Age Specific Abundance Indices for the Indian Ocean Albacore Caught by the Taiwanese Longline Fishery, 1980-2002

Hui-Hua Lee [1],Yu-Min Yeh [2] and Chien-Chung Hsu [1]

[1] Institute of Oceanography, National Taiwan University, 1 Section 4, Roosevelt Road, Taipei, 106 Taiwan
[2] Fisheries Agency, Council of Agriculture, 2 Chao-Chow Street, Taipei, 106 Taiwan

SUMMARY

The abundance indices were standardized by general linear model (GLM) with lognormal error structure for albacore (*Thunnus alalunga*) caught by the Taiwanese longline fishery in Indian Ocean from 1967 to 2002 Depending on size data available, overall abundance indices were estimated from 1967 to 2002; and age-specific indices from 1980 to 2002. Factors including year, quarter, sub-area and two-way interaction were used for the seclected GLM model of standardizing abundance indices. The age-specific abundance index was computed by multiplying annual standardized abundance index with its corresponding catch at age composition. As this to do so, the catch-at-age matrix was converted from catch-at-size matrix by MUTIFAN, and the age composition was used to derive age-specific abundance index. The results indicated that the standardized abundance index showed decreasing trend from 1979 to 1991, increased from 1991 to 199, then decreased again with a fluctuation till 2002. The age composition illustrated that albacore catch at age 1, 7, 8, or 9+ accounted for less than 10% from year to year and catch at the main target ages (age 3 to age 5) accounted for about 20-30. As the consequence, a deceasing tendency of the index has been investigated from the overall trend, however, it also has been sighted that a stable trend with a slight fluctuation was detected in a certain level after 1993. Moreover, age-specific abundance indices show decreasing fluctuated trend; however, the abundance index at age 5 has rapidly increased since 2000.

1. INTRODUCTION

Albacore (*Thunnus alalunga*) is a highly migratory meso-pelagic and economically important species that distributes all over the temperate waters. In the Indian Ocean, albacore distributes between 15°N and 40°S, and is more abundant between 15°S and 35°S (Collete and Nauen, 1983; Hsu and Liu, 2001). The production of the species in the Indian Ocean is mainly caught by Taiwanese, Japanese, and Korean longlining, and by Taiwanese gillnetting; And minor productions were made by purse seining. Commercial exploitations were commenced by Japanese longline fleets from 1950s, then Taiwanese longline fleets from 1963 and Taiwanese gillnet was operated from 1983 to 1992 to target the species (Hsu and Liu, 1990b). During the past three decades, about 60% to 90% of albacore productions were made by Taiwanese fisheries from year to year (Anon., 2000). Since 1986, Taiwanese longline vessels facilitated "super-cold freezers"; therefore, shifted their target from albacore to bigeye tuna due to the economic value.

Studies of Indian Ocean albacore are numerous on stock assessment, such as production models analyses (Shiohama, 1985a, b; 1986a, b; 1988; Huang *et al.*, 1986; Lee and Liu, 1988a, b; 1990; Hsu and Liu, 1990a; Hsu, 1995; Huang *et al.*, 2002; Wang *et al.*, 2001a, b), yield per recruit model analysis (Lee *et al.*, 1990a; Lee and Liu, 1992; Chang *et al.*, 2001), virtual population analysis (Lee and Liu, 1995) and time series modeling and prediction (Wang *et al.*, 2000). However, the catch and effort data applied in those analyses are updated; those studies were optimistic in evaluating the state of stock without incorporating recent high catch levels from 1999 onwards; and age-structured models analysis had never been pursued since 1995. Hence, for this uncertain stock the state of stock should be re-evaluated by using newly update information.

Therefore, the objective of this paper is to derive an overall abundance index and to create catch-at-age matrix, and then to derive age-specific abundance indices of Indian albacore caught by Taiwanese longline fishery in the Indian Ocean.

2. MATERIALS AND METHODS

2.1. Data source

2.1.1. Catch/effort data and annual catch data

The longline catch/effort data used in this study are were compiled from logbooks submitted by captains of Taiwanese longline vessels from 1979 to 2000, and category II data compiled from category I and logbooks aggregated by month and 5°X 5° rectangles from 1967 to 1978. Those logbooks data were first examined by daily hooks set during fishing operation. Then the catch-effort data were not used during effort standardization if daily set included very high hooks used (>6000 hooks) or very low hooks used (<400 hooks). The logbooks were then compiled their time frame as quarter and sub-area basis, but leave the records as they were without aggregating catch and effort into the new spatial and temporal categories.

Category II data were aggregated by month and by 5-degree squared area, and raised by the same raising factor, which was estimated by the ratio of landed albacore in category I with that in the returned logbooks. The category II data were used in the standardization because the logbooks used to compile the category II were not available.

2.1.2. Length data

Length data were collected in two ways: on-board measurement and port sampling. The on-board measurement was made by fishermen following to measure the initial 30 fishes hooked from each operation. The port sampling was carried out when fishing vessels returned to domestic ports harbors, usually Kaohsiung. The length data is recorded by vessel, month and 5°X5° blocks from 1980 to 2002. Number of fish length measured is shown in Table 1.

2.2. Estimation of catch-at-age

2.2.1. Catch-at-size

The procedure to estimate catch-at-size matrix was listed in Table 2. Then the length measurements were aggregated into quarterly and of 10° x 20° (latitude x longitude) rectangles, as shown in Fig. 1, from 1979 to 2002. In order to substitute the missing size measurements in time and space, thirty-seven 10° x 20° sub-areas were classified in Fig. 1.

Substitution was made for either missing size data or small sample size in a quarterly sub-area block. To do so a substitution principle was schemed in according to different levels as:

Level-1 substitution: Substitution with neighboring rectangle in the same quarter and latitude, priority was given in the order of east and west in which larger sample size is chosen.

Level-2 substitution: Substitution with neighboring rectangle in the same quarter and hemisphere, priority was given in the order of lower latitude, higher latitude, lower east, lower west, higher east, and higher west, where larger sample size for east or west is chosen.

Level-3 substitution: Same substitution as Level-1 but neighboring quarter, only between 2nd and 3rd quarters and between 4th and 1st quarters in the following year.

Level-4 substitution: Same substitution as Level-2 but neighboring quarter, only between 2nd and 3rd quarters and between 4th and 1st quarters in the following year.

Level-5 substitution: Same substitution as Level-1 but all available catch at size was summed for 16 large areas (10°x 60°). The areas were made based on 80°E.

Level-6 substitution: Same substitution as Level-1 but all available catch at size was summed for 8 large areas (20°x 60°). The areas were made based on 80°E.

Level-7 substitution: Same substitution as Level-1 but all available catch at size was summed for 1 area (total Indian Ocean).

Then catch-at-size by quarter, sub-area, and 2-cm interval were estimated by multiplying composition of length frequency distribution by total catch in number.

2.2.2. Catch at age slicing

Age slicing from catch at size was pursued by assuming that the length distribution at age is a normal distribution around its corresponding mean length, so that the mean of normal distribution follows growth equation derived from Chang *et al*. (1993) because the Chang et al. (1993) used size fitting to estimate the growth parameters and the estimated growth parameters seemed much more reliable than the other three estimates (Huang et al. 1990; Hsu 1991; Lee and Liu 1992).

