ESTIMATION OF THE CATCH-AT-AGE MATRIX OF BIGEYE TUNA (*THUNNUS OBESUS*) FISHERIES IN THE INDIAN OCEAN (1970-96)

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ASBTRACT

This paper describes the estimation of the catch-at-age matrix of bigeye tuna fisheries for the period 1970-96. An age-length-weight key was constructed using published length-weight relationships and growth equations. Catches at age were estimated for longline (substituting Japanese size-frequency data for other fleets), purse seine and other gears separately and summed. The resultant catch-at-age matrix suggested that ages 2 to 6+ dominated the predominantly longline catches from 1970-85, afterwards ages 0 and 1 have dominated catches as a result of the sharp growth of the purse seine fishery.

1. INTRODUCTION

Strengthening tuna management role is one of the primary task for the newly established Indian Ocean Tuna Commission (IOTC). Hence, the stock assessment will become the essential work for the successful management because it provides the basic information for decision process. Under such circumstances, age based stock assessment such as the cohort analysis is expected to be conducted as one of the stock assessment methodologies. As bigeye tuna is highlighted in the first tropical tuna working party meeting of the IOTC, catch-at-age (CAA) of bigeye tuna of the Indian Ocean tuna fisheries (1970-96) are estimated in this paper for bridging to the age structured stock assessment. Within available information, CAA are carefully estimated as accurate as possible. The Indian Ocean bigeye tuna is assumed to be a single stock.

2. DATA

2.1 SOURCE

Data (size, weight and catch) from 1970-96 are used. Sources of the information used in this paper is listed as below:

- IOTC (IPTP) databank
- FISH_STAT (FAO)
- Database from NRIFSF (Japan) for Japanese longline (LL) and purse seine (PS)
- IRD (former ORSTOM), Montpellier, France: estimated catch-at-size data of all purse seine fisheries from Drs Renaud Pianet (1984-90) and Alain Fonteneau (1991-98),
- Maldivian size data (troll and pole & line) from Marine Research Station, Charles Anderson,
- Marine Research Station, Maldives

2.2 GEAR TYPE

Upon careful review of the gear types for BET fisheries in the region, they are classified into eight categories and the CAA matrix for each gear is estimated. Table 1 shows eight gear types and corresponding countries.

Table 1 Eight gear types for BET catch by scale of fisheries and country (1970-96)

	Gear type	Country (small – medium scale)	Country (large scale)
Surface	(1) Pole & line (PL)	Australia	
	(2)Troll (TROLL)	Australia, Comoros, Mauritius, Seychelles, Sri Lanka,	
Surface To Sub-surface	Purse seine (PS) (3) free schools (4) log schools		France, Japan, Mauritius, Seychelles, Soviet (Russia), Spain and others (*)
Sub-surface	(5) Gillnet (GILL)	Sri Lanka	China (Taiwan)
To mid water	(6) Handline (HAND)	Comoros, France, South Africa	
Mid water	(7) Longline (LL)	Australia, France, Honduras, India, Indonesia, Kenya, Mauritius, Seychelles, Soviet (Russia), Sri Lanka, Spain	China (Taiwan), Korea, Japan,
	(8) Unclassified (UNCL)	India (LL) (**) Mozambique (TROLL) (**) Seychelles (LL/HAND) (**)	

Note (*) : Belize, Cayman Island,, Ivory coast ,Liberia, Malta and Panama

(**): LL or TROLL are assumed (per.comm with IOTC).

