

AN UPDATED VIRTUAL POPULATION ANALYSIS OF THE INDIAN OCEAN ALBACORE STOCK, 1980-1992

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ABSTRACT

The Indian Ocean albacore stock is analysed to discuss the age structure and exploited status using a virtual population analysis model (VPA). The following data are used in this study: 1980-1992 catch/effort data of Taiwanese longliners; 1986-1992 catch/effort data of Taiwanese gillnetters; 1980-1992 size-frequency data of Taiwanese longliners; 1986-1992 size-frequency data of Taiwanese gillnetters; landings by gear; natural mortality rate = 0.2207 per year; and von Bertalanffy's growth curve: $W_t = 75.5(1 - e^{-0.1019(t+2.0668)})^{2.8758}$.

The results revealed that: (1) the exploited age groups of the longline fishery were from age 1 to age 8+, and targeted at the medium and old fishes; (2) the exploited age groups of the gillnet fishery were also from age 1 to age 8+, and heavily targeted at the age 3 and 4 groups; (3) the estimated stock numbers were between 3 million and 15 million from 1980 to 1992; (4) the estimated biomass was between 36 thousand t and 151 thousand t from 1980 to 1992; (5) the mean fishing mortalities were between 0.06 and 1.04 from 1980 to 1992; (6) the trends of the estimated stock number and longline CPUE were similar from 1982 to 1986, also the trends of the estimated stock number and gillnet CPUE from 1986 to 1992 were similar; (7) that many age 3 and 4 groups caught by the gillnet fishery one year will result in the stock number of age 4 and 5 groups sharply decreasing next year. This implies that the longline and gillnet fisheries maybe have an interaction of exploiting age groups. From the above results, we find that the VPA analytical model can explain the stock exploitation and fluctuation of Indian Ocean albacore very well

INTRODUCTION

In the Indian Ocean albacore (*Thunnus alalunga*) is exploited mainly by both longline and surface fisheries. Up to now, a single stock is assumed in the Indian Ocean (Nishikawa *et al.*, 1985; Lee and Liu, 1988), and the spatial distribution of the stock spreads over the area between 20°N and 40°S (HL and FSFRL, 1980).

Most of the landings have been made by Japanese longliners since 1953, by Taiwanese longliners since 1963 and by Korean longliners since 1965 (Shiohama, 1988). Since 1985, the vulnerability of the stock to surface gears such as Taiwanese large-scale pelagic driftnets and purse seiners has also increased. Although numerous studies have already been done (Koto, 1969; Lee and Liu, 1988; Liu and Lee, 1990, 1992; Shiohama, 1988; Hsu and Liu, 1990; Huang *et al.*, 1990; Lee *et al.*, 1990; Lee and Liu, 1992), the stock situation is still unclear. Among the studies, the virtual population analysis (VPA) of the Indian Ocean albacore stock was submitted to the IPTP session in Seychelles in 1993 (Lee and Liu, 1993), but an error in the estimate of the purse-seine catch for 1991, which was taken from the IPTP Data Summary for 1991, cast doubt

on the results of the analysis. The report also felt that variable catchability for the younger age classes through time indicated that the analysis needed to be tuned (Anon., 1994). At the same time, because the Taiwanese gillnet fishery was closed at the end of 1992, it is necessary to analyse the influence of the fishery on the stock. Therefore, the main purpose of this study is not only to correct the error and doubt but also to analyse the stock dynamics again using the virtual population analysis model.

MATERIALS AND METHODS

Catch/effort data and size-frequency data

The albacore catch of the Taiwanese longline fishery accounted for at least 81% of the catch of the entire longline fisheries except in 1985, and that of the Taiwanese gillnet fishery accounted for at least 79% of the catch of the entire surface fisheries except in 1985 and 1992. Besides, Taiwanese landings accounted for at least 83% except in 1985 and 1992 (Table 1). Therefore, the Taiwanese albacore catch/effort and size-frequency data can represent the stock dynamics adequately. The

Table 1. Percentage of total landings by all surface fisheries caught by the Taiwanese gillnet fishery, percentage of all longline catches caught by the Taiwanese longline fishery, and portion of all landings landed by Taiwanese vessels, for albacore from the Indian Ocean, 1980-1992.

Year	Taiwanese longline (t)	All longline (t)	%	Gillnet fishery (t)	Surface fishery (t)	%	Taiwanese landings sum (t)	All landings (t)	%
1980	9,974	12,045	82.81	-	-	-	9,974	12,045	82.81
1981	11,205	13,309	84.19	-	-	-	11,205	13,309	84.19
1982	21,930	23,354	93.90	-	-	-	21,930	25,393	86.36
1983	16,958	18,606	91.14	-	-	-	16,958	18,620	91.07
1984	13,932	15,809	88.13	-	-	-	13,932	16,262	85.67
1985	6,155	8,839	69.63	721	1,263	57.09	6,876	10,102	68.07
1986	11,052	13,394	82.51	15,176	15,591	97.34	26,228	28,991	90.47
1987	13,137	15,066	87.20	12,179	12,444	97.87	25,316	27,510	92.02
1988	11,048	12,386	89.20	14,441	14,904	96.89	25,489	27,290	93.40
1989	7,097	8,207	86.47	14,357	14,599	98.34	21,454	22,806	94.07
1990	5,756	7,105	81.01	21,142	21,472	98.46	26,898	28,577	94.12
1991	13,102	14,230	92.07	9,001	11,366	79.19	22,103	25,596	86.35
1992	11,103	12,420	89.40	1,322	5,140	25.72	12,425	17,560	70.76

catch/effort data of Taiwanese longliners from 1967 to 1992 and Taiwanese gillnetters from 1986 to 1992 were used in this study. The size-frequency data of Taiwanese longliners from 1980 to 1992 and Taiwanese gillnetters from 1986 to 1992 were also used in this study (Tables 2 and 3). To minimise the sampling error of Taiwanese longline size-frequency measurements, which were taken on board by fishermen, the relative size frequency of whole years were adopted. Because albacore are distributed heterogeneously in the Indian Ocean, three fishing areas were defined by the 10°S and 30°S lines of latitude. The mature group is north of 10°S, the spawning group is between 10°S and 30°S, and the immature group is south of 30°S (Liu and Lee, 1990). Therefore, the relative size frequency was computed by weighting the total catch of three fishing areas, and then the whole year's size frequency was summed. On the other hand, the size-frequency data of Taiwanese gillnetters were obtained by port sampling in domestic harbours from 1986 to 1992. Besides, the annual total landings by gear of Indian Ocean albacore from 1980 to 1992 are also used in this study (Table 4).

