Standardized Taiwanese longline CPUE for bigeye tuna in the Indian Ocean up to 2002 applying targeting index in the model

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ABSTRACT

Taiwanese longline CPUE for bigeye tuna from 1968 to 2002 was standardized by GLM (CPUE-LogNormal error structured model) applying the same model used for Japanese longline CPUE in which SST (Sea Surface Temperature) and MLD (Mixed Layer Depth) were included in the model as oceanographic factors. The target effect was estimated based on catch composition approach in the GLM model for 1968-1995, instead of using NHF (Number of Hooks between Floats) due to insufficient information. For the period of 1995-2002, targeting effect was estimated based on real NHF information.

The standardized CPUE trend of Taiwanese longline fleet showed quite similar with that of Japanese fleet in the temperate area while Taiwanese CPUE was a little bit lower than that of Japanese during the middle 1980's. In the tropical area, Taiwanese CPUE showed declining trend during 1968 through 1991 which is basically similar to that of Japanese too. However, the CPUE increased significantly after 1991 and then was gradually declined until 2000 to the level of early 1980s. In the same period, the Japanese series has declined continuously to 2002.

1. Introduction

Japanese and Taiwanese longliners commenced their fishing operation in the Indian Ocean in 1952 and 1954, respectively (Chang and Liu 2000; Lee et al. 2004). Japanese longliners had targeted mainly on yellowfin until around 1975 and after then shifted rapidly their target species to bigeye with change of gear configuration from shallow set (regular set) to deeper set. Thereafter, Japanese longliners have principally targeting on bigeye except for the high latitudinal fishing ground for southern bluefin tuna. On the other hand, Taiwanese longliners which originally targeted on yellowfin, has currently established two different operation patterns following the development of the fishery: The first targets on albacore (ALB) for canning and the other on tropical tuna species (bigeye, BET and yellowfin, YFT) for sashimi market (Chang and Liu 2000; Chang 2002; Chang 2004). Since around 1986, the Taiwanese longliners in the Indian Ocean equipped with super-cold storage, started to catch bigeye by the deep setting operation (Hsu et al. 2001, Lee et al. 2004), shifting from their original target species, albacore in the temperate or yellowfin in the tropical Indian Ocean.

Bigeye CPUE for Japanese longline fishery in this Ocean has been standardized mainly by GLM (generalized linear model) method (Okamoto et al. 2001, Okamoto and Miyabe 2003). In the model, the number of hooks between float (NHF) was used to adjust the target effect. Before the shift of target species which occurred in the middle 1970's, NHF less than or equal to six was the major. Recently NHF greater than 10 became the major instead and has gradually increased to more than or equal to 18 in the tropical area (Okamoto et al. 2004). If the NHF information is not included in the model, the bigeye CPUE of longline operations targeting non-bigeye species using lesser NHF would relatively be under-estimated as indicated by the effect of NHF in the GLM results (Okamoto et al. 2004). Since the Taiwanese longline data did not include NHF information until 1995, it has been a problem how the target effect should be estimated before then (Hsu et al. 2001). There were many papers dealing with this issue (Chang et al. 1993; Lin 1998; Lee and Nishida 2002; Chang 2004), and among them, Lee and Nishida (2002) developed a criteria to classify the logbook data (set by set data) into regular (NHF less than 11) and deep (NHF equal or greater than 11) by using species composition (detail of this method is described in the Materials and Methods section). They applied the method into the LL type (operation type) known data set (1995-99, learning data set) and showed that 67.7% data were correctly classified, while 23.1% were un-classified and 9.2% were mis-classified.

In this paper, Taiwanese longline CPUE for bigeye in the Indian Ocean was standardized by using the same GLM model as that used for Japanese longline data (Okamoto et al. 2004), to provide as input data to ASPM (Age Structured Production Model) analyses for bigeye stock assessment in the WPTT 2004 of IOTC. Many treatments on target effect have been conducted in this paper with Lee and Nishida's method (arbitrarily abbreviated as L-N method in this paper) been used to compensate the lack of NHF information.

2. Material and Methods

1) General description on the Taiwanese longline catch and effort data

The catch and effort data for Taiwanese longline fishery is available from 1967. For 1967-1978, only data aggregated by month and 5 degree square is available. Data of 1967 was not used in this study since insufficiency of the first half year data. No NHF information was recorded in this period.