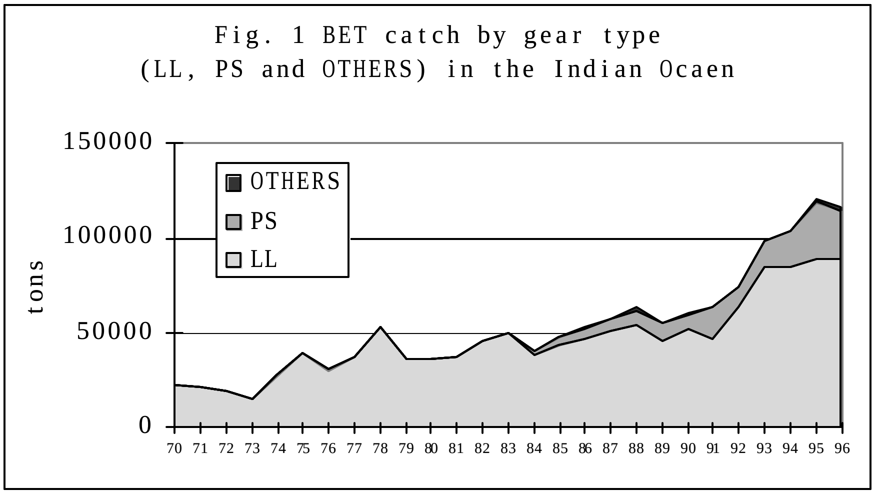


Fig. 1 shows the trend of BET catch by LL, PS and others gears in the Indian Ocean. It is clear that the most important gears are LL and PS, which account more than 97 % of the total BET catch (in weights).

LENGTH-WEIGHT (LW) RELATIONSHIP

During the process to estimate the CAA, the LW relationship is needed for conversion between length and weight. Following equation is used (Table 2). For young BET, average of the two equations was applied.

Table 2 LW relationship used in this paper

For young BET (less than 80 cm in for length) based on the PS data in the Indian Ocean.

Equation	Units	Reference
$W = (2.7 \times 10^{-5})l^{2.951}$	Kilograms, centimeters	Cort 1986
$W = (2.74 \times 10^{-5})l^{2.908}$	Kilograms, centimeters	Poreeyanond 1994

For larger BET (longer than 80 cm in fork length) based on the LL data in the Central Pacific.

	Units	Reference
$W = (3.661 \times 10^{-5})l^{2.90182}$	Kilogram s, centimeters	Nakamura and Uchiyama 1966 (n=9,144)

GROWTH EQUATION

During the process to estimate the CAA, the growth equation is needed for the age-length keys. The following equations by Tankevich (1982) were used. As male and female data are pooled, average of the two equation was applied.

females: $L_{t(cm)} = 209.8\left(1 - e^{-0.171[t-(-0.86)]}\right)$

males: $L_{t(cm)} = 423.0\left(1 - e^{-0.058[t-(-1.773)]}\right)$

Using these equations and LW relationship, the age-length-weight key was computed (Table 3)

Table 3 Age-Length-weight key

Ag	L (cm)	W(kg)
0.0	35.014	0.995
0.5	47.890	2.334
1.0	60.001	4.445
1.5	71.402	7.367
2.0	82.144	13.168
2.5	92.273	18.447
3.0	101.830	24.554
3.5	110.857	31.417
4.0	119.388	38.962
4.5	127.457	47.116
5.0	135.097	55.808
5.5	142.334	64.973
6.0	149.196	74.551
6.5	155.707	84.485
7.0	161.891	94.727
7.5	167.767	105.232
8.0	173.356	115.959

ESTIMATION AND RESULTS

CAA will be estimated for each gear type. Basically, CAA for PS and LL were estimated by applying MULTIFAN by quarter, while CAA of other gears (PL, TROLL and GILL) were estimated by the slicing method by year because the quarterly information were not available. Box 1 -4 summarize the estimation procedures for the CAA.

BOX 1

Procedures to estimate the global CAA of all BET fisheries in the Indian Ocean

CAA for LL (BOX 2)

+CAA for PS (BOX 3)

+CAA for other gears (BOX 4)

? Global CAA

LONGLINE

Box 2 shows the estimation procedures for the CAA of the all BET LL fisheries in the Indian Ocean.