Computer software MULTIFAN was used to this purpose. MULTIFAN can provide a good tool to slicing catch at size into catch at age. The von Bertalanffy growth parameter K was fixed at 0.118 as estimated by Chang et al. (1993)~~,~~ with the length~~s~~ interval between 30 cm and 140 cm (lengths outside this range were considered as outliers and discarded. The age groups were assigned from age 1 to age 8, and age 9+ was used to aggregated all age groups larger than and equal to age 9. The standard deviation at age was set as the same among age. It was assumed that there were no age 0 fish caught by the Taiwanese longline fleets. Because of ~~this~~ sample size limitation, two time frames, 1980-1990 and 1991-2002 were divided for the entire time series catch at size data, then estimated quarterly catch-at-size was converted to quarterly catch-at-age by MULTIFAN. Then the quarterly catch-at-age was summed up to annual catch-at-age.

2.3. Standardizing abundance index

Because there are two different fishing patterns operated in the Indian Ocean (i.e. regular and deep fishing patterns), an appropriate separation method to partition fishing patterns is helpful in standardizing catch per unit effort as the representative of abundance index (Lin et al. 1999; Lee and Nishida 2002). Accordingly, the Lee and Nishida's criteria (Lee and Nishida, 2002) were used: if 0.8≤BET/(BET+ALB)≤1 and 0≤BET/(BET+ALB+SWO)≤0.4, the daily set were classified into deep set and regular set, respectively. Category II was also applied to this criterion to partition fishing patterns. And finally, the regular sets were used as the base data on standardization of abundance index in the present study.

In order to quantified the area effect in GLM, six sub-areas were divided in the Indian Ocean (Fig. 2) in accordance with the distribution of catch per unit effort (Fig. 3). Each sub-area was assumed to have homogeneous species density and used in the following standardized process.

The general linear model (GLM) was used. Observed catch per unit effort was assumed to follow a lognormal error distribution (lnCPUE-nominal) of a linear function with fixed factors. The model used for GLM analyses is

$$\ln(CPUE_{ijk}+constant) = \mu + Y_i + Q_j + A_k + Q_j{*}A_k + \varepsilon_{ijk}, \qquad (1)$$

where μ is overall mean, *constant* is 10% of overall mean of nominal CPUEs, Y_i is effect of year *i*, Q_j is effect of quarter *j*, $Q_j{*}A_k$ is interaction term between quarter and area, and ε_{ijk} is error term with $N(0, \sigma^2)$.

Factors of year, quarter, and sub-area were used as main fixed effects, and the two-way interaction between quarter and area was considered. Relative indices were calculated as the least square means (LSMeans) on year effect for the selected model. The computation was run with the SAS GLM procedures (ver. 8.02, SAS Inst. Inc.).

2.4. Age specific abundance index

Pseudo code used to estimate age specific abundance index was listed in Table 3. Annual age composition was calculated by multiplying the annual age composition with the abundance index, age specific abundance index was evaluated from age 1 to age 9+.

3. RESULTS AND DISCUSSION

3.1. Catch-at-age

The time-age proportion of catch-at age sliced from catch at size was tabulated in Table 4 and tendencies of time-age distributions of albacore caught by Taiwanese longline fleets in the Indian Ocean were illustrated in Fig. 4. Hence, the catch-at-age matrix is tabulated in Table 5, and Fig. 5 indicates the proportion of annual age composition estimated from catch at age matrix as in Table 4. The results depicted that age 1, age 7, age 8, and age 9+ accounted for less than 10% from year to year except age 1 in 1998, age 7 in 1993 and 2000, and age 9+ in 1999 (Fig. 5); age 2, age 3 and age 5 showed a widely fluctuated trend around 10%, 25% and 10%, respectively; age 6 was similar trend as age 5's, but fluctuated around 8%; and age 4 accounted for more than 20% all over the study years except 1992 (Fig. 5). Re-examining the time-age distributions (Fig 4), it is obvious that age 3 to age 5 were the major targeting ages from the actual size samples analysis of Taiwanese longline fishery. Nonetheless,. All age's distribution has not shown very apparent decreasing trend. Even though the combined tendency indicates that two catch levels could be detected, those are in average around 0.5-1.0 million fish caught from 1980 t0 1991, and 0.8-1.5 million fish caught from 1992 to 2002 (Fig. 4). However, most age groups were caught in a certain level in 2001, then decreased in 2002, except age 5 that rapidly increased since 2000 (Figs. 4 and 5). This may indicate that large amount of spawners were caught by longline fleets recently.

3.2. Standardized catch per unit effort

The analysis of variance (Table 6 and Table 7).indicates that the factors used in the GLM were statistically significant ($P<0.0001$), and the area factor is the most important source of variability among those factors. The frequency distribution of residuals and QQ plots were analyzed to validate the error assumption (Fig. 6), indicating that the distribution of residuals is likely as a normal distribution and the QQ plot shows very minor departure from the log-normal assumption

When nominal catch per unit effort (number of fish per 1,000 hooks) from the Taiwanese longline fleet between 1967 and 2002 was investigated as illustrated in Fig. 7 (top curve), a largely fluctuated decreasing trend was detected. Even though the current nominal catch per unit effort (2002) was not the lowest level historically from the beginning of the series, the 2002-2002 levels showed a slightly decreasing trend, and the 2002 level was a little higher than 1989 level that was the stock was heavily exploited by gillnet fleets. Moreover, the aggregated abundance index standardized by GLM also indicates a similar trend with the nominal catch per unit effort, but showing less fluctuation (Fig. 7 bottom curve). It is apparent that the standardized series showed gradually decreasing trend from 1967 to 1971, increased from 1971 to 1974, declined again in 1974 and 1975, then showed increasing trend from 1976 to 1978. Following that the standardized series decreased then after with two higher catch per unit effort appeared in 1986 and 1992. Regardless of slight fluctuation, the abundance index declined from 1979 to 1991, increased from 1991 to the high level in 1992, and showed declining trend from 1992 to 1995. Since then, it showed successively convex shapes. The abrupt decline of both nominal and standardized catch per unit during 1986-1991 might relate to the heavy exploitation by gillnet fishery. Spatial and temporal changes of standardized catch per unit effort for quarter and area are illustrated in Fig. 8, showing that abundance indices for area 4, 5, and 6 where albacore were abundant are higher than other areas.

According to Lee and Nishida's criteria, the method could be effective to separate the albacore-targeting from bigeye-targeting settings in temperate area (area 3 to area 6 in Fig. 2); however, the method might not be an appropriate means in tropical area (area 1 and area 2 in Fig. 2) because tropical area is the main fishing ground for bigeye tuna even before 1986 when bigeye tuna was not the target and most of longline operation will be classified to be deep (Okamoto *et al.*, 2004). Notwithstanding the limitation, the fact is that most albacore distribute in temperate area and a few albacore caught in the tropical area. The separation by Lee and Nishida's method might lose some data information of albacore stock in tropical area.