For 1979-2002, set by set logbook data are available in this period. The NHF information has been included in the logbook data since 1995, but the percentage of logbook which the NHF is recorded is about 40% of all logbook data.

Coverage of logbook was about 60-90% during 1979-1985, but went down to below 20% during 1989-1993. For the recent years, the coverage is about 30%. To increase the coverage, a logbook recovering program was conducted in 2003 to collect more logbooks from industry for the most recent two years (2001-2002). The new recovered logbooks were compiled together with those submitted regularly by fishermen, and the coverage has thus increased to above 50% in 2001. But they have not yet been reviewed completely and therefore the 2001 and 2002 data are still preliminary at present.

2) Environmental data

Environmental factors which are available for the analysis from 1960 to 2002 include SST (Sea Surface Temperature) and MLD (Mixed Layer Depth). These were obtained and applied as described in Okamoto et al. (2004).

3) Area definition

The area definition used for standardization of Japanese longline CPUE (Fig. 1 a) was used as the basis of this study. This area consists of five subareas in tropical and two subareas in the temperate areas (seven subareas in all). As the fishing effort in Subarea 5 was very few in the recent ten years, north equatorial and south equatorial parts of the Subarea 5 were then combined with Subarea 2 and Subarea 4, respectively (Fig. 1b). Thus there were six subareas left, and we refer Tropical for Subareas 1-4 combined, Temperate for Subareas 6 & 7 and ALL for Subareas 1-4, 6&7 in this study and perform CPUE standardization on the three areas.

4) Target effect estimation by L-N method

For the logbook data which did not include NHF information or the case in which NHF information was not used, setting type of each set was classified based on the criteria of Lee and Nishida (2004) in which $0.8 \leq BET/(BET+ALB) \leq 1$ and $0 \leq BET/(BET+ALB+SWO) \leq 0.40$ were classified as DEEP set ($11 \leq NHF \leq 20$) and as REGULAR set ($6 \leq NHF \leq 10$), respectively. Any set that can not be classified as any of the two set types, was referred as 'UNKNOWN'. As described in the general description of data, Task II (aggregated data by year, month and 5 degree square) without NHF information is the only available data in the period of 1968-1978. Therefore, for convenience, the same criterion was applied to the Task II data.

5) Case studies conducted in this study

Since the GLM model to be used and the method to estimate target effect was determined beforehand, the main subject to be considered was the treatment of target effect for the Task II data during 1968-1978 and for the logbook data during 1995-2002 (when the NHF information covers about 40% of logbook data). To compare the CPUE trends derived from different target effect treatments, the following seven CASEs were tested. Annual change of the ratio of deep set assumed or estimated for each CASE was shown in Fig. 2.

<u>CASE A SERIES:</u> This series was to examine the discrepancies among the CPUE series derived from different target effect assumptions before 1979 (1968-1978).

CASE A1 (1968-2002): All sets before 1979 (Task II data, 1968-1978) were assumed to be REGULAR in ALL AREAS, and targeting was estimated by L-N method for 1979-2002.

CASE A2 (1968-2002): ALL sets before 1979 (Task II data 1968-1978) were assumed to be DEEP in north of 15S and REGULAR in south of 15S, and targeting was estimated by L-N method for 1979-2002.

CASE A3 (1968-1981 & 1979-2002):

1968-1981 (RUN1): Targeting was not estimated, that is, the effect of targeting was not included in the GLM model in this RUN.

1979-2002 (RUN2): Targeting was estimated by L-N method for 1979-2002.

Each RUN was done separately for each data, and results from each data were connected at

1979 by adjusting average CPUE of three years from 1979 to 1981 to be 1.0.

CASE A4 (1968-2002): Targeting was estimated by L-N method for ALL YEARS (not only for logbook but also for Task II data).

<u>CASE C SERIES:</u> This series was to examine the discrepancies among the CPUE series derived from different target effect assumptions after 1995

CASE C1 (1968-2002):

1968-1994: Targeting was estimated by L-N method.

1995-2002: For the logbook with NHF, target was estimated by NHF (DEEP: 11<=NHF and REGULAR: NHF<=10). For the logbook without NHF, target was estimated by L-N method.

CASE C2 (1968-2002):

1968-1994: Targeting was estimated by Lee & Nishida's method.

1995-2002: Targeting was estimated by NHB (DEEP: 11<=NBH and REGULAR: NBH<=10) for logbook data in which NBH was recorded. Logbook data without NBH data were not used.