Catch-at-size for China (Taiwan), Korea and Japan

Catch-at-size were estimated by quarter and sub-area. Sub-areas were needed because the size frequency distributions (catch-at-size, hence age compositions) were heterogeneous by sub-area. Five sub-areas were established (Fig. 2). Japanese size data (1970-96) were used because (a) there were no Koran size data and (b) there were Taiwanese size data (1985-89), but they were raised and original sample sizes were not known, which were needed to evaluate if sample sizes were statistically enough. Initially, sample sizes of the Japanese size frequency distribution by year, quarter and sub-area were investigated. If sample sizes were not enough (less than 150) in some quarter and sub-area, neighboring size frequency (in terms of time or sub-area) were substituted.

BOX 2

Procedures to estimate CAA of LL

Catch-at-size for China (Taiwan), Korea and Japan (*)

Japanese size frequency distribution

by year, quarter and sub-area (**)

? compositions of size frequency distribution

? catch-at-size = (composition of size frequency distribution) x (total catch in number) by year, quarter and sub-area

? catch-at-size by year and quarter

Catch-at-size for other LL countries (*)

Japanese size frequency distribution

by year, quarter and sub-area (F51 and F57)

? compositions of size frequency distribution

? catch-at-size = (composition of size frequency distribution) x (total catch in number)

by year, quarter and sub-area

? catch-at-size by year and quarter

Global CAA of LL

? global catch-at-size = (1) + (2)

? MULTIFAN

? Age compositions by year and quarter

? CAA = (age composition) x (total catch in number)

by year and quarter

? Annual CAA

Note: (*) :If catch in umber is not available, catch (in number) is estimated by dividing catch (in weight) by the average weight based on the Japanese LL data. The average weight is available by year, quarter and sub-area

Note (**) :If there are not enough sample sizes in the size frequ ency distribution, neighboring size distribution (in terms of time and sub-area) is substituted. .

