Indonesian size (fork length) data (1985 and 1987) are substituted to estimate annual age composition.

***Appendix B** (.. Continued)*

PS (log school)

Catch (t)

	France (1)		*Spain (2)*		*Japan*		*Mauritius*		*Panama (3)*		*Russia*	
Year	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*
1970	0		0		0		0		0		0	
1971	0		0		0		0		0		0	
1972	0		0		0		0		0		0	
1973	0		0		0		0		0		0	
1974	0		0		0		0		0		0	
1975	0		0		0		0		0		0	
1976	0		0		0		0		0		0	
1977	0		0		0		0		0		0	
1978	0		0		0		0		0		0	
1979	0		0		0		0		0		0	
1980	0		0		0		0		0		0	
1981	98	(4)	0		0		0		0		0	
1982	376	(A)	0		0		0		0		0	
1983	3,132	(A)	,0		165	(6)	1,057	(6)	0		0	
1984	7,391	(A)	2,247	(6)	161	(6)	1,234	(6)	454	(6)	0	
1985	10,274	(A)	3,984	(6)	75	(6)	914	(6)	1,094	(6)	183	(6)
1986	8,357	(A)	3,273	(6)	160	(6)	661	(6)	1,424	(6)	643	(6)
1987	14,330	(A)	5,134	(6)	154	(6)	1,597	(6)	981	(6)	1,148	(6)
1988	9,342	(A)	8,616	(6)	356	A)(7)	1,231	(6)	493	(6)	732	(6)
1989	15,368	(A)	13,278	(6)	883	A)(7)	1,679	(6)	755	(6)	1,182	(6)
1990	10,285	(A)	6,030	(6)	2,973	(6)	1,357	(6)	3,037	(6)	516	(6)
1991	12,209	(A)	10,998	(6)	5,053	(6)	2,621	(6)	3,164	(6)	650	(6)
1992	19,451	(5)	11,667	(A)	1,437	(A)	2,130	(5)	1,901	(5)	786	(5)

Notes:

(A): Available annual size (fork length) data are used to estimate annual age composition.

(1): Ivory Coast and Seychelles are included.

(2): Malta and UK are included.

(3): Cayman Island is included.

(4): France 1982 size data are substituted to estimate 1981 age composition.

(5): Spain 1992 size data are substituted to estimate 1992 age composition.

(6): Annual France size (fork length) data are substituted for each year to estimate annual age composition.

(7): Japan (1988-89 pooled) size (fork length) data are available in Tuna Fisheries Development and Management in the Indian Ocean and the Pacific off Southeast Asia/91/GEN/20 and used to estimate annual age composition.

***Appendix B** (.. Continued)*

PS (free school)

Catch (t)

	France (1)		*Spain (2)*		*Panama (3)*		*Russia*	
Year	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*
1970	0		0		0		0	
1971	0		0		0		0	
1972	0		0		0		0	
1973	0		0		0		0	
1974	0		0		0		0	
1975	0		0		0		0	
1976	0		0		0		0	
1977	0		0		0		0	
1978	0		0		0		0	
1979	0		0		0		0	
1980	0		0		0		0	
1981	162	(4)	0		0		0	
1982	621	(A)	0		0		0	
1983	6,548	(A)	0		0		0	
1984	31,326	(A)	11,603	(6)	2,441	(6)	0	
1985	25,005	(A)	12,647	(6)	3,318	(6)	488	(6)
1986	27,723	(A)	14,258	(6)	3,057	(6)	2,213	(6)
1987	22,787	(A)	15,334	(6)	2,849	(6)	2,288	(6)
1988	44,806	(A)	34,542	(6)	3,103	(6)	3,307	(6)
1989	23,042	(A)	20,573	(6)	1,185	(6)	1,805	(6)
1990	34,179	(A)	30,690	(6)	10,376	(6)	1,912	(6)
1991	29,306	(A)	34,153	(6)	10,810	(6)	2,408	(6)
1992	33,936	(4)	24,460	(A)	6,496	(5)	2,914	(5)

Notes:

(A): Available annual size (fork length) data are used to estimate annual age composition.