CASE C3 (1968-1997 & 1995-2002):

1968-1997 (RUN1): Targeting was estimated by Lee & Nishida's method.

1995-2002 (RUN2): NHF was grouped into six classes (NHFCL_1: NHF 5-7, NHFCL_2: NHF 8-10, NHFCL_3: NHF 11-13, NHFCL_4: NHF 14-16, NHFCL_5: NHF 17-19, NHFCL_6: NHF 20-21) for logbook data in which NHF was recorded. Logbook data without NHF data were not used.

Each RUN was done separately and connected at 1995 by adjusting average CPUE from 1995 to 1997 to be 1.0.

6) GLM (General Linear Model) used

CPUEs based on the number of catch were used (number of fish/1000 hooks).

The model used for GLM analyses (log normal error structure model) with SST and MLD was as follows.

Model (lognormal error structured model)**:**

$$\text{Log}(CPUE_{ijkl} + const) = \mu + YR_{(i)} + MN_{(j)} + AREA_{(k)} + NHF_{(l)} + SST(m) + MLD(n) + YR(i)*AREA_{(k)} + MN(j)*AREA_{(k)} + AREA(k)*NHFCL(l) + AREA(k)*SST(m) + AREA(k)*MLD(n) + SST(k)*MLD(n) + e_{(ijkl....)}$$

Where Log : natural logarithm,
CPUE : catch in number of bigeye per 1000 hooks,
Const : 10% of overall mean of CPUE
μ : overall mean,
$YR_{(i)}$: effect of year,
$MN_{(j)}$: effect of fishing season (month),
$AREA_{(k)}$: effect of subarea,
$NHFCL_{(l)}$: effect of gear type (class of the number of hooks between floats),
$SST_{(m)}$: effect of SST,
$MLD_{(n)}$: effect of MLD,
YR (i)*AREA (k) : interaction term between year and subarea,
MN (j)*AREA (k) : interaction term between fishing season and subarea,
AREA (k)*NHFCL (l) : interaction term between subarea and gear type,
AREA(k)*SST (m) : interaction term between subarea and SST,
AREA(k)*MLD(n) : interaction term between subarea and MLD,
SST(m)*MLD(n) : interaction term between SST and MLD,
$e_{(ijkl..)}$: error term.

In CASE C3, six classes of NHFCL were applied while the targeting index (1=DEEP and 2=REGULAR) estimated by L-N method or specific classification of NHF (CASE C2) were used instead of NHFCL. The targeting estimated as 'UNKNOWN' was treated as '.', that is, the data with 'UNKNOWN' was treated as that without targeting information in the GLM analysis.

Effect of each Year was gotten by the method used in Ogura and Shono (1999) that uses lsmean of Year-Area interaction as the following equation.

$CPUE_i = \Sigma\, W_j * (\exp(\text{lsmean}(\text{Year } i*\text{Area }_j))-\text{constant})$
Where $CPUE_i$ = CPUE in year i,
W_j = Area rate of Area j , ($\Sigma W_j = 1$),
lsmean($Year*Area_{ij}$) = least square mean of Year-Area interaction in Year i and Area j,
constant = 10% of overall mean of CPUE.

3. Results and Discussion

1) Year trend of targeting estimated by L-N method and real NHF

Annual changes of the ratio of the three categories, DEEP, REGULAR and UNKNOWN based on Lee and Nishida (2002) for 1968-2002, were shown in Fig. 3. In the temperate area, most operations were REGULAR before 1990 but DEEP and UNKNOWN have increased to about 20% and 15%, respectively, in recent nine years. This trend did not deviate much from the knowledge on the development of fishery as more operations have been deployed in the western region of Subarea 6 and eastern region of Subarea 7 for bigeye in recent years. However, even such, the magnitude was not expected to be so high.

On the other hand, there is no clear trend in the tropical area. The ratio of DEEP in this area was larger than 80% and increased to 90% in the recent four years. However, it is worthwhile to note that the ratio of DEEP set from L-N method in tropical area was larger than 70% in 1979 and was also larger than 50% in the period of 1968-1978, except in 1973 (30%). Comparatively, Japanese longliners shifted their target in tropical area from yellowfin to bigeye since around 1975 (Suzuki et al 1977), and before that time, Japanese longliners used REGULAR set (NHF<=10) in all areas and no DEEP set was used.