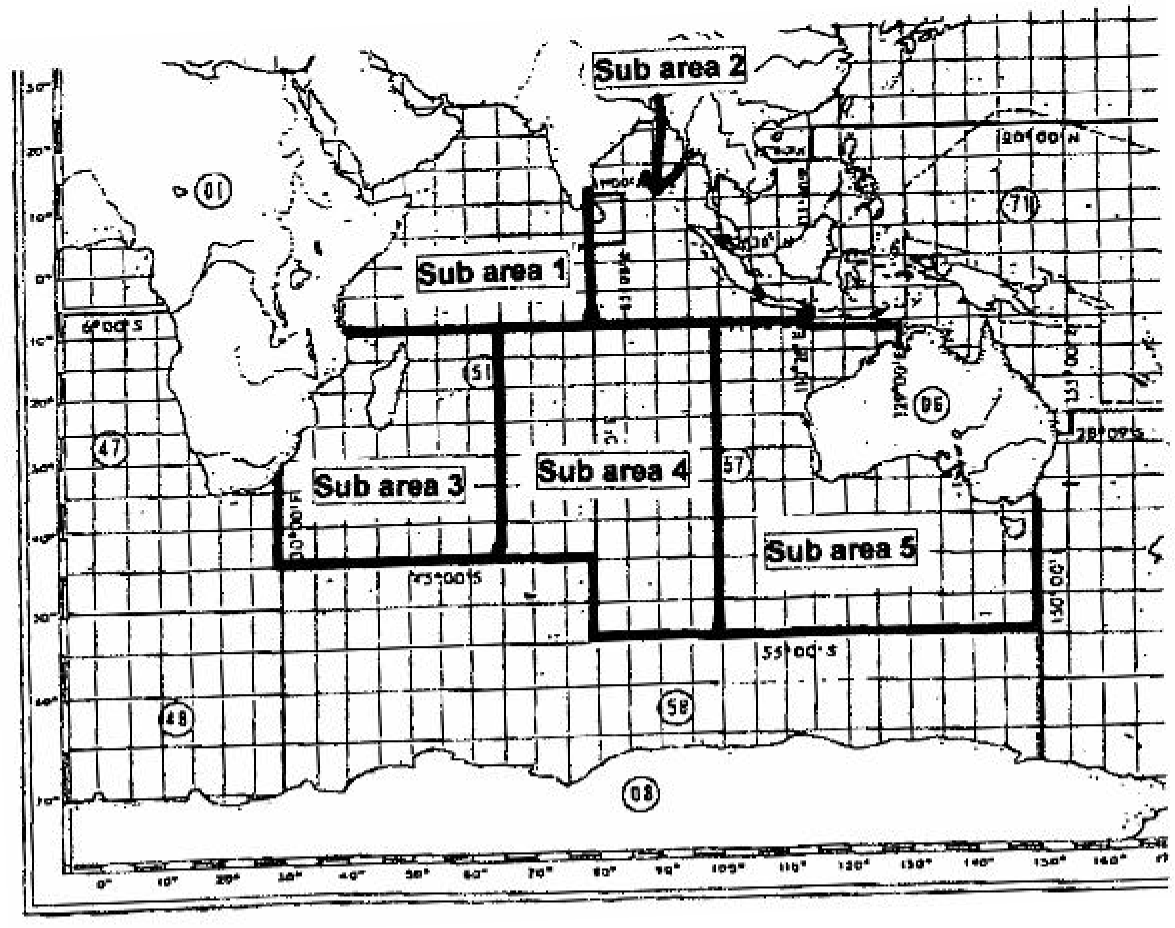


Fig. 2 Sub-area to estimate age compositions

Catch-at-size for all other LL countries

For all other LL countries, CAA was estimated by slightly different method from those of three major LL countries (China/Taiwan, Korea and Japan) because they did not have quarterly catch information. Catches of handline and UNCL (Indian and Seychelles) were also included in this category. Initially, catch of all other countries are separated by F51 and F57. Then, quarterly catch for F51 and F57 were estimated using the Japanese quarterly catch pattern in each area. Then, using average Japanese BET weight by quarter and F51/F57 area, numbers of catch were estimated by dividing catch (in weight) by average weight. Then, number of catch by quarter was computed by pooling those of F51/F57 areas. Finally, catch-at-size were estimated by multiplying compositions of size frequency distribution estimated in (1) by quarterly total catch (in number).

Global catch-at-size

The global catch-at-size data were computed by adding those estimated in (1) and (2). Then, they were converted to the 4-cm based size frequency distributions by year quarter and sub-area. "4-cm intervals" were used due to the constraints of the MULTIFAN. Moving average was applied to smooth the frequency distributions because some Japanese size frequency data include 5-cm interval information. Then, global size frequency distribution by quarter was computed by pooling those of all sub-areas.

Estimation of age compositions

Using MULTIFAN, annual global size frequency distribution estimated in (3) were converted to age composition, In MULTIFAN, K, sizes of the initial and last age (1 and 8+ respectively) were fixed to get the estimations smoothly. It was assumed that there were no age 0 fish caught by the Japanese LL.

Global CAA

The global CAA for all LL were computed by simply multiplying age compositions estimated in (4) by the global catch (in number).

PURSE SEINE

The estimation procedures are summarized in Box 3. Details estimation procedures are explained as follows :

Catch-at-size

Initially, the catch-at-size by quarter and school type (free or free) are estimated for Japan (1978-96) and all other PS

(1980-96) . For all other PS (1980-96), the size-at-catch were estimated by three time periods due to different data source, i.e., 1980-83, 1984-90 and 1991-96.

BOX 3

Procedures to estimate CAA of PS (FREE/LOG)

Catch -at-size for Japan (1978-96)

Japanese size frequency distribution

by year, quarter, sub-area and school type (F51 and F57) (*)

? compositions of size frequency distribution

? catch-at-size = (composition of size frequency distribution) x (catch in number)

by year, quarter, sub-area and school type

? catch-at-size by year, quarter and school type

Catch -at-size for Mauritius PS (1980, 1982-83)

Mauritius catch-at-size (1984-89) from Dr Pianet

by year, quarter and school type------(a)