Standardization of fishing effort

The Taiwanese longline and gillnet effort data sets were first standardised individually with a generalised linear model (GLM) on the factors of year, season, area, and target species. For details of standardising procedures, refer to Chang and Liu (1995).

Age compositions

The age compositions of the longline and gillnet fisheries are estimated from the size-frequency data and Age-Length Key table (cited from Lee *et al.*, 1990) using the Iterated Age-Length-Key algorithm (IALK) (Kimura and Chikuni, 1987; Lee *et al.*, 1990).

Catch-at-age number

It is assumed that all the longline albacore catch can be substituted using the average weight of albacore caught by the Taiwanese longline fishery (Table 5). The annual longline landings were divided by the average weight of albacore in the Taiwanese longline catch to estimate the annual longline total catch number. Then, the annual total catch number was multiplied by the age compositions to estimate the catch-at-age in numbers caught by longline each year.

It is also assumed that the average weight of albacore caught by the Taiwanese gillnet fishery can be used to substitute all the surface fisheries albacore catch including gillnet, purse-seine, trolling *etc.* (Table 5). The annual landings of all surface fisheries are divided by the average weight of albacore in the Taiwanese gillnet catch to estimate the annual gillnet total catch number, and then times the age compositions to estimate the gillnet catch-at-age number each year.

Table 2. The relative size frequencies data of Indian albacore for Taiwanese longline fishery from 1980 to 1992.

Size class (cm)	Number of fish												
	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
44	46,827	11,360	12,649	10,918	5,754	1,496	186	3,124	28,118	13,531	0	1,370	18
48	4,942	5,335	16,584	13,722	17,632	2,208	450	2,254	22,059	9,833	0	24,699	0
52	11,266	7,800	20,471	17,003	23,672	6,953	562	4,695	35,282	12,871	0	2,457	18
56	12,423	18,424	28,007	20,313	26,734	10,848	1,176	12,603	15,190	5,468	0	4,116	0
60	38,897	20,722	60,830	24,289	28,565	12,913	6,138	23,663	14,797	11,042	696	7,240	77
64	27,306	20,443	51,842	35,220	33,533	14,005	11,822	29,782	9,041	17,037	4,706	1,661	63
68	31,733	35,393	59,424	57,905	89,018	23,453	16,975	41,880	16,083	42,364	15,345	17,559	169
72	52,149	47,967	84,783	60,819	110,126	36,725	59,680	70,625	35,702	45,804	31,956	62,304	1,178
76	44,676	53,784	88,704	57,458	98,740	60,366	115,194	83,352	53,486	58,724	42,035	77,917	3,069
80	66,135	83,011	146,353	108,195	128,464	55,129	146,982	118,307	102,725	76,901	66,247	88,932	7,631
84	72,977	97,415	171,430	122,059	111,445	51,134	112,431	127,877	131,726	50,169	55,338	71,334	27,439
88	63,423	85,637	155,754	110,535	89,722	27,268	66,669	67,362	88,411	39,823	38,034	83,548	118,246
92	57,655	75,171	124,149	91,989	58,424	25,814	58,834	56,578	63,768	31,648	24,294	79,938	103,862
96	37,150	62,471	103,079	81,730	41,475	28,139	47,819	31,088	29,862	21,553	13,236	72,007	84,150
100	44,161	67,141	120,902	88,902	33,573	25,991	29,486	28,894	37,700	15,879	14,164	37,401	78,950
104	26,946	32,797	70,081	59,815	26,095	9,111	15,260	23,951	19,055	12,331	13,303	25,065	31,895
108	20,746	21,414	34,672	36,854	12,283	2,148	3,548	24,804	11,798	9,333	9,143	52,934	93,071
112	15,895	9,939	18,872	23,060	7,851	1,245	2,300	35,144	12,605	6,272	9,932	61,966	83,020
116	11,566	2,114	8,289	17,541	7,510	1,564	1,337	28,420	17,023	1,740	13,161	25,685	37,947
120	15,222	5,071	17,402	18,879	18,449	3,762	865	28,583	30,233	2,335	10,709	25,485	100,342

Data sources: Tuna Research Center, Institute of Oceanography, National Taiwan University

Table 3. The Indian albacore size frequencies data of Taiwanese gillnet fishery from 1986 to 1992.

Size (cm)	Number of fish						
	1986	1987	1988	1989	1990	1991	1992
44	8	2	15	33	6	13	1
48	11	1	23	61	14	22	0
52	0	1	4	16	3	6	0
56	2	1	4	26	3	12	0
60	12	14	24	84	32	159	10
64	42	9	38	88	112	228	32
68	125	103	143	185	355	470	105
72	328	295	355	373	899	1279	258
76	248	231	324	199	539	822	91
80	155	251	372	141	248	370	51
84	114	153	252	69	180	171	33
88	54	43	112	25	64	54	15
92	21	17	28	17	11	26	5
96	5	1	11	6	13	11	4
100	5	3	6	0	6	3	0
104	0	0	2	0	1	4	0
108	0	0	1	0	1	2	0
112	0	0	1	0	1	0	0
116	0	0	0	0	0	0	0
120	0	0	0	0	0	0	0

Data sources: Tuna Research Center, Institute of Oceanography, National Taiwan University

Virtual population analysis (VPA) model

The catch-at-age data have been analysed using the software for VPA tuning described and evaluated by the ICES Methods Working Group (Anon., 1988).