(1): Ivory Coast and Seychelles are included.

(2): Malta and UK are included.

(3): Cayman Island is included.

(4): France 1982 size data are substituted to estimate 1981 age composition.

(5): Spain 1992 size data are substituted to estimate 1992 age composition.

(6): Annual France size (fork length) data are substituted for each year to estimate annual age composition.

(7): Japan (1988-89 pooled) size (fork length) data are available in Tuna Fisheries Development and Management in the Indian Ocean and the Pacific off Southeast Asia/91/GEN/20 and used to estimate annual age composition.

Appendix B *(.. Continued)*

Gillnet

Catch (t)

	Iran		*Pakistan*		*Taiwan*	
Year	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*
1970	0		2,827	(2)	0	
1971	0		2,306	(2)	0	
1972	0		2,750	(2)	0	
1973	0		2,162	(2)	0	
1974	0		2,965	(2)	0	
1975	0		3,272	(2)	0	
1976	0		3,070	(2)	0	
1977	0		2,743	(2)	0	
1978	0		1,598	(2)	0	
1979	0		2,762	(2)	0	
1980	0		1,275	(2)	0	
1981	0		1,958	(2)	0	
1982	0		2,450	(2)	0	
1983	0		827	(2)	0	
1984	0		,893	(2)	0	
1985	0		1,487	(2)	0	
1986	0		2,517	(2)	28	(2)
1987	0		2,336	(A)	45	(2)
1988	0		3,733	(A)	1	(2)
1989	980	(?)	8,560	(A)	2	(2)
1990	2,280	(?)	3,156	(A)	4	(2)
1991	3,238	(?)	4,780	(A)	0	
1992	12,104	(?)	3,769	(A)	0	

Notes:

(A): Available annual size (fork length) data are used to estimate annual age composition.

(?): Annual Pakistan size (fork length) data are substituted to estimate annual age composition.

(2): Average percent size frequency distribution of Pakistan (1987-92) are substituted to estimate annual age composition.

Appendix B *(.. Continued)*

Gillnet based combined gear

Catch (t)

	Oman type (1)		*Sri Lanka type (2)*	
Year	*Catch*	*Size*	*Catch*	*Size*
1970	0		5,800	(4)
1971	0		4,700	(4)
1972	0		6,500	(4)
1973	0		5,100	(4)
1974	0		6,070	(4)
1975	0		6,611	(4)
1976	0		6,915	(4)
1977	0		5,720	(4)
1978	0		5,369	(4)
1979	0		6,166	(4)
1980	16	(3)	6,906	(A)(5)
1981	12	(3)	7,662	(A)(5)
1982	5	(3)	7,932	(A)(5)
1983	44	(3)	8,594	(A)(5)
1984	222	(3)	6,181	(A)(5)
1985	4,604	(3)	6,689	(A)(5)
1986	4,846	(3)	7,975	(A)
1987	6,361	(3)	7,146	(A)
1988	17,113	(A)	7,424	(A)
1989	17,744	(3)	7,535	(A)
1990	14,951	(3)	6,406	(A)
1991	9,863	(3)	10,664	(4)
1992	23,419	(3)	7,118	(4)

Notes:

(A): Available annual size (fork length) data are used to estimate annual age composition.

(1): Handline data are partially included. Yemen data are included.

(2): Handline, longline and troll data are partially included.

(3): Size (fork length) data of Oman in 1989 are substituted to estimate annual age compositions.

(4): Average percent size frequency distribution for 1985-90 are used to estimate annual age composition.

(5): Identical percent size frequency distribution (based on the IPTP database).