? catch-at-size = (a) x (raising factor) (**)

by year, quarter and school type

Catch-at-size for all PS (1984-89) except Japan

Catch-at-size (1984-89) by year, quarter and school type from Dr Pianet

Catch-at-size for all PS (1990-96) except Japan

Catch-at-size (1984-89) from Dr Fonteneau

by year, quarter and school type -------(b)

? catch-at-size = (b) x (raising factor) by year, quarter and school type (**)

Global CAA of all PS

Global catch-at-size by year, quarter and school type = (1)+(2)+(3)+(4)

? MULTIFAN

? Age compositions by year, quarter and school type

? CAA = (age composition) x (total PS catch in number) by year, quarter and school type

? Annual CAA by school type (LOG/FREE)

Note (*): If there are not enough sample sizes in the size frequency distribution, neighboring size distribution (in terms of time and sub-area) is substituted.

(**): See the text details regarding the raising factors.

Japan PS (1978-96)

Using the PS database in the National Research Institute of Far Seas Fisheries (NRIFSF) of (Japan), catch-at-size are estimated. Catch-at-size were estimated by quarter, sub-area (F51/F57) and school type. Initially, sample sizes of the Japanese size frequency distribution by year, quarter and sub-area were investigated. If sample sizes were not enough in some quarter and sub-area, neighboring size frequency (in terms of time or sub-area) were substituted. Then, catch-at-size by year, quarter and school type were finally obtained.

Mauritius PS (1980-83)

There are some catch by Mauritius in 1980 and 1982-83. Catch-at-size by year and quarter were estimated by multiplying size frequency distribution of Mauritius during 1984-89 by the raising factors. *(Note: school type of Mauritius PS catch are all "log associated").* Size frequency distribution of Mauritius (1984-89) were provided by Dr. Renaud Pianet and these frequency data had been raised to the total catch. Raising factors (RF) = Catch i / Total catch (1984-89), where i=1980 or 1982-83. RF(1980)=0.0031, RF(1981)=0.0220 and RF(1982)=0.0725.

All PS (1984-90) except Japan

Dr Renaud Pianet, IRD (former ORSTOM), Montpellier, France provided the estimated catch-at-size data (by year, quarter and school type) of all purse seine fisheries except Japan.

All PS (1991-96) except Japan

Dr Alain Fonteneau, IRD (former ORSTOM), Montpellier, France provided catch-at-size data (by year, quarter and school type) of all purse seine fisheries. The Japanese PS data were deleted from the data set because the Japanese PS catch-at-size (1987-96) is estimated separately. According to Dr Fonteneau, his catch-at-size data set represents nearly all PS, but it is not fully raised. Thus, in order to raise it to the total catch, the total annual catch (in tons) was computed using average weight, then the raising factor was estimated by dividing it by the IOTC's PS catch data (tons) except Japan. This is because the IOTC figure represents the total catch. Table 4 shows the result. Using these RF, the catch-at-size were raised and the catch-at-size by year, quarter and school type were computed.

Table 4 Estimated raising factor (RF) for the Fonteneau 's catch-at-size data set

YR	Fonteneau	IOTC	RF
91	14236.90	15417	1.08289
92	8276.30	8893	1.07451
93	12156.30	12093	0.99479 (≅1)
94	13717.80	14473	1.05505
95	22561.30	26823	1.18889
96	21863.20	24036	1.09938

Note: Japanese PS data are not included.

Global catch-at-size

The global catch-at-size of all PS was computed by adding those of all four PS data by type of school, quarter and 2 cm interval.

AGE COMPOSITIONS

Using MULTIFAN, annual age compositions of BET by school type and quarter were estimated by converting the estimated global catch-at-size. In MULTIFAN, K, sizes of the initial and last age (0 and 7+ respectively) were fixed to get the estimations easily. It was assumed that there were no age 8 or older fish caught by the PS.

Global CAA

The global CAA were computed by multiplying age compositions and total catch (in number) by year, quarter and school type.