3.3. Age-specific abundance index

Fig. 9 illustrates the time series annul abundance index (in number per 1,000 hooks) by age. In general, the abundance indices at age 1, 6, 7, 8, or 9+ (CPUE<1.0) is lower than other age groups. For the main target ages (age 3 to age 5), age 3 and age 5 were jumped up to 3.5 in 1992. Most ages show decreasing trend or flatten from 2001; however, the abundance indices at age 5 has rapidly increased since 2000 (Fig. 5).

4. REFERENCES

Chang, S. K. and C. C. Hsu. 2001. Management implication on Indian albacore from simple yield analysis incorporating parameter uncertainty. *Fish. Res.* **51**: 1-10.

Chang, S. K., H. C. Liu, and C. C. Hsu. 1993. Estimation of vital parameters for Indian albacore through length frequency data. *J. Fish. Soc. Taiwan.* **20(1):** 1-13.

Collette, B. B. and C. E. Nauen. 1983. FAO Species Catalogue. Vol. 2. Scombrids of the world, an annotated and illustrated catalogue of tunas, mackerels, bonitos and related species know to data. *FAO Fisheries Synopsis No.* 125 (2): 1-137.

Hsu, C. C. 1991. Parameter estimation of generalized von Bertalanffy growth equation. ACTA Oceanographica Taiwanica, 26:66-77.

Hsu, C. C. 1995. Stock assessment of albacore in the Indian Ocean by age-structured production model. *J. Fish. Soc. Taiwan.* **22(1)**: 1-13.

Hsu, C. C. and H. C. Liu. 1990a. An brief updated stock assessment of Indian albacore by production model. Indo-Pacific Tuna Development and management Programme, *Coll. Vol. Work. Doc.4***3**, 123-125.

Hsu, C. C. and H. C. Liu. 1990b. Taiwanese longline and gillnet fisheries in the Indian. *Indo-Pacific Tuna Development and management Programme, Coll. Vol. Work. Doc.* **4:** 244-258.

Huang, C. S., C. L. Wu. C. L. Kao and W. C. Su. Age and growth of the Indian Ocean albacore, *Thunnus alalunga*, by scales. FAO/IPTP/TWS/90/53.

Huang, H. W., C. C. Hsu, H. H. Lee and Y. M. Yeh. 2003. Stock assessment of albacore, *Thunnus alalunga*, in the Indian Ocean by surplus production models with a new relative abundance index. *Terrestrial, Atomospheric and Oceanic Sciences (TAO).* **14(2)**: 201-220.

Huang, F. T, C. H. Wang, and H. C. Liu. 1986. Estimation of overall fishing intensity and stock assessment of Indian Ocean albacore (*Thunnus alalunga*), 1963-1984. *Indo-Pacific Tuna Development and management Programme, Coll. Vol. Work. Doc.* **1**, 23pp.

Lee, Y. C. and H. C. Liu. 1988a. An investigation of selecting undetermined parameters in fitting the generalized stock production model. *ACTA Oceanogr. Taiwanica*. **20**: 41-52.

Lee, Y. C. and H. C. Liu. 1988b. Estimation of effective fishing effort and overall fishing intensity and stock assessment of Indian Ocean albacore (*Thunnus alalunga*), 1962-1986. Indo-Pacific Tuna Development and management Programme, *Coll. Vol. Work. Doc.* **3**, 10pp.

Lee, Y. C. and H. C. Liu. 1990. Stock assessment of albacore resource in the Indian Ocean, pp. 861-864. In: R. Hirano and I. Hanyu, Eds., *Proc. of the 2nd Asian Fish. Forum*, Tokyo, Japan, 17-22 April, 1989. 991pp.

Lee, Y. C. and H. C. Liu. 1992. Age determination, by vertebra reading, in Indian albacore, *Thunnus alalunga* (Bonnaterre). J. Fish. Soc. Taiwan, 19(2):89-102.

Lee, Y. C., C. C. Hsu, S. K. Chang and H. C. Liu. 1990. Yield per recruit analysis of the Indian Ocean albacore stock. Indo-Pacific Tuna Development and management Programme, *Coll. Vol. Work. Doc.* **4**, 136-147.

Lee, Y. C. and T. Nishida. 2002. Some considerations to separate Taiwanese regular and deep longliners. IOTC/WPTT-02-19. IOTC Proceedings no.5. 328-334.

Lin, C. J., C. C. Hsu and H. C. Liu. 1999. Spatial and temporal diversity of catch species for Taiwanese longline fishery in the Indian Ocean. The 5th Asian Fisheries Forum, November 10-14, 1998, Chiang-Mai, Thailand.

Okamoto, H. S. K. Chang, Y. M. Yeh, and C. C. Hsu. 2004. Standardized Taiwanese longline CPUE for bigeye tuna in the Indian Ocean up to 2002 applying targeting index in the model. IOTC/WPTT-04-xx. IOTC Proceedings no.x.

Shiohama, T. 1985a. Overall fishing intensity of longline fishery on albacore in the Indian Ocean, 1952-1982. Indo-Pacific Tuna Development and management Programme, *Coll. Vol. Work. Doc.*

Shiohama, T. 1985b. Stock assessment of Indian albacore by production model analysis, 1952-1982. Indo-Pacific Tuna Development and management Programme, *Coll. Vol. Work. Doc.*

Shiohama, T. 1986a. Overall fishing intensity of longline fishery on albacore in the Indian Ocean, 1952-1984. Indo-Pacific Tuna Development and management Programme, *Coll. Vol. Work. Doc.* 86/24.

Shiohama, T. 1986b. Stock assessment of Indian albacore by production model analysis, 1952-1984. Indo-Pacific Tuna Development and management Programme, *Coll. Vol. Work. Doc.* 86/25.

Shiohama, T. 1988. Stock assessment of Indian albacore, 1988. Indo-Pacific Tuna Development and management Programme, *Coll. Vol. Work. Doc.* **4**: 88/42.

Silas, E. G. and P. P. Pillai. 1982. Resources of tunas and related species and their fisheries in the Indian Ocean. *CMFRT Bull.* **32:** 6-10, 35-43.

Wang, S. H. C. C Hsu, and H. C. Liu. 2000. Comparison of time series models for the forecasting of albacore commercial harvest in the Indian Ocean. *J. Fish. Soc. Taiwan.* **27(2)**: 63-75.

Wang, S. H. C. C Hsu, and H. C. Liu. 2001a. Using fuzzy synthesis approach to extract fishing efforts directed on albacore for Taiwanese longline fleets in the Indian Ocean. *J. Fish. Soc. Taiwan.* **28(2)**: 36-49.

Wang, S. H. C. C Hsu, and H. C. Liu. 2001b. A new assessment approach using fuzzy surplus production model to evaluate the albacore stock in the Indian Ocean. *J. Fish. Soc. Taiwan.* **28(4)**: 329-338.

Table 1. Actual fork length of albacore (in number of fish) measured on board by Taiwanese longline fleets in the Indian Ocean from 1980 to 2002.