Basically, the model aims at estimating the fishing mortalities at age in the terminal year data which, in traditional VPA, can only be obtained by trial and error. It utilises time series of CPUE-at-age data for selected fleets and, based on the relationship between these CPUEs and the stock numbers at age in past years, estimates the catchabilities at age for each fleet and year. Those in the terminal year can be inferred by assuming that they are equal to the mean in past years (Laurec and Shepherd method) (Laurec and Shepherd, 1983). However, one fleet at least should be considered to have its catchabilities estimated from the mean in each age. Each tuning fleet yields an estimate of the partial and total fishing mortality at age in the terminal year; these are combined among fleets to produce the tuned estimate of total F at age by calculating a weighted average in which the weights are the inverse of the variance in the time series of catchabilities by each fleet at each age. The procedure is iterated a fixed number of times, whence the name of "ad hoc" method, in contrast to integrated methods (like

Table 4. Total catch by gear of Indian albacore from 1980 to 1992

Year	Longline			Surface Fisheries			TOTAL
	LL	GILL	PS	TROL	BB	UNCL	
1980	12,045	-	-	-	-	-	12,045
1981	13,309	-	-	-	-	-	13,309
1982	23,354	-	2,024	15	-	-	25,393
1983	18,606	-	-	14	-	-	18,620
1984	15,809	-	439	14	-	-	16,262
1985	8,839	721	531	11	-	-	10,102
1986	13,394	15,176	409	12	-	-	28,991
1987	15,066	12,179	252	13	-	-	27,510
1988	12,386	14,441	447	16	-	-	27,290
1989	8,207	14,357	226	15	1	-	22,806
1990	7,105	21,142	315	15	-	-	28,577
1991	14,230	9,001	2,309	53	-	3	25,596
1992	12,420	1,322	3,756	59	-	3	17,560

Data sources: IPTP Data Summary No. 12, 1992 and No. 14, 1994
 Note: LL:Longline; BB:Pole-and-line; PS: Purse seine; GILL:Gillnet; TROL:Trolling;
 UNCL:Unclassified

Table 5. The average weight (in kg) of catches of Taiwanese longline and gillnet fisheries from 1980 to 1992.

Year	Longline	Gillnet
1980	14.15	-
1981	14.6	-
1982	14.31	-
1983	14.62	-
1984	13.03	-
1985	13.92	-
1986	14.19	9.81
1987	14.06	9.81
1988	12.97	9.81
1989	13.31	9.81
1990	14.44	9.38
1991	14.46	8.03
1992	13.21	8.94

Data sources: Tuna Research Center, Institute of Oceanography, National Taiwan University

CAGEAN or CAL) which minimise some target function of deviations between estimates and observations. However, all these methods have the common advantage of reducing subjectivity in the choice of input parameters and of providing consistently reproducible results (ICCAT, 1991).

RESULTS

Age compositions

The age compositions of the Taiwanese longline fishery from 1980 to 1992 estimated by the IALK algorithm are presented in Table 6 and Figure 1, which show that Indian Ocean albacore was exploited from the age-1 group to the age-8+ groups. The full recruitment age began at the age-3 group in 1984, at the age-4 group in 1980 and 1985-1991, at the age-5 group in 1981-1983, and at the age-6 group in 1992, *i.e.*, the medium and old fishes were exploited by the longline fishery.

The age compositions of the Taiwanese gillnet fishery from 1986 to 1992 estimated by the IALK algorithm are presented in Table 7 and Figure 2, which show that Indian Ocean albacore was also exploited from the age 1 group to age 8+ groups. The full recruitment age began at the age-3 group in 1986 and 1989-1992, and at the age-4 group in 1987 and 1988. The catch is heavily concentrated in the age-3 and -4 groups for the gillnet fishery in the Indian Ocean.

Figure 1. The age distributions of albacore for the Taiwanese longline fishery.

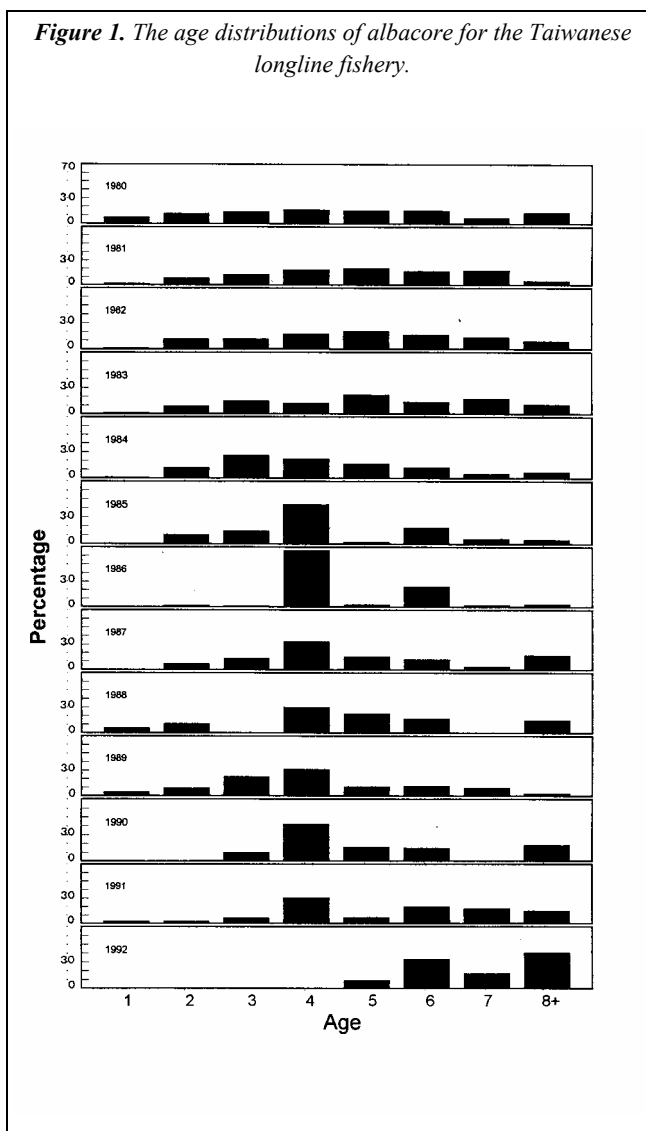
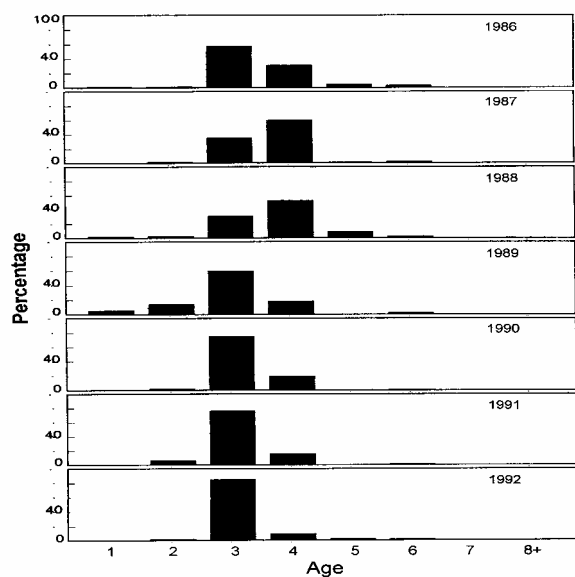


Figure 2. The age distributions of albacore for the Taiwanese gillnet fishery.