Other gears

CAA for other gears (pole & line, troll and gillnet) were estimated based on the slicing method because there were no seasonal size and catch data required by the MULTIFAN. Box 4 shows the estimation procedure and the details are described as follow:

BOX 4

Procedures to estimate CAA of other gears (PL, TROLL and GILL)

(1) CAA for PL

Maldivian PL size frequency distribution

? compositions of size frequency distribution

? slicing method

? Age composition

? Annual CAA= (age composition) x (total catch in number)

CAA for TROLL

Maldivian TROLL size frequency distribution

? compositions of size frequency distribution

? slicing method

? Age composition

? Annual CAA= (age composition) x (total catch in number)

CAA for GILL

No size data

? Annual age composition between Age 2: Age 3=6: 4 is assumed ---(a) *(per. comm. with Prof. Hsu)*

? annual CAA= (a)/10 x catch (in number)

Global CAA of other gears

Global annual CAA = (1)+(2)+(3)

POLE & LINE

Dr Charles Anderson, Marine Research Station, Marine Research Station, Maldives provided Maldivian size data (pole & line). Using this size frequency data set, Australian pole and line data were converted to the catch-at-size, then using the slicing method, it was further converted to CAA.

TROLL

Dr Charles Anderson, Marine Research Station, Marine Research Station, Maldives provided Maldivian size data (troll fishery). Using this size frequency data, troll catch data (Australia, Comoros, Mauritius, Seychelles and Sri Lanka) were converted to the catch-at-size, then using the slicing method, it was further converted to CAA. UNCL gear of Mozambique is assumed to be TROLL (*per. comm. with IOTC*) and included in this computation.

GILLNET

No size data were available from the gillnet fisheries. Professor Chien Chung Hsu, Ocean Research Institute, Taiwan National University suggested that Taiwan's gillnet fisheries had caught about 78 cm in average. By considering this size, selectivity of the gillnet and the age-lengthy key (Table 3), it was assumed that gillnet fisheries catch for Taiwan and Sri Lanka exploited age 2 and 3 fish and the composition rate is about 6 : 4. With this ratio, CAA of the gillnet fisheries were estimated.

GLOBAL CAA

The final CAA were computed by adding CAA for all gears (LL, PS and all others). Table 5 and Fig. 3 show the results.

Table 5 Estimated catch-at-age matrix of all BET fisheries in the Indian Ocean (1970-96) (in millions of fish)

YR	Age 0	Age 1	Age 2	Age 3	Age 4	Age 5	Age 6+	ALL
70	0.00	0.02	0.15	0.21	0.18	0.07	0.01	0.64
71	0.00	0.03	0.14	0.21	0.14	0.06	0.01	0.59
72	0.00	0.01	0.09	0.19	0.13	0.05	0.02	0.49
73	0.00	0.00	0.03	0.14	0.13	0.06	0.01	0.37
74	0.00	0.01	0.06	0.20	0.26	0.11	0.03	0.68
75	0.00	0.04	0.15	0.23	0.32	0.18	0.03	0.93
76	0.00	0.02	0.26	0.24	0.17	0.13	0.03	0.85
77	0.00	0.01	0.09	0.32	0.27	0.14	0.06	0.89
78	0.00	0.02	0.11	0.47	0.45	0.15	0.04	1.24
79	0.00	0.01	0.19	0.30	0.28	0.13	0.03	0.93
80	0.00	0.02	0.21	0.32	0.29	0.11	0.02	0.97
81	0.00	0.03	0.37	0.32	0.21	0.09	0.03	1.05
82	0.01	0.02	0.21	0.35	0.30	0.14	0.07	1.11
83	0.05	0.04	0.22	0.44	0.33	0.14	0.05	1.27
84	0.12	0.12	0.06	0.32	0.35	0.17	0.08	1.22
85	0.08	0.37	0.12	0.45	0.40	0.18	0.07	1.66
86	0.33	0.32	0.18	0.46	0.45	0.18	0.07	1.99
87	0.36	0.25	0.18	0.37	0.55	0.23	0.08	2.02
88	0.87	0.75	0.22	0.37	0.56	0.22	0.10	3.09
89	1.04	0.82	0.17	0.39	0.43	0.19	0.07	3.12
90	1.01	0.35	0.09	0.42	0.48	0.16	0.07	2.58
91	1.33	1.14	0.17	0.27	0.57	0.20	0.05	3.73
92	0.96	0.73	0.10	0.35	0.40	0.21	0.04	2.78
93	1.33	0.71	0.06	0.35	0.65	0.24	0.17	3.50
94	1.49	1.28	0.13	0.27	0.47	0.32	0.26	4.22
95	2.84	1.97	0.29	0.33	0.30	0.43	0.37	6.52
96	2.13	2.36	0.25	0.37	0.49	0.27	0.24	6.11