Appendix B *(.. Continued)*

Handline

Catch (t)

	Comoros (1)		*Maldives (2)*		*Seychelles (3)*		*Mozambique*	
Year	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*
1970	100	(4)	0		100	(4)	0	
1971	100	(4)	0		100	(4)	0	
1972	100	(4)	0		100	(4)	0	
1973	100	(4)	0		100	(4)	0	
1974	100	(4)	0		150	(4)	0	
1975	100	(4)	0		100	(4)	0	
1976	100	(4)	0		50	(4)	0	
1977	100	(4)	0		80	(4)	0	
1978	100	(4)	0		100	(4)	0	
1979	100	(4)	0		128	(4)	0	
1980	100	(4)	0		357	(4)	0	
1981	110	(4)	0		949	(4)	0	
1982	120	(4)	0		518	(4)	0	
1983	130	(4)	0		114	(4)	0	
1984	140	(4)	1	(4)	0		0	
1985	140	(4)	27	(4)	0		0	
1986	140	(4)	0	(4)	6	(4)	15	(4)
1987	140	(4)	2	(4)	5	(4)	15	(4)
1988	150	(4)	3	(4)	2	(4)	15	(4)
1989	2,115	(4)	6	(4)	0		15	(4)
1990	2,115	(4)	2	(A)	14	(4)	16	(4)
1991	2,115	(4)	1	(4)	9	(4)	16	(4)
1992	1,330	(4)	2	(4)	4	(4)	16	(4)

Notes:

(A): Size (fork length) data are available and used to estimate 1990 age composition.

(1): Catch data of unclassified gear (1970-88) in the IPTP database are included because it is the handline based gear.

(2): Catch data of unclassified gear (1970-82) in the IPTP database are included because it is the handline based gear.

(3): Catch data of unclassified gear (1989-92) in the IPTP database are included because it is the handline based gear.

(4): Size (fork length) data of Maldives (1990) was substituted to estimate annual age composition.

***Appendix B** (..continued)*

Longline (LL)

Catch (t)

Region	*Whole Region*								*NE*		*NW*		*SW*	
Country	*Japan*		*Korea*		*Taiwan*		*Others (1)*		*(2)*		*(3)*		*(4)*	
Year	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*	*Catch*	*Size*
1970	6,800	(A)	7,045	(5)	4,922	(5)	0		0		0		0	
1971	9,500	(A)	7,475	(5)	14,021	(5)	0		0		0		0	
1972	5,400	(A)	11,040	(5)	6,786	(5)	0		0		0		0	
1973	2,000	(A)	10,580	(5)	2,165	(5)	0		0		0		0	
1974	1,943	(A)	13,297	(5)	1,500	(5)	0		0		0		0	
1975	2,195	(A)	10,,236	(5)	1,032	(5)	0		0		0		0	
1976	1,342	(A)	9,144	(5)	881	(5)	0		1,840	(6)	0		0	
1977	1,146	(A)	28,549	(5)	4,069	(5)	0		719	(6)	0		0	
1978	2,822	(A)	20,741	(5)	2,080	(5)	0		0		0		17	(8)
1979	810	(A)	12,218	(5)	1,684	(5)	0		392	(6)	0		0	
1980	1,784	(A)	8,159	(5)	886	(5)	0		370	(6)	0		78	(8)
1981	2,856	(A)	11,513	(5)	1,273	(5)	0		0		0		198	(8)
1982	4,755	(A)	20,830	(5)	2,111	(5)	0		0		0		235	(8)
1983	4,814	(A)	16,727	(A)	1,380	(5)	0		15	(6)	0		419	(8)
1984	4,559	(A)	10,503	(A)	1,120	(5)	0		45	(6)	0		432	(8)
1985	6,435	(A)	13,104	(A)	1,523	(A)	0		29	(6)	0		161	(8)
1986	8239	(A)	16,171	(5)	10,610	(A)	0		1,659	(6)	0		219	(8)
1987	4,985	(A)	13,481	(5)	15,491	(A)	0		769	(6)	0		81	(8)
1988	6,090	(A)	14,228	(5)	13,764	(A)	8	(5)	822	(6)	0		113	(8)
1989	2,336	(A)	8,304	(5)	10,026	(5)	72	(5)	3,161	(6)	0		121	(8)
1990	3,560	(A)	7,583	(5)	10,523	(5)	1,471	(5)	9,830	(6)	4,212	(7)	26	(8)
1991	2,968	(A)	3,325	(5)	8,860	(5)	1,164	(5)	3,594	(6)	1,229	(7)	71	(8)
1992	2,823	(A)	4,489	(5)	19,388	(5)	20,906	(5)	4,508	(6)	1,976	(7)	71	(8)