Year	Fork Length measured (in number of fish)	Year	Fork Length measured (in number of fish)	Year	Fork Length measured (in number of fish)
1980	24,600	1990	8,836	2000	66,926
1981	130,163	1991	10,573	2001	90,882
1982	215,834	1992	17,460	2002	60,090
1983	172,754	1993	22,584		
1984	167,678	1994	56,082		
1985	55,650	1995	47,879		
1986	55,418	1996	94,729		
1987	49,276	1997	47,769		
1988	32,058	1998	66,977		
1989	10,750	1999	41,986		

Table 2. Procedures to estimate catch-at-age matrix for Taiwanese longline fishery caught albacore in the Indian Ocean.

Catch-at-size

Taiwanese length frequency distribution by year, quarter, and sub-area

↓

Verification by vessels and substitute rules

↓

Composition of length frequency distribution

↓

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

Catch-at-age

Catch-at-size by year and quarter

↓

MULTIFAN

↓

Age compositions by year and quarter

↓

Catch-at-age= (age composition)×(total catch in number) by year and quarter

↓

Annual catch-at-age

Table 3. Procedures to estimate age specific abundance index for Taiwanese longline fishery caught albacore in the Indian Ocean.

Age specific abundance index

Catch-at-size by year and quarter

↓

MULTIFAN

↓

Age compositions by year and quarter

↓

Annual age compositions

↓

Age specific abundance index

= (annual age compositions)×(abundance index: all ages pooled)

Table 4. Age frequency distribution of albacore for Taiwanese longline fishery catch in the Indian Ocean (1980-2002).

	Frequency (%)								
Year	1	2	3	4	5	6	7	8	9+
1980	0.070	0.189	0.236	0.276	0.138	0.046	0.035	0.007	0.003
1981	0.016	0.085	0.161	0.338	0.300	0.081	0.011	0.006	0.002
1982	0.037	0.108	0.202	0.343	0.184	0.103	0.007	0.011	0.007
1983	0.041	0.111	0.247	0.258	0.197	0.093	0.039	0.011	0.004
1984	0.033	0.099	0.305	0.308	0.156	0.062	0.007	0.016	0.013
1985	0.008	0.104	0.397	0.306	0.126	0.036	0.007	0.003	0.014
1986	0.029	0.289	0.277	0.192	0.172	0.025	0.003	0.005	0.006
1987	0.004	0.135	0.292	0.340	0.085	0.029	0.090	0.021	0.003
1988	0.207	0.054	0.085	0.402	0.072	0.095	0.017	0.054	0.015
1989	0.054	0.088	0.391	0.318	0.039	0.063	0.040	0.005	0.003
1990	0.002	0.018	0.389	0.399	0.016	0.006	0.088	0.080	0.003
1991	0.083	0.008	0.084	0.247	0.332	0.148	0.061	0.034	0.003
1992	0.002	0.096	0.351	0.054	0.326	0.088	0.044	0.035	0.004
1993	0.002	0.027	0.163	0.270	0.088	0.134	0.249	0.014	0.053
1994	0.020	0.168	0.038	0.374	0.212	0.108	0.049	0.027	0.004
1995	0.061	0.089	0.124	0.507	0.110	0.073	0.023	0.004	0.010
1996	0.059	0.185	0.228	0.301	0.194	0.009	0.017	0.004	0.003
1997	0.025	0.378	0.066	0.278	0.080	0.098	0.028	0.009	0.037
1998	0.043	0.150	0.201	0.256	0.176	0.074	0.037	0.017	0.047
1999	0.028	0.108	0.136	0.200	0.146	0.172	0.040	0.008	0.164
2000	0.010	0.045	0.173	0.345	0.073	0.065	0.189	0.051	0.048
2001	0.008	0.139	0.305	0.281	0.126	0.083	0.018	0.033	0.006
2002	0.005	0.019	0.106	0.273	0.411	0.107	0.035	0.027	0.016

Table 5. Estimated catch-at-age (number of fish) matrix for Taiwanese longline fishery caught albacore in the Indian Ocean (1980-2002).

	Age (yr)									
Year	1	2	3	4	5	6	7	8	9+	All
1980	46,315	125,272	156,006	182.684	91,065	30,500	23,126	4,386	1,918	661,276
1981	10,820	58,989	111,815	234,262	207,650	55,940	7,780	4,177	1,664	693,099
1982	48,773	141,472	264,248	448,240	240,184	134,286	8,682	13,969	8,633	1,308,488
1983	40,993	110,234	244,654	256,107	195,207	91,962	38,359	10,585	3,971	992,072
1984	29,142	87,647	271,660	273,745	138,879	55,529	6,398	14,602	11,919	889,523
1985	2,712	37,282	141,565	109,224	45,084	12,690	2,501	975	4,827	356,857
1986	20,567	206,040	197,088	136,999	122,591	18,059	2,398	3,767	4,611	712,119
1987	4,461	135,615	293,322	341,344	85,514	29,079	90,084	21,210	2,638	1,003,268
1988	174,928	45,380	71,983	340,066	60,607	80,612	14,599	46,056	12,401	846,633
1989	24,606	39,596	176,651	143,564	17,468	28,387	17,970	2,039	1,235	451,515
1990	972	8,654	184,117	188,858	7,430	2,693	41,766	37,825	1,197	473,513
1991	58,730	5,397	59,035	173,611	233,800	104,033	42,575	24,160	2,104	703,447
1992	3,415	143,350	526,243	81,549	489,074	132,118	66,161	52,201	6,087	1,500,198
1993	3,763	44,312	264,569	437,618	142,244	217,284	404,152	22,178	86,233	1,622,354
1994	22,968	190,367	43,294	423,342	239,827	122,413	55,079	31,039	4,550	1,132,880
1995	50,184	73,203	102,484	417,935	91,058	60,165	18,822	3,194	8,041	825,084
1996	68,142	212,470	262,537	346,340	223,250	10,197	19,163	4,569	3,520	1,150,189
1997	23,397	349,120	61,205	256,469	74,261	89,983	25,743	8,188	34,195	922,562
1998	62,872	216,751	290,546	369,802	254,040	107,433	52,789	24,456	67,369	1,446,057
1999	24,536	95,091	119,907	176,662	128,839	151,810	35,060	7,053	144,759	883,719
2000	13,158	56,807	217,593	433,533	91,138	82,141	237,236	64,538	60,091	1,256,236
2001	10,988	188,072	412,131	380,286	171,175	112,915	24,650	44,747	8,225	1,353,188
2002	3,830	14,811	82,914	213,041	320,558	83,592	27,212	20,798	12,710	779,466

Table 6. The ANOVA table of GLM fitting for Taiwanese longline fishery caught albacore in the Indian Ocean (1967-1978).

Class	Levels	Values
year	24	1967-1978
loc	6	1 2 3 4 5 6
quarter	4	1 2 3 4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	34	727.1184	21.38584	64.2	<.0001
Error	2197	731.8411	0.333109		
Corrected Total	2231	1458.959584			

R-Square	Coeff Var	RootMSE	ln(cpue+10%cpue) Mean
0.498381	20.21552	0.577156	2.855015

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	11	48.57661	4.416055	13.26	<.0001
quarter	3	15.6114	5.2038	15.62	<.0001
area	5	310.697	62.1394	186.54	<.0001
quarter*area	15	40.99443	2.732962	8.2	<.0001

Table 7. The ANOVA table of GLM fitting for Taiwanese longline fishery caught albacore in the Indian Ocean (1979-2002).