Fig. 3 Trend of catch by age of all BET fisheries in the Indian Ocean (1970-96)

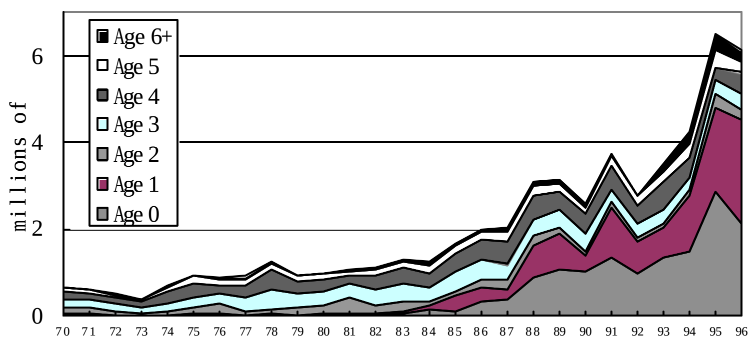
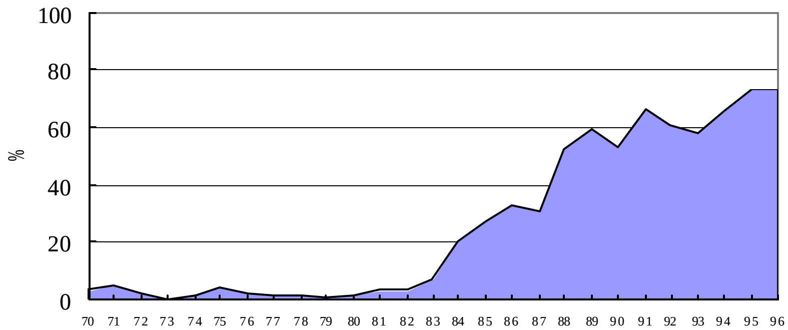


Fig. 4 Catch (in number) compostions of age 0-1 *(lower: dark)* and age 2+ *(upper : white)*