By experience, there was a time lag of a few years before the transferring of operation pattern from Japanese fishery to Taiwanese, such as change of gear configuration and shift of target species. Since DEEP set ratio in Japanese longline in tropical area exceeded 80% not until 1982 and have been kept in high ratio thereafter (Okamoto et al. 2004), the DEEP set ratio for targeting bigeye of Taiwanese fishery might not have been such high before that time because of the time lag described above and because yellowfin has always been one of the major target species in the tropical area for the fishery.

In Fig. 4, the ratio of NHF classified into six categories (NHFCL) for 1995-2002 was shown. The ratio of DEEP set (NHFCL 3 – 6) has increased from 70% to 90% and from 10% to 60% in tropical and temperate areas, respectively.

Based on the knowledge on the targeting of Taiwanese fleet, the ratio of DEEP set (targeting bigeye) should have been very low or not existed before at least 1975, and would be higher since 1995 (over 70%, as shown in Fig. 4). Considering that 1) Japanese longline took five years to gradually shift to deep setting type, from ratio of DEEP set of nearly 0% in 1975 to 80% in 1980, 2) there should have been a time lag (maybe several years) to transfer the operating pattern to Taiwanese fleet, and 3) Yellowfin has always been one of the major target species for Taiwanese fleet in the tropical area, the continuous high ratio of DEEP set (larger than 60 or 70%) estimated by L-N method in the tropical area throughout the years from 1968 (1979) – 2002, seems unnatural.

The historical change of species composition in each tropical subareas (Fig. 5) showed that, in Subarea 1 and 2, the north equatorial areas, most of catch consisted of yellowfin and bigeye, and the percentage of albacore catch was very low. The same catch composition pattern could also be observed in early years (1960s-mid 1970s) in Subarea 3 and 4. According to L-N criteria, most of longline operations in the north of equator will be classified to be DEEP or UNKNOWN set (DEEP: $0.8 \leq BET/(BET+ALB) \leq 1$, and REGULAR: $0 \leq BET/(BET+ALB+SWO) \leq 0.40$) in any period, even in the 1960's when bigeye was not the target. In this regard, the L-N criteria might not be an appropriate tool to estimate the actual gear configuration in the tropical area where is the main fishing ground for bigeye tuna. This was due to the L-N method did not consider the yellowfin-targeting setting type. However, the method might be effective to separate the albacore-targeting from bigeye-targeting settings in the temperate area especially after the target-shifting was virtualized around 1986.

2) Case studies on CPUE standardizations by GLM:

<u>CASE A:</u>

Annual trends of standardized bigeye CPUE derived from four cases of CASE A were overlaid in Fig. 6. All the CPUE series have adjusted so that average of 1997-2002 equals 1.0. There have not many discrepancies among the CPUE series in the temperate area.. In the tropical area, however, there exist large gap in relative CPUE in CASE A1 between 1978 and 1979, that is, the CPUE before 1979 was extremely high comparing to that after 1979. This gap was apparently caused by the target assumption of CASE A1, in which targeting was all assumed to be REGULAR during 1968-1978. For the tropical area, this assumption should be in accordance with the fishery development in terms of change of gear configuration, however the result for whole series from 1968-2002 seems most unrealistic.

To the contrary, in CASE A2 all operation in the north of 15S before 1979 was assumed to be DEEP set and this has eased off the fluctuation of DEEP set ratio. The result in CPUE trend (Fig. 6) showed that the gap between 1978 and 1979 has disappeared, however the CPUE level before 1979 was depressed to be a little bit lowered than that during 1979-1987 in the tropical area.

In CASE A3 in which no targeting assumption was made in the model before 1979, the gap in relative CPUE in tropical area between 1978 and 1979 was still noted but was much flattened than that observed in CASE A1.

In CASE A4, L-N criteria was applied not only to logbook data (1979-2002) but also to TASK II data (1968-1978) to keep the consistency of targeting assumption between the periods before 1979 and after 1979. The result (Fig. 6) showed a slight decreasing trend during 1968-1991 in the tropical, and no gap was detected before and after 1979. As shown in Fig. 5, the ratio of albacore catch was relatively high with large fluctuation in the tropical area between the equator and 15˚S or 20˚S. This is because the definition of Subareas 4 and 5 have covered the albacore fishing ground in between 15°S and 20°S. But for this study, it also implied that both operations targeting on albacore and on tropical tunas (yellowfin and bigeye) have co-existed in the tropical area.