Class	Levels	Values
year	24	1979-2002
loc	6	1 2 3 4 5 6
quarter	4	1 2 3 4

Source	DF	Sum of Squares	Mean Square	F Value	Pr > F
Model	46	76787.4171	1669.2917	3831.40	<.0001
Error	162312	70717.3300	0.4357		
Corrected Total	162358	147504.7471			

R-Square	Coeff Var	RootMSE	ln(cpue+10%cpue) Mean
0.520576	24.32357	0.660066	2.713690

Source	DF	Type III SS	Mean Square	F Value	Pr > F
year	23	8651.18586	376.13852	863.32	<.0001
quarter	3	29.32785	9.77595	22.44	<.0001
area	5	21822.99680	4364.59936	10017.7	<.0001
quarter*area	15	741.17202	49.41147	113.41	<.0001

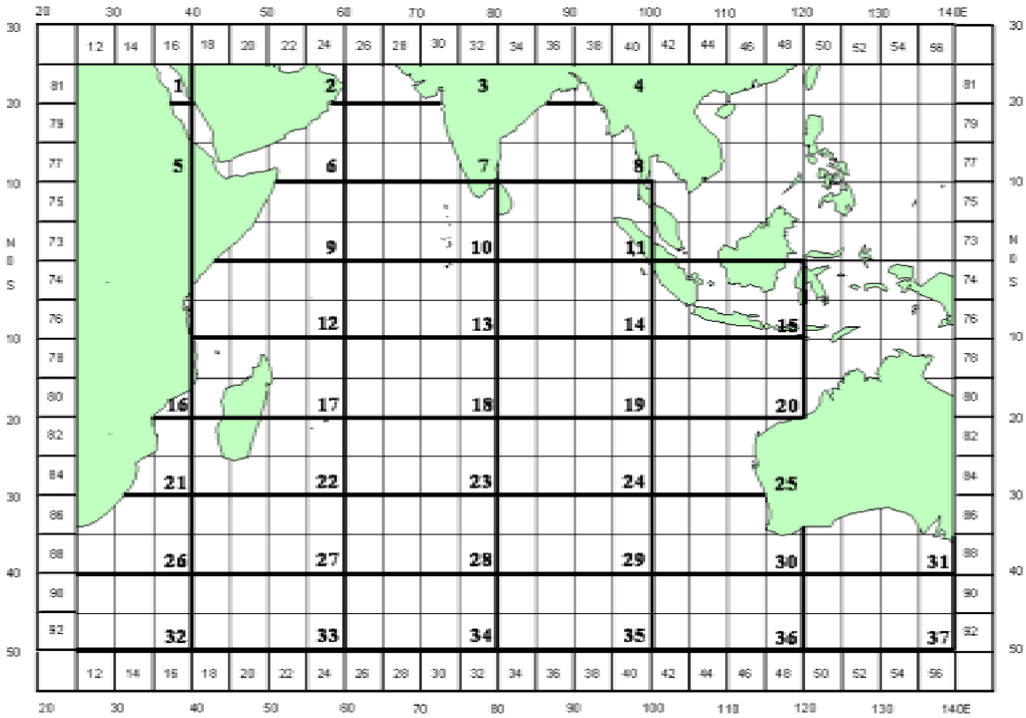

Fig. 1. Sub-area stratification used for catch at size substitution.

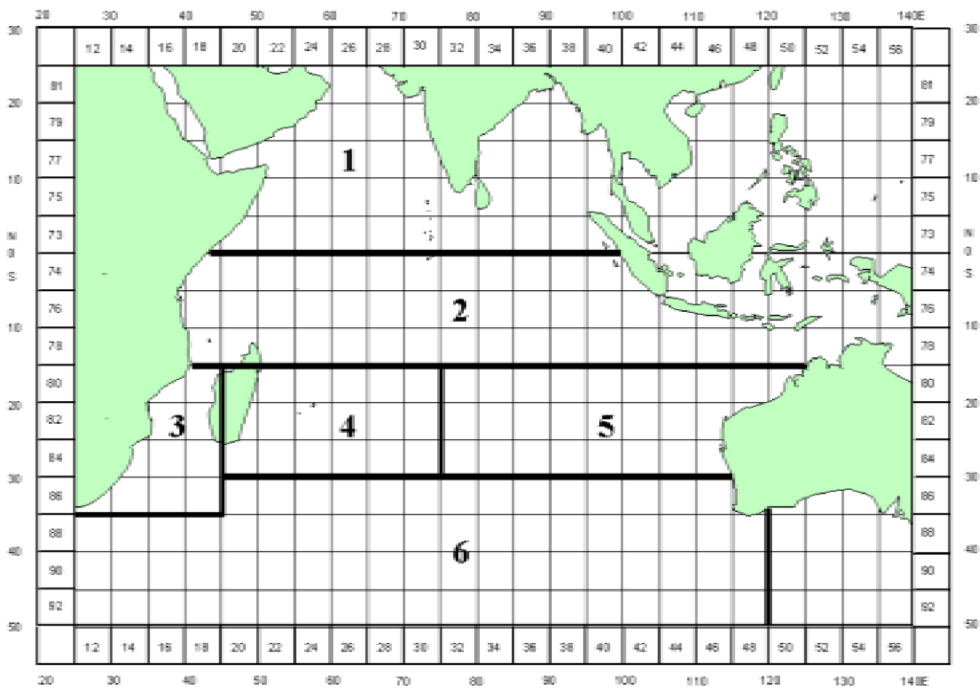

Fig. 2. Sub-area stratification used as an area effect on the standardization of catch per unit effort.