Standardised fishing effort and catch-at-age number

The fishing effort, standardised by GLM, for the Taiwanese longline fishery from 1980 to 1992 are shown in Table 8, and for the Taiwanese gillnet fishery from 1986 to 1992 in Table 9. The estimated catch-at-age number for the longline and gillnet fisheries are also shown in Tables 8 and 9, respectively.

Estimated stock number

The input data include the standardised fishing effort, catch-at-age number (Tables 8 and 9), the annual landings (Table 4), the weight at age adopted from the von Bertalanffy's growth curve, $W_t = 75.5(1 - e^{-0.1019(t+2.0668)})^{2.8758}$ (Lee and Liu, 1992), the natural mortality rate (M) adopted as 0.2207 per year (Liu and Lee 1992), and the initial fishing mortalities of last years (F_t) set as the average of 5 younger ages. The results of tuning are as follows:

Figure 4. Estimated biomass at age from 1980 to 1992.

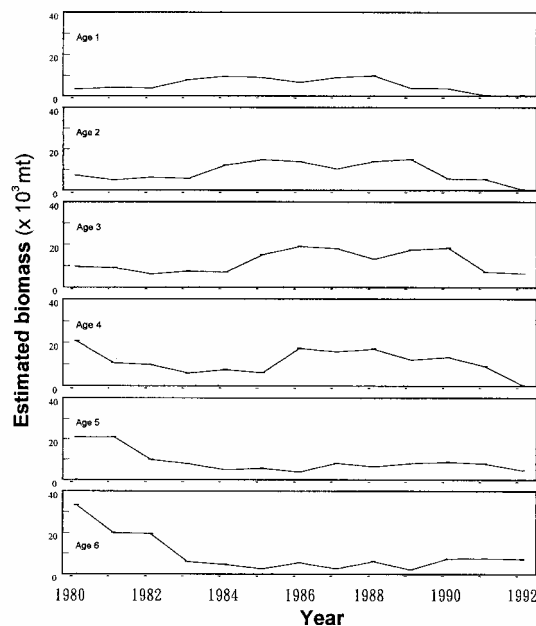


Table 6. Age distributions of IALK estimates of Indian albacore using Taiwanese longline fishery data from 1980 to 1992.

Year	1	2	3	4
1980	0.0734	0.1187	0.1392	0.1649
1981	0.0191	0.0834	0.1249	0.1818
1982	0.0132	0.1158	0.1164	0.169
1983	0.0164	0.0889	0.1444	0.1197
1984	0.0115	0.1182	0.2592	0.2204
1985	0.0048	0.1038	0.141	0.4411
1986	0.0003	0.0151	0.0089	0.6385
1987	0.0044	0.0686	0.1308	0.3279
1988	0.0572	0.1088	0.0037	0.299
1989	0.0422	0.0864	0.2233	0.3105
1990	0.0001	0.0024	0.1001	0.4161
1991	0.0273	0.023	0.0608	0.3001
1992	0.0001	0.0001	0.0016	0.0036

Figure 3. Estimated stock number at age from 1980 to 1992.

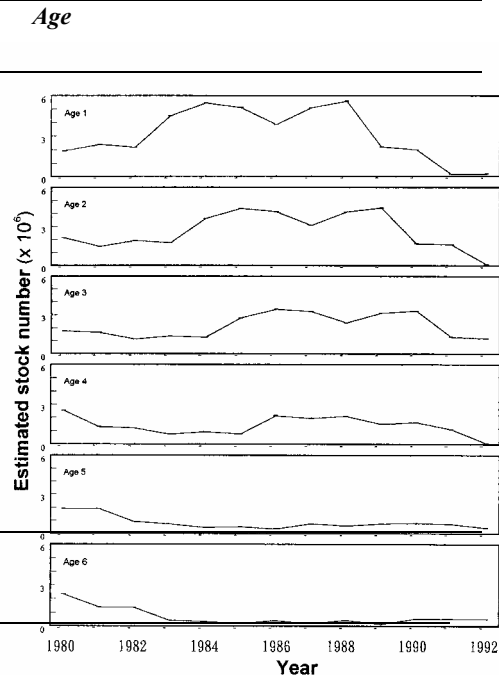


Table 7. Age distributions of IALK estimates of Indian albacore using Taiwanese longline fishery data from 1986 to 1992.

Year	1	2	3	4
1986	0.0149	0.0169	0.577	0.3097
1987	0.0021	0.0163	0.3506	0.5946
1988	0.0191	0.0255	0.3082	0.5269
1989	0.0542	0.1396	0.6025	0.182
1990	0.0053	0.0213	0.7492	0.2009
1991	0.005	0.064	0.7607	0.1558
1992	0.0017	0.0198	0.8485	0.0908

The age-3 group increased gradually from 1980 to 1986, and then gradually decreased till 1992. The estimated stock number of the age-3 group ranged from 1,100 to 3,400 thousand. The age-4 group decreased from 1980 to 1985, and then increased to the second maximum in 1986. After that, it decreased till 1992 smoothly. The estimated stock number of the age-4 group ranged from 60 to 2,500 thousand. Both age-5 and age-6 groups decreased gradually from 1980 to 1992. The estimated stock number of the age-5 and age-6 groups ranged from 150 to 2,300 thousand (Table 10, Figure 3).

The tuning does not consider the plus group (8+) and cannot use the indices for the last true age (7) from which the VPAs start during the iterations. Therefore, the results shown and discussed are from age 1 to age 6 groups. The estimated stock number of the age-1 group increased from 1980 to 1984, then decreased till 1986, and increased again to the maximum in 1988. After that, it decreased till 1992. The estimated stock number of the age-1 group ranged from 140 to 5,600 thousand fish. The age-2 group increased gradually from 1980 to 1985, then decreased till 1987, and increased again to the maximum in 1989. Finally, it decreased till 1992. The estimated stock number of the age-2 group ranged from 850 to 4,400 thousand.