DISCUSSION

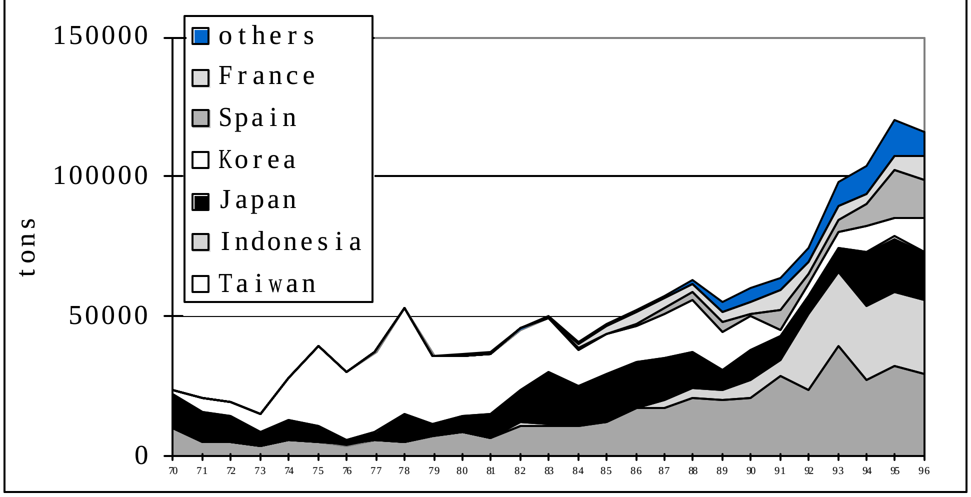
Age 0-1 BET catch

As clearly observed in Figs. 3 and 4, considerable number of young BET (age 0-1) has been expoited after 1984 due to the PS catches. The trend of catch (in weight) (Fig. 1) does not show large portion of the PS catch. However, the catch in number shows a large proportion of the age 0-1 catch.

Catch of China (Taiwan) and Indonesia

As clearly observed in Fig. 4, catch by China (Taiwan) and Indonesia in 1990's are 42-67% of the total BET catch in the whole Indian Ocean. However, it is expected that even catch data can not be obtained from these two countries, it will be quite difficult to conduct the accurate stock assessment. Thus, the reliable stock assessment depends on the acquisitions of the information from these countries.

Fig. 5 Trend of BET catch (tons) in the Indian Ocean



Size data

As was in the case of the YFT CAA in the 7th consultation meeting (Nishida, 1998), size information was not sufficient to conduct satisfactory estimations of the CAA. Especially, size from Korea, China (Taiwan) and Indonesia are essential.

India and Maldives Catch

Indian and Maldives BET catch are negligible or none, but it is likely more or some catch, which need to be investigated.

LW relationship

The LW for the immature BET from PS for the Indian Ocean has been estimated, but the one for the Indian Ocean from the LL are not established, which need to be studied.

Sex based CAA estimation

As size composition of BET is different by sex, sex based CAA estimation will provide more accurate

Picture. However it might be difficult task due to lack of the sex based fisheries information.

Estimation of age composition by MULTIFAN

MULTIFAN likely worked well to convert catch-at-size (size frequency distribution) to CAA because it could estimate the joint probability density function of the length-at-age with a mixture of bivariate distributions. The only problem is that the spawning season is fixed in the MULTIFAN, but in reality, it varies. Such adjustment needs to be incorporated for this gap in the MULTIFAN analyses.

Free and log basis PS catch data

The catch-at-size of PS catch provided by French scientists were very useful. It is hoped that the updated catch-at-size can be provided every year.

RECOMMENDATIONS

Based on the analyses and discussion, recommendations to improve the CAA estimations are listed as below:

DATA

- Data from China (Taiwan) and Indonesia are essential for the stock assessment as they catch nearly 70% of the total BET catch in the Indian Ocean.
- Size data for Korea and Taiwan are also essential for more accurate assessment.
- Discrepancies in the nominal catch were noticed between the IOTC and FISH_STAT, which need to be investigated.
- Although there are negligible catch, catch from China, Maldives, Russian are needed.
- Although there are negligible catch, size information of troll, pole & line and gillnet are also essential.
- There were BET data in the Maldivian catch data (troll and pole & line). They need to be included in the IOTC database if data can be obtained from Maldives.
- NEI LL catch (4300 tons in recent years) needs to be clarified.
- Some Japanese size include 5-cm interval data, which should be collected in 2-cm interval.

ANALYSES

- Establish ecologically meaningful sub-areas (statistical areas) of BET in considering the sample size of size frequency data and/or for GLM analyses.
- LW relationship for the larger BET from LL need to be studied.

- As size composition of BET is different by sex, sex based CAA estimation will provide more accurate

picture. However it might be difficult task due to lack of the sex based fisheries information.

- MULTIFAN likely worked well to convert catch-at-size (size frequency distribution) to CAA because it could estimate the joint probability density function of the length-at-age with a mixture of bivariate distributions. The only problem is that the spawning season is fixed in the MULTIFAN, but in reality, it varies. Such factor needs to be incorporated in the MULTIFAN analyses.

- The catch-at-size of PS catch provided by French scientists were very useful. It is hoped that the updated catch-at-size can be provided every year.

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