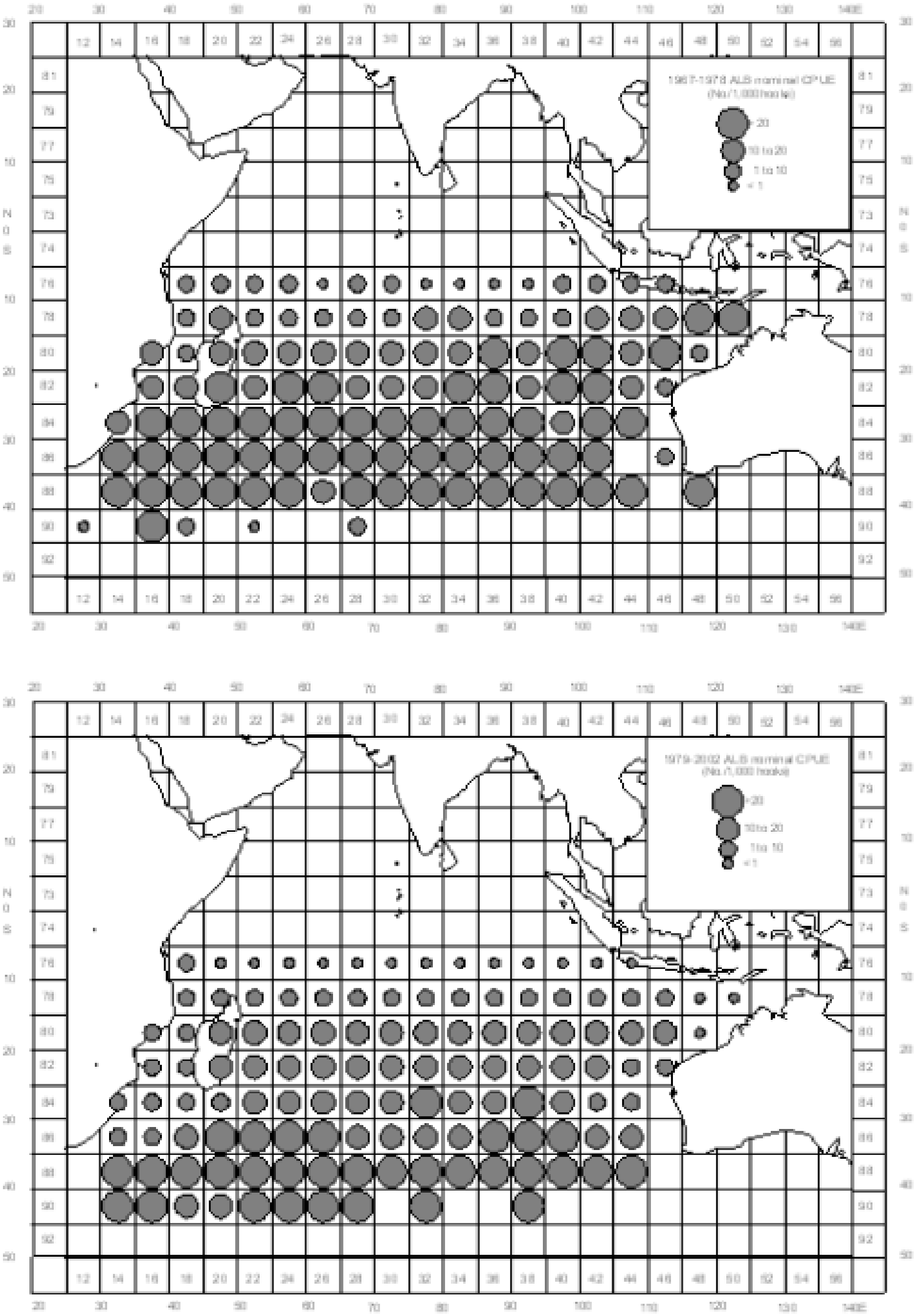

Fig. 3. Distribution of nominal catch per unit effort for albacore caught by Taiwanese longline fishery in the Indian Ocean for averaging 1967-1978 (top) and 1979-2002 (bottom).

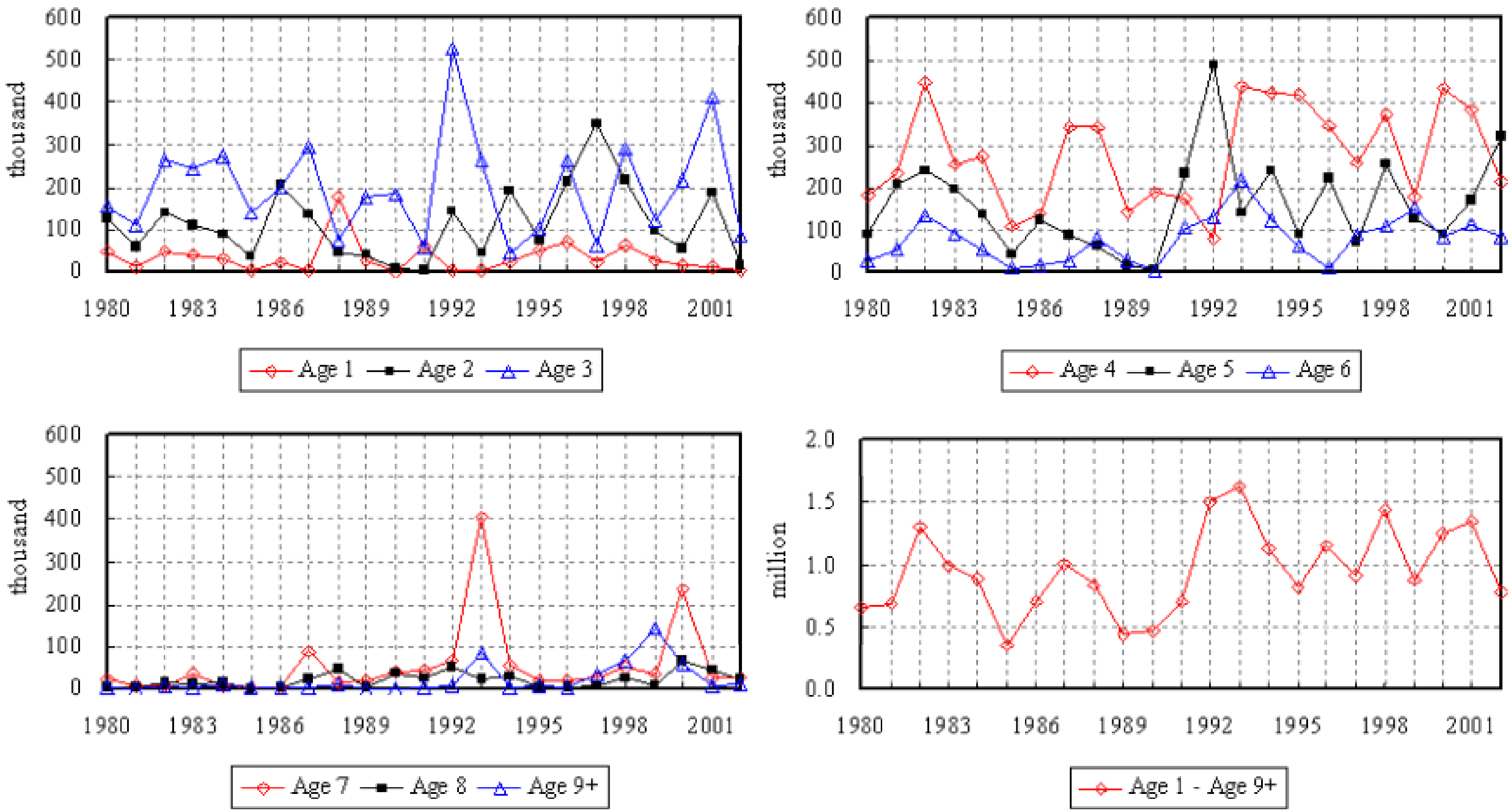

Fig. 4. Time-age distribution of catch at age of albacore caught by Taiwanese longline fleets in the Indian Ocean, 1980-2002.