Estimated biomass at age

Table 8. The standardised fishing efforts and catch matrix of Indian Ocean albacore for longline fishery from 1980 to 1992

Year	Fishing effort (100 hks)	Age							
		1	2	3	4	5	6	7	8+
1980	147,324	62,481	101,042	118,492	140,369	129,218	130,920	58,820	109,895
1981	153,536	17,411	76,025	113,856	165,724	182,953	151,960	160,984	42,753
1982	174,720	21,542	188,986	189,965	275,809	328,849	266,507	215,588	144,759
1983	223,219	20,871	113,138	183,769	152,335	273,872	174,097	218,258	136,045
1984	269,965	13,953	143,409	314,481	267,406	194,124	145,715	56,539	77,771
1985	120,600	3,048	65,912	89,533	280,092	14,287	115,440	36,575	30,162
1986	120,600	283	14,253	8,401	621,561	27,279	222,856	18,689	30,488
1987	186,912	4,715	73,508	140,159	351,361	158,804	128,050	36,433	178,627
1988	185,367	54,624	103,901	3,533	285,537	214,200	155,374	0	137,707
1989	227,479	26,021	53,275	137,688	191,456	65,052	70,046	57,344	15,723
1990	220,239	0	1,181	49,253	204,785	78,185	71,247	98	87,336
1991	298,192	26,866	22,634	59,833	295,327	69,477	191,505	171,528	146,925
1992	310,194	0	94	1,504	3,385	87,062	310,077	158,987	378,993

Table 9. The standardised fishing efforts and catch matrix of Indian Ocean albacore for gillnet fishery from 1986 to 1992

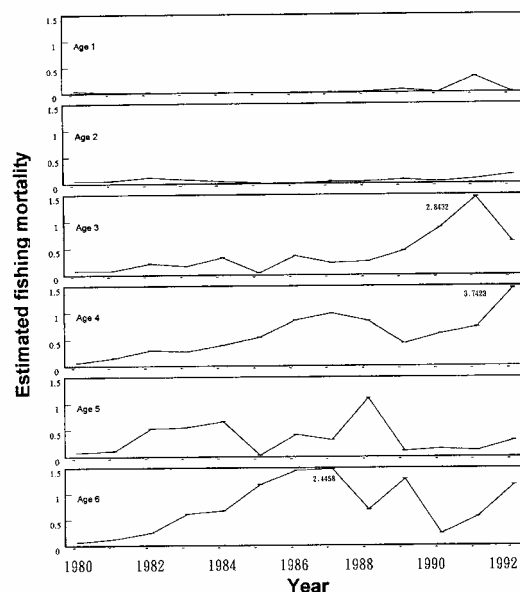
Year	Fishing effort (days)	Age							
		1	2	3	4	5	6	7	8+
1986	132,169	23,681	26,859	917,024	492,205	79,465	50,222	0	0
1987	71,627	2,664	20,677	444,737	754,251	16,744	29,683	0	0
1988	191,503	29,018	38,741	468,238	800,501	139,469	37,070	5,166	1,215
1989	145,208	80,659	207,749	896,626	270,848	298	31,996	0	0
1990	123,215	12,132	48,758	1,715,013	459,885	18,084	25,638	9,614	0
1991	162,702	7,077	90,588	1,076,868	220,526	0	17,693	2,831	0
1992	48,346	977	11,384	487,840	52,205	13,339	9,199	0	0

The annual trends of the estimated biomass were the same as the trends of the estimated stock number (Figure 4). The biomass of the age-1 group ranged from 250 t to 9,600 t, the age-2 group from 290 t to 14,900 t, the age-3 group from 6,000 t to 19,000 t, the age-4 group from 490 t to 20,000 t, the age-5 group from 3,900 t to 21,000 t, and the age-6 group from 2,200 t to 33,000 t (Table 11).

Estimated fishing mortalities

The estimated fishing mortalities at age were shown in Table 12 and Figure 5. The estimated fishing mortalities of the age-1 and age-2 groups were all very low from 1980 to 1992, except in 1991, and they ranged from 0.0007 per year to 0.30 per year. The age-3 group was also low from 1980 to 1985, but it increased from 1986 to the very high values in 1991. Its estimated fishing mortalities ranged from 0.04 per year to 0.32 per year in 1980-1985, and from 0.22 per year to 2.84 per year in 1986-1992. The age-4 group gradually increased from 1980 to 1987, then decreased till 1989, and increased again to a maximum in 1992.

Figure 5. Estimated fishing mortality at age from 1980 to 1992.



The estimated fishing mortalities of the age-4 group ranged from 0.06 per year to 0.98 per year in 1980-1991, and was 3.74 per year in 1992. The age-5 and age-6 groups fluctuated heavily from 1980 to 1992. The fishing mortalities of the age-5 group ranged from 0.08 to 1.1 per year. The fishing mortalities of the age-6 group ranged from 0.06 per year to 2.45 per year.

Estimated catchabilities

The estimated natural logarithm of catchabilities at age for

and gillnet CPUE (ages 3-4) is shown in Figure. 8. There was a similar trend between the estimated stock number and longline CPUE from 1982 to 1986, and also between the estimated stock number and gillnet CPUE from 1986 to 1992. In other words, the longline CPUE can be used as a stock index well from 1982 to 1986 and gillnet CPUE can be also used as stock index well from 1986 to 1992 for Indian Ocean albacore.

Relationship between estimated stock number and observed catch

Table11. Estimated biomass at age (in tonnes)

Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	3,257	4,088	3,721	7,726	9,359	8,806	6,618	8,790	9,616	3,757	3,435	247	271
2	7,156	4,936	6,379	5,789	12,091	14,680	13,844	10,339	13,805	14,876	5,590	5,367	287
3	9,644	8,933	6,131	7,475	7,071	15,229	19,027	18,047	13,163	17,493	18,319	7,122	6,515
4	20,511	10,508	9,703	5,850	7,478	6,059	17,302	15,734	17,033	12,097	13,152	8,951	489
5	20,825	21,002	9,833	7,874	4,884	5,532	3,866	8,017	6,410	7,992	8,659	7,842	4,725
6	33,298	19,857	19,356	5,996	4,670	2,595	5,530	2,639	6,051	2,193	7,420	7,716	7,214
7	17,477	30,899	17,267	14,980	3,223	2,355	788	1,281	226	2,996	600	5,825	4,375
8+	39,010	9,804	13,851	11,155	5,297	2,320	1,535	7,501	7,274	981	6,442	5,864	12,460
sum	151,178	110,028	86,243	66,845	54,073	57,578	68,509	72,348	73,578	62,386	63,616	48,933	36,336

longline fishery are shown in Table 13 and Figure 6. Basically, the annual fluctuation of the age-1 group was smooth from 1980 to 1992 except in 1990-1991. The age-1, 2 and -3 groups were relatively low compared with median and old groups. Their means were -11.08, -9.31 and -8.56, respectively. However, age-4, -5 and -6 groups were higher than the younger groups, and their means were similar, at -6.66, -6.94 and -5.99, respectively.