Notes:,

(A): Available annual size (fork length) data are used to estimate annual age composition.
(1): Russia, France, Honduras, and unknown catch are included.
(2): India and Iran.
(3): Oman.
(4): Kenya, Mauritius, Mozambique and Seychelles.
(5): Annual Japanese size (fork length) data in the whole region are substituted for each year to estimate annual age composition.
(6): Annual Japanese size (fork length) data in the NE region are substituted for each year to estimate annual age composition.
(7): Annual Japanese size (fork length) data in the NW region are substituted for each year to estimate annual age composition.
(8): Annual Japanese size (fork length) data in the SW region are substituted for each year to estimate annual age composition.

Appendix C: *SAS outputs of the GLM analyses (1 - Coarse scale data)*

The GENMOD Procedure
Criteria for Assessing Goodness of Fit

Criterion	*DF*	*Value*	*Value/DF*
Deviance	22E3	9333027	421.3176
Scaled Deviance	22E3	22152.00	1.0000
Pearson Chi-Square	22E3	12066965.140	544.7348
Scaled Pearson X2	22E3	28641.0182	1.2929
Log Likelihood	.	147288.1635	.

Analysis of Parameter Estimates

Parameter		*DF*	*Estimate*	*Std Err*	*ChiSquare*	*Pr>Chi*
Intercept	-	1	1.5063	0.0299	2535.1214	0.0000
YR	70	1	0.4561	0.0458	99.0650	0.0000
YR	71	1	1.1596	0.0385	905.4150	0.0000
YR	72	1	0.4629	0.0423	119.9761	0.0000
YR	73	1	-0.0449	0.0622	0.5210	0.4704
YR	74	1	-0.5545	0.0703	62.2142	0.0000
YR	75	1	-0.5752	0.0608	89.4613	0.0000
YR	76	1	-0.3129	0.0592	27.9466	0.0000
YR	77	1	0.4685	0.0359	170.1413	0.0000
YR	78	1	-0.0789	0.0384	4.2229	0.0399
YR	79	1	-0.4835	0.0437	122.6493	0.0000
YR	80	1	-0.7476	0.0475	248.1739	0.0000
YR	81	1	-0.5273	0.0437	145.5689	0.0000
YR	82	1	-0.3928	0.0368	113.8086	0.0000
YR	83	1	-0.5009	0.0387	167.4778	0.0000
YR	84	1	-0.4773	0.0435	120.6387	0.0000
YR	85	1	-0.3656	0.0411	79.2513	0.0000
YR	86	1	0.0340	0.0336	1.0245	0.3115
YR	87	1	0.0396	0.0332	1.4198	0.2334
YR	88	1	-0.0695	0.0396	3.0798	0.0793
YR	89	1	-0.2808	0.0422	44.3848	0.0000
YR	90	1	-0.1588	0.0404	15.4419	0.0001
YR	91	1	-0.7487	0.0452	274.1056	0.0000
YR	92	0	0.0000	0.0000	.	.
Q	1	1	-0.2456	0.0178	191.0411	0.0000
Q	2	1	-0.6189	0.0190	1058.8400	0.0000
Q	3	1	-0.4786	0.0190	633.2929	0.0000
Q	4	0	0.0000	0.0000	.	.
AREA	ne	1	0.5515	0.0171	1035.8910	0.0000
AREA	nw	1	0.5713	0.0209	744.3704	0.0000
AREA	se	1	0.0189	0.0186	1.0333	0.3094
AREA	sw	0	0.0000	0.0000	.	.
C	j	1	0.1553	0.0176	77.6446	0.0000
C	k	1	0.8103	0.0187	1870.0638	0.0000
C	t	0	0.0000	0.0000	.	.
SOI		1	-0.0034	0.0008	17.6016	0.0000
SCALE		0	20.5260	0.0000	.	.