In the early years when bigeye has not been significantly exploited, the bigeye CPUE might not be decreasing significantly as the result of CASE A1 or A3. We therefore choose CASE A4 arbitrarily between the two left cases, to keep consistencies of targeting assumption before and after 1979.

CASE C:

Annual trends of standardized bigeye CPUE derived from four cases of CASE C and that from CASE A4 were overlaid in Fig. 7. All the CPUE series have been adjusted so that average of 1968-1994 equals 1.0. L-N criteria were applied to 1968-1994 data for all CASE C as well as CASE A4. The CPUE trends from all cases were quite similar in the temperate area which is not traditionally bigeye fishing ground. In the tropical area, the CPUE trends of CASE A4 and C3 were similar while that of CASE C1 for 1995-2002 was relatively higher than other CASEs. The CPUE of CASE C2 was a little bit higher than CASE A4 and C3, but the level is much closer to CASE A4 and C3 than CASE C1. In the selection of the final model from CASE A4, C2 and C3, we adhered to using the real NHF information after 1995. It might be a good idea to group NHF information into several categories in the standardization, as in CASE C3. However, a preliminary test running on CASE C3 using data with or without 2001-2002 showed very different relative CPUE trends (not shown here), which might imply that this treatments to NHF data was not appropriate for this study. Therefore, CASE C2 was adopted as the final CASE for further studies.

Results of ANOVA and distributions of the standard residual in CASE C2 were shown in Table 1 and Fig. 8, respectively. Distributions of the standard residual did not show remarkable difference from the normal distribution.

3) The standardized CPUE trend of Taiwanese fleet and comparison with Japanese:

Standardized CPUE (1968-2002) derived from CASE C2 was shown in Fig. 9 overlaid with standardized Japanese longline CPUE. Each CPUE series has been adjusted to its average. In the temperate area, the relative CPUE of Taiwanese fleet decreased to 0.6 in 1975 and increased steeply to 1.6 in 1976. Since then, it gradually decreased to 0.5 in 1985 and increased again to 1.0 in 1990; after when it has been kept at about the same level to the 2002. This trend is quite similar to that of Japanese fleet, except that Taiwanese series was a little bit lower in the middle 1980's than Japanese, and the Japanese series declined more significantly after 1994.

In the tropical area, Taiwanese CPUE showed declining trend in general during 1968 through 1991 which is basically similar to that of Japanese. After 1991, however, it increased to a level as in the end 1960s and then declined gradually until 2000 to the level of early 1980s. In general the 1990s series were relatively higher than those of 1970s and 1980s. The CPUE was then increased sharply in the last two years (2001-2002), but as mentioned in the Material and Methods section, these two years data are still quite preliminary. Comparatively, the Japanese CPUE series has declined continuously during this period. This discrepancy might partly be resulted from the abovementioned possible over-estimation of deep setting ratio for Taiwanese CPUE in the early period by the L-N method.

Considering the preliminary status of 2001-2002 data and their unnatural rise-up in CPUE series, CASE C2 was applied also to the period from 1968 to 2000. Annual values of standardized CPUEs by CASE C2 for 1968-2002 and for 1968-2000 are listed in Appendix table.

4) Examinations of CPUE by season, area and setting types from the GLM results:

Standardized bigeye CPUE trend of season (month) and setting type or target assumption (based on L-N criteria) derived from LSMEANS (least square means) of GLM, was compared by major area. In Fig. 10, the effect of month and target assumption based on the GLM results of 1979-1994 were shown.

In the temperate area, the peaks of CPUE were observed in March – April in western part (Subarea 6) and July and August in eastern part (Subarea 7), respectively while the CPUE in October – December was lowest in the year. This was not well accordant with the recent knowledge about Taiwanese fleet movement. On the other hand, no remarkable trend was observed in the tropical area although the CPUE was slightly higher from September to January. The relative CPUE series by setting type (or targeting) were quite similar in all areas. In general, CPUE of DEEP set was five to eight times higher than that of REGULAR set.