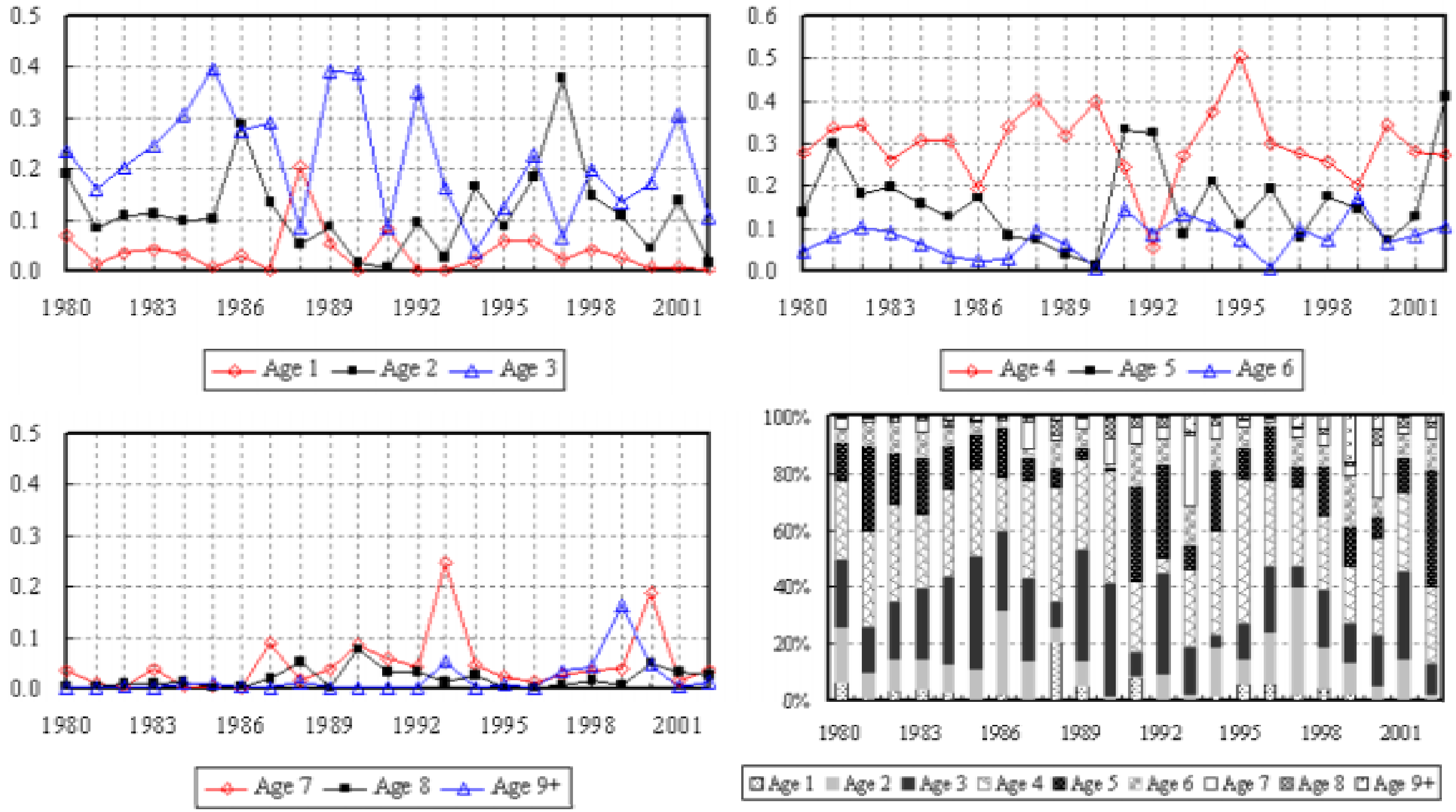

Fig. 5. The proportions of annual age distribution of albacore estimated from catch at age matrix from Taiwanese longline fishery in the Indian Ocean, 1980-2002.

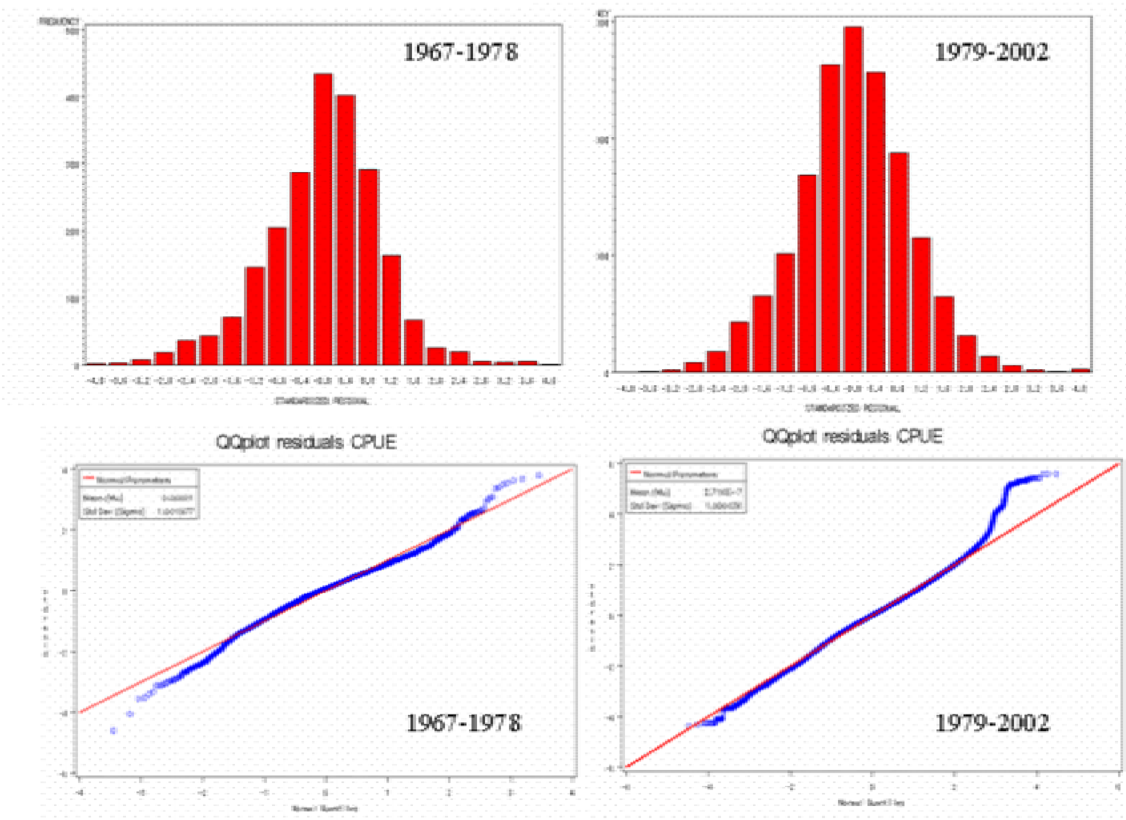

Fig. 6. The frequency distribution of residuals derived from general linear model expressed in histograms and QQ plots.