The estimated natural logarithm of catchabilities at age for the gillnet fishery is shown in Table 14 and Figure 7. The annual fluctuation of each group was low from 1986 to 1992 except for the age-5 group. The age-1, -2, -5 and -6 groups were lower than the age-3 and -4 groups, and their means were -9.50, -8.32, -8.78 and -6.78, respectively. In contrast, the age-3 and age-4 groups had high values, and their means were -5.43 and -5.32, respectively.

Relationship between estimated stock number and CPUEs

The relationship between the estimated stock number (ages 4-6) and CPUEs which include longline CPUE (ages 4-6)

Figure 6. The estimated natural logarithm of catchabilities at age for longline fishery from 1980 to 1992.

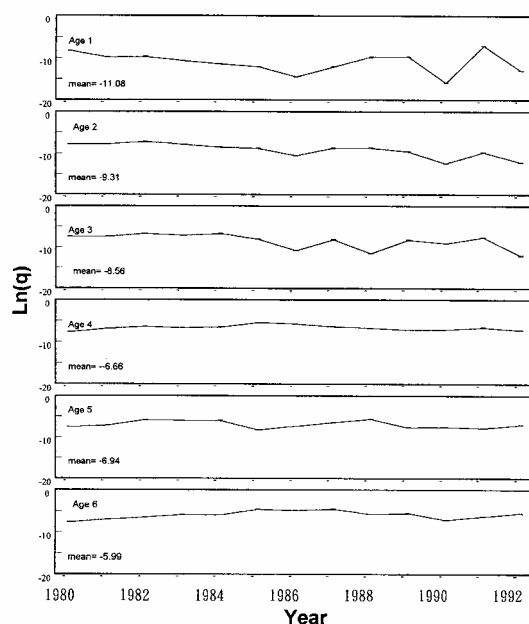
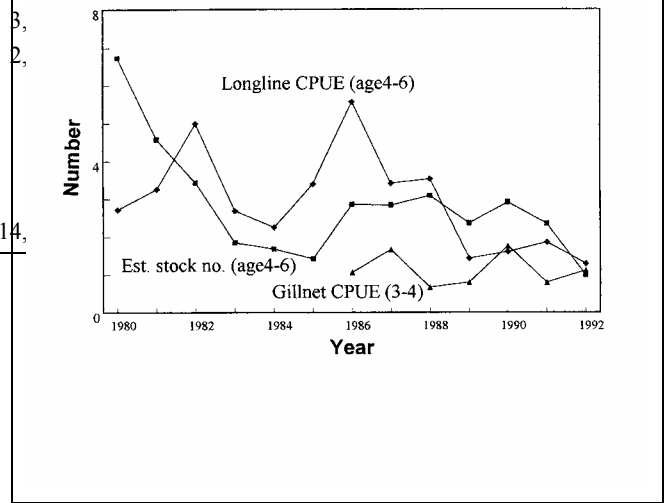


Table 10. Estimated stock number at age (x1000).

Age	1980	1981	1982	1983	1984	1985
1	1,895	2,378	2,165	4,494	5,444	5,123
2	2,122	1,464	1,892	1,717	3,586	4,354
3	1,740	1,612	1,106	1,349	1,276	2,748
4	2,517	1,290	1,191	718	918	744
5	1,878	1,893	887	710	440	499
6	2,331	1,390	1,355	420	327	182
7	991	1,753	980	850	183	134
8+	1,852	466	658	530	251	110
Sum	15,327	12,246	10,232	10,787	12,425	13,892

Figure 8. The relationship between estimated stock number (x 10⁶), longline CPUE (no./100 hooks) and gillnet CPUE (no./day).



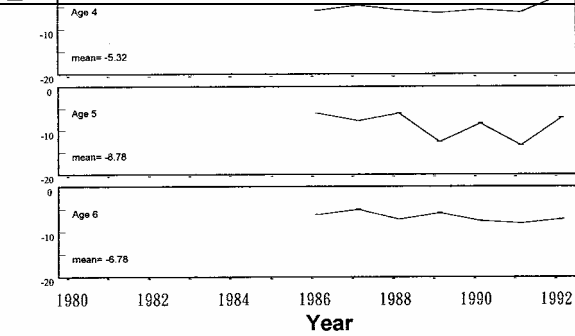
The relationship between the estimated stock number and observed catch is shown in Figure 9. From 1980 to 1985 the catch number was only a small part of the stock number, so the two curves did not show clear relationships. Many fish of the age-3 group were caught by surface fisheries in 1986, 1989, 1990 and 1991. Therefore, the estimated stock number of the age 4 group decreased sharply in 1987, 1990, 1991 and 1992. At the same time, a lot of the age-4 group were also caught by surface fisheries in 1986, 1987 and 1988, so the estimated stock number of the age 5 group decreased sharply in 1987, 1988 and 1989, respectively. From the above results, we find that the VPA analytical model can explain the stock exploitation and fluctuation of Indian Ocean albacore very well.