Fig. 11 shows the comparison of bigeye CPUE by month and setting type for 1995-2002 between setting type defined based on L-N method and actual NHF information. The monthly CPUE trends were very similar between the two estimation methods. However, the seasonal pattern in the temperate area was different in this period from that in 1979-1994 in Fig. 10 and shows that the peak CPUE exists in summer season, June-July and lowest in winter season, December-January. Nevertheless, in terms of setting type (bottom panels of Fig. 11), the CPUE of DEEP estimated from L-N method was much higher than that from NHF information, and CPUE of REGULAR was adversely much lower. This phenomenon was noted both in the temperate and tropical areas. This was mainly because that the L-N method classifies catch records with high bigeye catch rate, $0.8 \leq BET/(BET+ALB) \leq 1$ as DEEP and those with low catch rate, $0 \leq BET/(BET+ALB+SWO) \leq 0.40$, as REGULAR. On the other hand, the DEEP setting type based on actual NHF ($11 \leq NHF$) includes data records with low bigeye catch, even zero catch, to high catch, and this is also true for the REGULAR setting type ($NHF \leq 10$).

This difference in the nature between setting type defined based on species composition and that from actual NHF information would be a fundamental and important point for considering further improvements when dealing with target effect in CPUE standardization. It is also worthwhile to examine the consequences between setting type (deep and shallow) and target species.

Fig. 12 showed the standardized relative CPUE of NHFCL derived from GLM for 1995-2002. In the temperate area, the CPUE went up from 0.8 in NHFCL_1 to 1.4 in NHFCL_4, and declined to 0.5 in NHFCL_6. In the tropical area, the CPUE increased from 0.9 in NHFCL_1 to the peak (1.2) in NHFCL_5 and decreased slightly to 1.1 in NHFCL6. The observation showed that there was different critical depth that will produce higher CPUE in the temperate area against in the tropical area. Comparatively, the CPUE trend of NHFCL in the tropical area is similar to that observed in Japanese longline (Okamoto et al. 2004). But the CPUE of Japanese in the temperate area is flatter than that of Taiwanese, probably due to that Japanese fleet did not deploy many efforts in the temperate area for bigeye.

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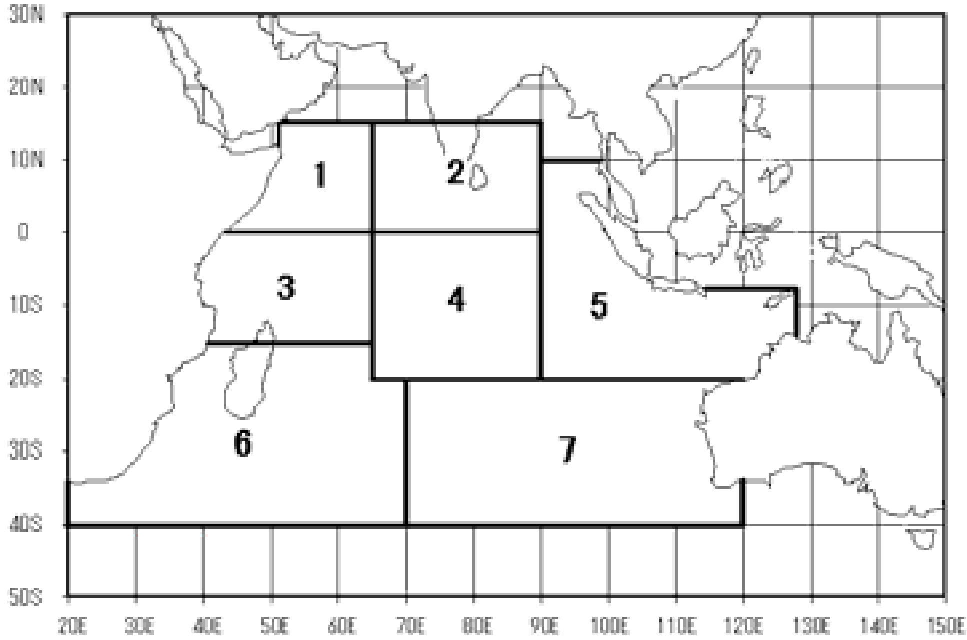
Table 1. ANOVA table of GLM applying CASE C2 for the tropical, temperate and all Indian Ocean for 1968-2002.