Appendix C *(...continued): SAS outputs of the GLM analyses (2 - Fine scale data)*

The GENMOD Procedure
Criteria for Assessing Goodness of Fit

Criterion	*DF*	*Value*	*Value/DF*
Deviance	64E3	1137774.9331	17.8724
Scaled Deviance	64E3	63661.0000	1.0000
Pearson Chi-Square	64E3	1477415.5619	23.2075
Scaled Pearson X2	64E3	82664.6372	1.2985
Log Likelihood	.	109696.7911	.

Analysis of Parameter Estimates

Parameter		*DF*	*Estimate*	*Std Err*	*ChiSquare*	*Pr>Chi*
Intercept		1	2.0573	1.7995	1.3070	0.2529
YR	79	1	-0.2955	0.0510	33.6272	0.0000
YR	80	1	-0.1282	0.0404	10.0542	0.0015
YR	81	1	-0.2872	0.0357	64.5956	0.0000
YR	82	1	0.1046	0.0322	10.5781	0.0011
YR	83	1	-0.0360	0.0326	1.2207	0.2692
YR	84	1	-0.0301	0.0330	0.8321	0.3617
YR	85	1	0.1294	0.0309	17.5505	0.0000
YR	86	1	0.3195	0.0301	112.7709	0.0000
YR	87	1	-0.0837	0.0314	7.1026	0.0077
YR	88	1	0.2425	0.0318	58.0348	0.0000
YR	89	1	-0.1181	0.0352	11.2311	0.0008
YR	90	1	-0.0653	0.0330	3.9121	0.0479
YR	91	1	0.2148	0.0335	41.0574	0.0000
YR	92	0	0.0000	0.0000	.	.
Q	1	1	-0.3351	0.0107	988.1126	0.0000
Q	2	1	-0.6385	0.0167	1457.5725	0.0000
Q	3	1	-0.4040	0.0159	646.6617	0.0000
Q	4	0	0.0000	0.0000	.	.
AREA	ne	1	-0.6488	0.0148	1922.6582	0.0000
AREA	nw	1	-0.2180	0.0163	179.5435	0.0000
AREA	se	1	-0.4707	0.0159	876.9193	0.0000
AREA	sw	0	0.0000	0.0000	.	.
BAIT		1	0.0392	0.0072	29.4217	0.0000
VS		1	-0.0353	0.0060	34.4743	0.0000
B		1	-0.0011	0.0028	0.1666	0.6832
ALB		1	0.0044	0.0009	23.1173	0.0000
BIG		1	0.0044	0.0002	574.8398	0.0000
SWO		1	0.0125	0.0016	60.2147	0.0000
MLS		1	0.0063	0.0018	12.4589	0.0004
BLM		1	0.0961	0.0067	203.6470	0.0000
BUM		1	0.0174	0.0025	50.1800	0.0000
SAI		1	0.0359	0.0038	89.4403	0.0000
SKJ		1	-0.0084	0.0069	1.4844	0.2231
SHK		1	0.0045	0.0022	4.0554	0.0440
MP		1	0.0046	0.0010	22.5438	0.0000
SOI		1	-0.0066	0.0007	94.1211	0.0000
SOI2		1	-0.0004	0.0000	174.4110	0.0000
SST		1	-0.1097	0.1253	0.7662	0.3814
SST2		1	0.0028	0.0022	1.5582	0.2119
WIND		1	0.0036	0.0014	6.6795	0.0098
WIND2		1	-0.0000	0.0000	3.5699	0.0588
SCALE		0	4.2276	0.0000	.	.