DISCUSSION

Figure 7. The estimated natural logarithm of catchabilities at age for the gillnet fishery from 1986 to 1992

Table 12. Estimated fishing mortality at age

Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992
1	0.0374	0.0082	0.0112	0.0052	0.0029	0.0007	0.007	0.0016	0.0168	0.0559	0.0068	0.3036	0.0076
2	0.0545	0.0595	0.1178	0.0762	0.0456	0.017	0.0112	0.0348	0.0396	0.0681	0.0341	0.0825	0.1625
3	0.0788	0.0819	0.2115	0.1642	0.319	0.037	0.3545	0.2224	0.249	0.4498	0.8807	2.8432	0.614
4	0.0641	0.1541	0.2967	0.2683	0.3892	0.5372	0.8569	0.9857	0.8444	0.4221	0.6049	0.7266	3.7423
5	0.0797	0.1137	0.5267	0.5545	0.6645	0.0324	0.4136	0.3135	1.1046	0.1063	0.1474	0.1155	0.3027
6	0.0645	0.1296	0.2461	0.6106	0.6744	1.1819	1.4527	2.4458	0.6929	1.2866	0.2318	0.5571	1.17
7+	0.0683	0.1077	0.2797	0.3347	0.4185	0.3611	0.6178	0.8004	0.5861	0.4666	0.3798	0.8649	1.1998
8+	0.0683	0.1077	0.2797	0.3347	0.4185	0.3611	0.6178	0.8004	0.5861	0.4666	0.3798	0.8649	1.1998
mean	0.0645	0.0953	0.2462	0.2936	0.3666	0.3161	0.5414	0.7006	0.5149	0.4153	0.3332	0.7948	1.0498

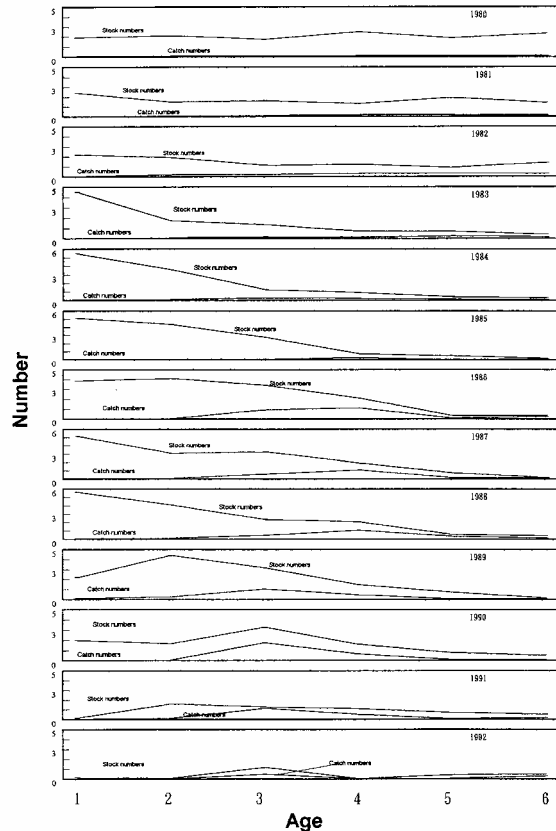


To minimise the sampling error of the Taiwanese longliners' size-frequency data, this study used relative size frequency, which was computed by weighting the total catch of three fishing areas, and then summing the whole year's size frequency. But it still had some higher changes in the estimated fishing mortalities in some years as well as in the estimated logarithm catchabilities of the age-1 group of the longline fishery (Figures 5 and, 6). These errors maybe come from (1) the year's relative size frequency computed by weighting the total catch of three fishing areas still cannot eliminate all noise, and (2) the fishermen's original sampling error in measuring fish on board: they probably did not measure the fish randomly, rather they measure them according to the captain's decision or the fishermen's own preferences (Lee and Liu, 1995).

The selection curve of a gillnet has a peak and falls off on each side, because the net has its peak effectiveness only for one size, failing to retain the bigger fish and allowing the smaller ones to pass through (Gulland, 1983). The catch of the Taiwanese gillnet fishery, concentrated in the

age-3 and -4 groups from 1986 to 1992, is a typical sample (Figure 2). However, from 1989 to 1992, the percentage age composition increasingly concentrated in the age-3 group. The result implies that the age group of Indian Ocean albacore was more and more mainly selected by this gear. The reasons perhaps came from either the characteristic of the gear or the recruitment size miniaturisation, or both. Nevertheless, it is necessary to study this in the future.

Figure 9. The relationship between estimated stock number ($\times 10^6$) and observed stock numbers (number $\times 10^6$) from 1980 to 1992.



If many fish of the age-3 and -4 groups are caught by the gillnet fishery one year, this will result in the stock number of the age-4 and -5 groups decreasing sharply the next year. These results imply that the longline and gillnet fisheries maybe have a interaction of exploiting age groups. Some researchers at the Institute of Oceanography, National Taiwan University, are studying and discussing the interaction between the two fisheries, using yield-per-recruit and production models, *etc.*

The estimated stock number (ages 4-6) and longline CPUE (ages 4-6) showed similar trend from 1982 to 1986, as did the estimated stock number (ages 4-6), and gillnet CPUE (ages 3-4) showed a similar trend from 1986 to 1992 (Figure 8). In other words, the longline CPUE cannot explain the stock index well from 1986 to 1992 for Indian

The estimated stock number, the estimated biomass and longline CPUE are low from 1989 to 1992. The authors predict that the longline CPUE is still low in recent years, although the gillnet fishery has been closed since the end of 1992. The nominal Taiwanese longline CPUE is 3.98 individuals per thousand hooks in 1993, which is lower than the 5.60 individuals per thousand hooks in 1992. The result shows that the prediction is correct. However, the responses from fishermen in 1994 and 1995 have pointed out a good fishing record (personal communication).

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Table13. Estimated natural logarithm of catchabilities (q) at age for the longline fishery

Age	1980	1981	1982	1983	1984	1985	1986	1987	1988	1989	1990	1991	1992	mean	S.E.
1	-8.28	-9.84	-9.66	-10.67	-11.46	-12.11	-14.46	-12.11	-9.73	-9.72	-15.9	-7.03	-13.02	-11.08	2.36
2	-7.9	-7.85	-7.3	-7.98	-8.69	-8.87	-10.61	-8.84	-8.77	-9.7	-12.52	-9.8	-12.25	-9.31	1.57
3	-7.53	-7.54	-6.72	-7.22	-6.74	-8.09	-10.79	-8.16	-11.51	-8.24	-9.1	-7.6	-12.01	-8.56	1.71
4	-7.74	-6.9	-6.38	-6.72	-6.54	-5.41	-5.79	-6.39	-6.73	-7.17	-7.08	-6.57	-7.22	-6.66	0.59
5	-7.52	-7.21	-5.8	-6	-6.01	-8.22	-7.3	-6.49	-5.62	-7.67	-7.52	-7.85	-7.07	-6.94	0.83
6	-7.73	-7.08	-6.57	-5.9	-5.99	-4.63	-4.89	-4.54	-5.8	-5.55	-7.16	-6.37	-5.61	-5.99	0.95
mean	-7.78	-7.74	-7.07	-7.42	-7.57	-7.89	-8.97	-7.76	-8.03	-8.01	-9.88	-7.54	-9.53	-	-
S.E	0.26	0.99	1.24	1.62	1.96	2.44	3.31	2.38	2.16	1.46	3.28	1.14	2.96	-	-

Table14. Estimated natural logarithm of catchabilities (q) at age for gillnet fishery.