	Model: Lognormal						
	Source	D.F.	S.S.	M.S.	F Value	Pr > F	R-Square
TROPICAL	Model	194	4791.02	24.70	55.04	<.0001	0.450593
	Year	34	174.54	5.13	11.44	<.0001	
	Month	11	78.86	7.17	15.98	<.0001	
	Area	3	90.76	30.25	67.42	<.0001	
	NHFCL	1	1669.45	1669.45	3720.60	<.0001	
	SST	1	41.82	41.82	93.20	<.0001	
	MLD	1	0.13	0.13	0.29	0.591	
	Year*Area	100	184.09	1.84	4.10	<.0001	
	Month*Area	33	58.19	1.76	3.93	<.0001	
	Area*NHFCL	3	206.23	68.74	153.20	<.0001	
	Area*SST	3	91.07	30.36	67.66	<.0001	
	Area*MLD	3	4.07	1.36	3.02	0.0285	
	SST*MLD	1	0.05	0.05	0.11	0.7427	
TEMPERATE	Model	97	2136.23	22.02	26.17	<.0001	0.254159
	Year	34	267.72	7.87	9.36	<.0001	
	Month	11	283.50	25.77	30.62	<.0001	
	Area	1	13.84	13.84	16.44	<.0001	
	NHFCL	1	153.43	153.43	182.29	<.0001	
	SST	1	10.30	10.30	12.23	0.0005	
	MLD	1	1.71	1.71	2.03	0.1541	
	Year*Area	33	96.76	2.93	3.48	<.0001	
	Month*Area	11	60.50	5.50	6.53	<.0001	
	Area*NHFCL	1	4.46	4.46	5.30	0.0213	
	Area*SST	1	8.08	8.08	9.59	0.002	
	Area*MLD	1	21.81	21.81	25.91	<.0001	
	SST*MLD	1	1.35	1.35	1.61	0.2051	
ALL_IND	Model	291	12430.02	42.71	83.23	<.0001	0.541973
	Year	34	189.13	5.56	10.84	<.0001	
	Month	11	70.96	6.45	12.57	<.0001	
	Area	5	235.76	47.15	91.87	<.0001	
	NHFCL	1	1741.09	1741.09	3392.44	<.0001	
	SST	1	96.35	96.35	187.72	<.0001	
	MLD	1	2.71	2.71	5.28	0.0216	
	Year*Area	167	388.78	2.33	4.54	<.0001	
	Month*Area	55	386.72	7.03	13.70	<.0001	
	Area*NHFCL	5	559.57	111.91	218.06	<.0001	
	Area*SST	5	309.57	61.91	120.64	<.0001	
	Area*MLD	5	19.52	3.90	7.61	<.0001	
	SST*MLD	1	1.60	1.60	3.11	0.0778	

a.



b.

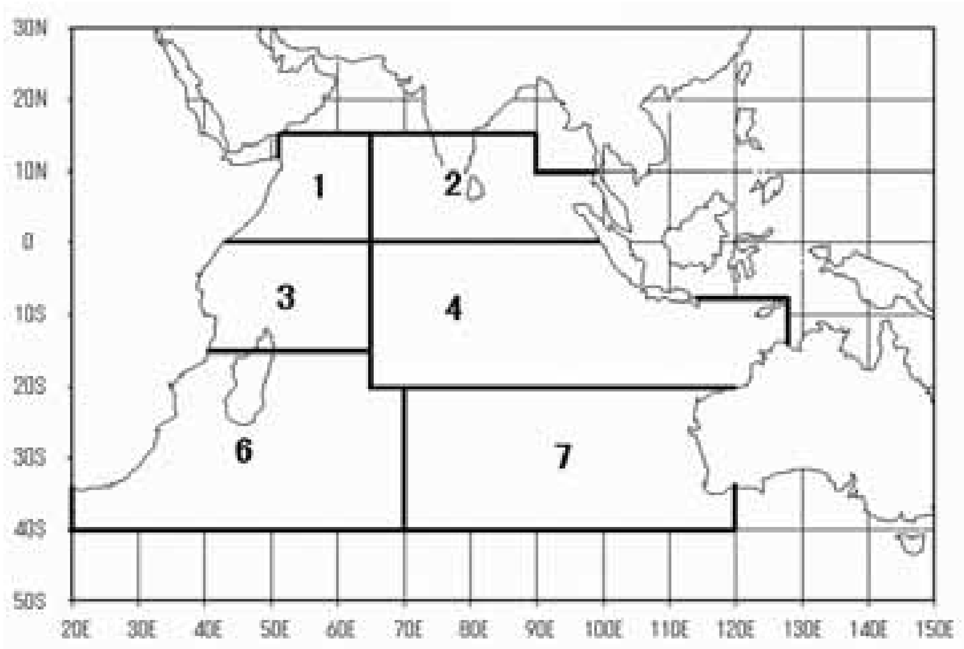


Fig. 1. Area definition used for standardization of bigeye CPUE for Japanese longline (a) in Okamoto et al. (2004) and for Taiwanese longline (b) in this study.