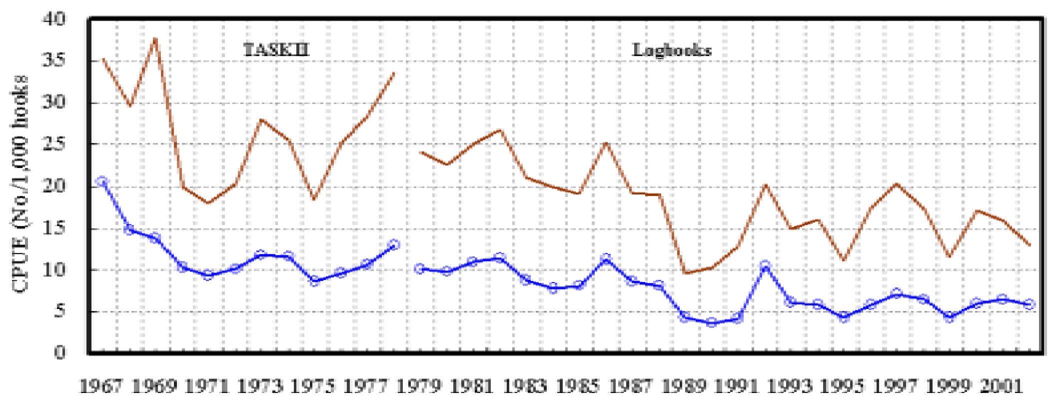

Fig. 7. Time series of albacore estimated by general linear model from Taiwanese longline fishery in the Indian Ocean for 1967-2002. Lines without circle represent nominal catch per unit effort.

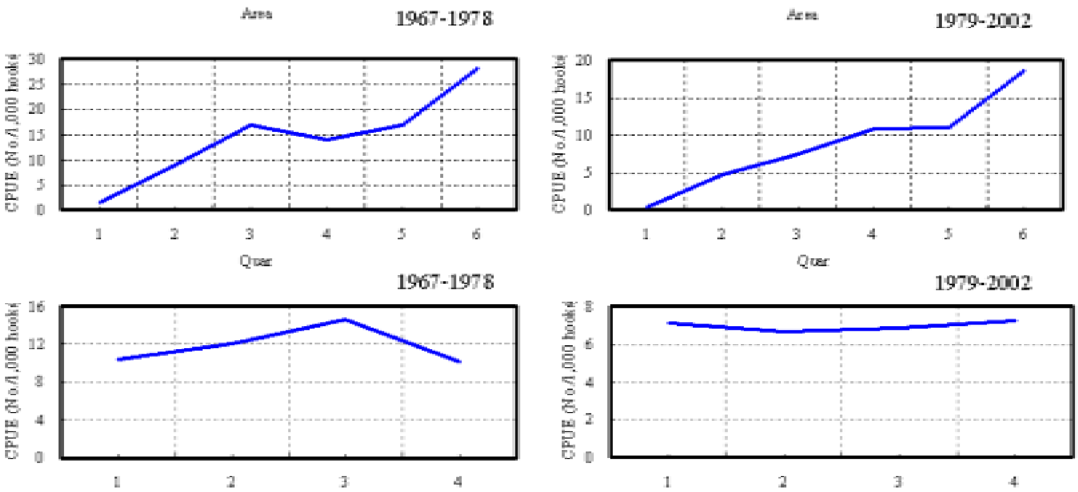

Fig. 8. Spatial and temporal changes of standardized CPUEs for quarter and area.

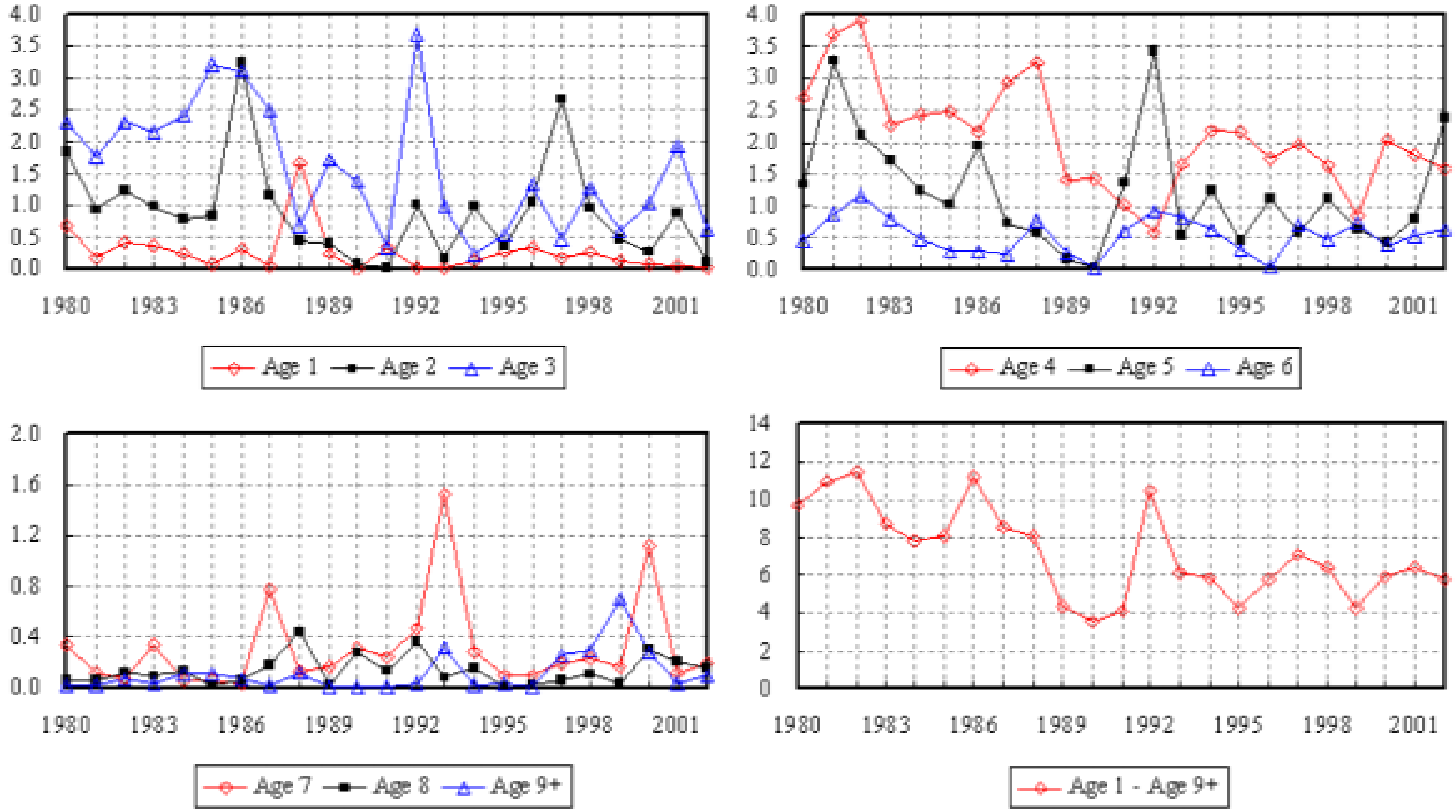

Fig. 9. Annual abundance indices by each age.