Age	1986	1987	1988	1989	1990	1991	1992	mean	S.E.
1	-9.86	-11.72	-10.4	-8.14	-9.81	-7.76	-8.82	-9.5	1.61
2	-9.8	-9.15	-9.79	-7.89	-8.22	-7.81	-5.59	-8.32	1.85
3	-5.93	-6.05	-6.65	-5.92	-4.97	-4.1	-4.37	-5.43	0.78
4	-5.86	-4.67	-5.73	-6.38	-5.69	-6.26	-2.62	-5.32	1.47
5	-6.06	-7.78	-6.09	-12.61	-8.4	-13.44	-7.09	-8.78	7.86
6	-6.2	-5.05	-7.27	-5.89	-7.61	-8.15	-7.27	-6.78	1.02
mean	-7.29	-7.4	-7.66	-7.81	-7.45	-7.92	-5.96	-	-
S. E.	1.8	2.47	1.8	2.33	1.65	2.83	2.04	-	-

Ocean albacore. The authors predict that the reasons are that (1) the gillnet fishery exploited the resource more heavily than the longline fishery in the period, and (2) the fishing pattern of the Taiwanese longliners has been changing since the mid-1980s. Some longliners have been transferring their target from albacore to yellowfin tunas and bigeye tunas. Therefore, how to find the longline CPUE which can well represent the stock status is a new and important topic for the future.

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REFERENCES

ANON. 1988. Cooperative Research Report No. 157, ICES, 1988.

- ANON, 1994. Report of the Expert consultation on Indian Ocean tunas, 5th Session, Mahé, Seychelles, 4-8 October, 1993. 32p.
- CHANG, S. K. AND H. C. LIU. 1995. Adjusted Indian albacore CPUE series of Taiwanese longline and drift net fisheries. FAO IPTP/TWS/95, Colombo, Sri Lanka, 25-29 September, 1995.
- GULLAND, J. A. 1983. Fish stock assessment: A manual of basic methods . A Wiley-Interscience publication, John Wiley and Sons, 223p.
- HL, AND FSFRL. 1980. State of selected stocks of tuna and billfish in the Pacific and Indian Oceans. Summary report of the workshop on the assessment of selected tunas and billfish stock in the Pacific and Indian Oceans. FAO Fish. Tech. Pap. 200:66-67.
- HSU, C. C. AND H. C. LIU. 1990. A brief update stock assessment of Indian albacore by production model. FAO IPTP/TWS/90/55, 26P.
- HUANG, C. S., C. L. WU, C. L. KUO AND W. C. SU. 1990. Age and growth of the Indian Ocean albacore, *Thunnus alalunga*, by scales. FAO IPTP/TWS/90/53, 111-122.
- ICCAT. 1991. Report of the second ICCAT Albacore Workshop. ICCAT Collec. Vol. Sci. Pap. Vol. 34, 1-16.
- IPTP. 1992. Indian Ocean and Southeast Asian tuna fisheries data summary for 1990, Inter-regional, IPTP data summary No. 12. FAO IPTP, Colombo, Sri Lanka.
- IPTP. 1993. Indian Ocean and Southeast Asian tuna fisheries data summary for 1992. IPTP data summary No. 14. FAO IPTP, Colombo, Sri Lanka.
- KIMURA, D. K. AND S. CHIKUNI. 1987. Mixtures of empirical distributions: an iterative application of the age-length key. *Biometrics*. 43:23-35.
- KOTO, T. 1969. Distribution and movement of the albacore in the Indian and the Atlantic Oceans based on the catch statistics of Japanese tuna long-line fishery. *Bull. Far Seas Fish. Res. Lab.* 1:115-129.
- LAUREC, A. AND J. G. SHEPHERD. 1983. On the analysis of catch and effort. *J. Cons. int. Explor. Mer.* 41:81-84.
- LEE, Y. C. AND H. C. LIU. 1988. Estimation of effective fishing effort and overall fishing intensity, and stock assessment of Indian Ocean albacore (*Thunnus alalunga*), 1962-1988. FAO IPTP/TWS/88/62, 109-118.
- LEE, Y. C. AND H. C. LIU. 1992. Age determination, by vertebrae reading, in Indian albacore, *Thunnus alalunga* (Bonnaterre). *J. Fish. Soc. Taiwan*. 19(2):89-102.
- LEE, Y. C. AND H. C. LIU. 1993. The virtual population analysis of Indian albacore stock. FAO IPTP Collect. Vol. 8:107-116.
- LEE, Y. C. AND H. C. LIU. 1995. The tuna statistics procedures of Taiwanese longline and gillnet fisheries in the Indian Ocean. FAO IPTP/TWS/95, 6p.
- LEE, Y. C., C. C. HSU AND H. C. LIU. 1990. Estimating catch matrix of Indian albacore by iterated age-length key algorithm. *J. Fish. Soc. Taiwan*. 17(3):153-159.
- LIU, H. C. AND Y. C. LEE. 1990. Stock assessment of albacore resource in the Indian Ocean. pp.861-864. In R. Hirano and I. Hanyu. (eds.) 1990. *The Second Asian Fisheries Forum*. 991p. Asian Fisheries Society, Manila, Philippines.
- LIU, H. C. AND Y. C. LEE. 1992. The yield per recruit analysis for Indian Ocean albacore stock. *Proc. of the 3rd Asian Fisheries Forum*, Singapore, October 26-30, 1992, 4p.
- NISHIKAWA, Y., M. HONMA, S. UEYANAGI, AND S. KIKAWA. 1985. Average distribution of larvae of oceanic species of scombroid fishes, 1956-1981. *Far Seas Fish. Res. Lab. S. Series* 12.
- SHIOHAMA, T. 1988. Stock assessment of Indian albacore, 1988. FAO IPTP/TWS/88/42.