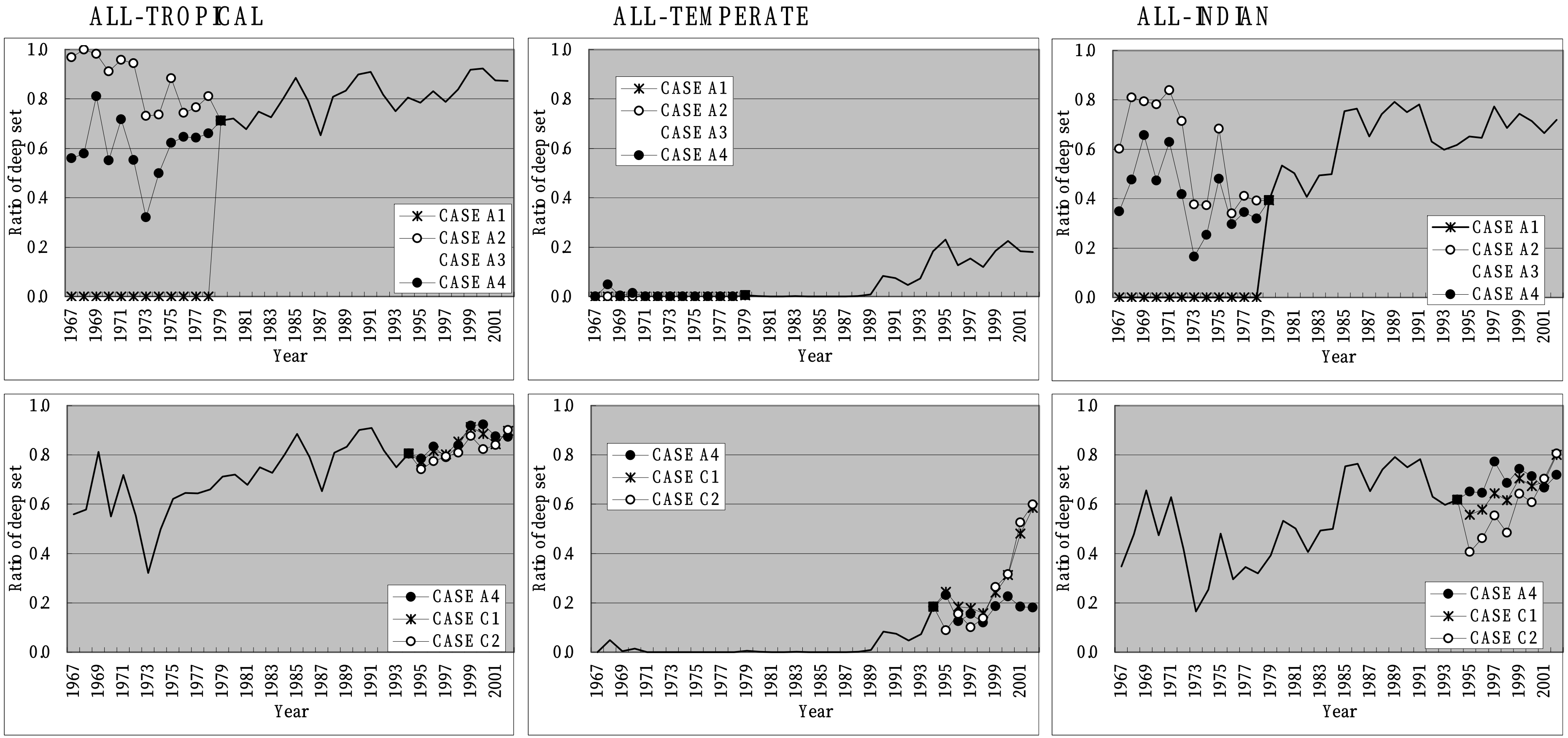


Fig. 2. The ratio of DEEP set assumed or estimated by Lee and Nishida's criteria in each CASE.

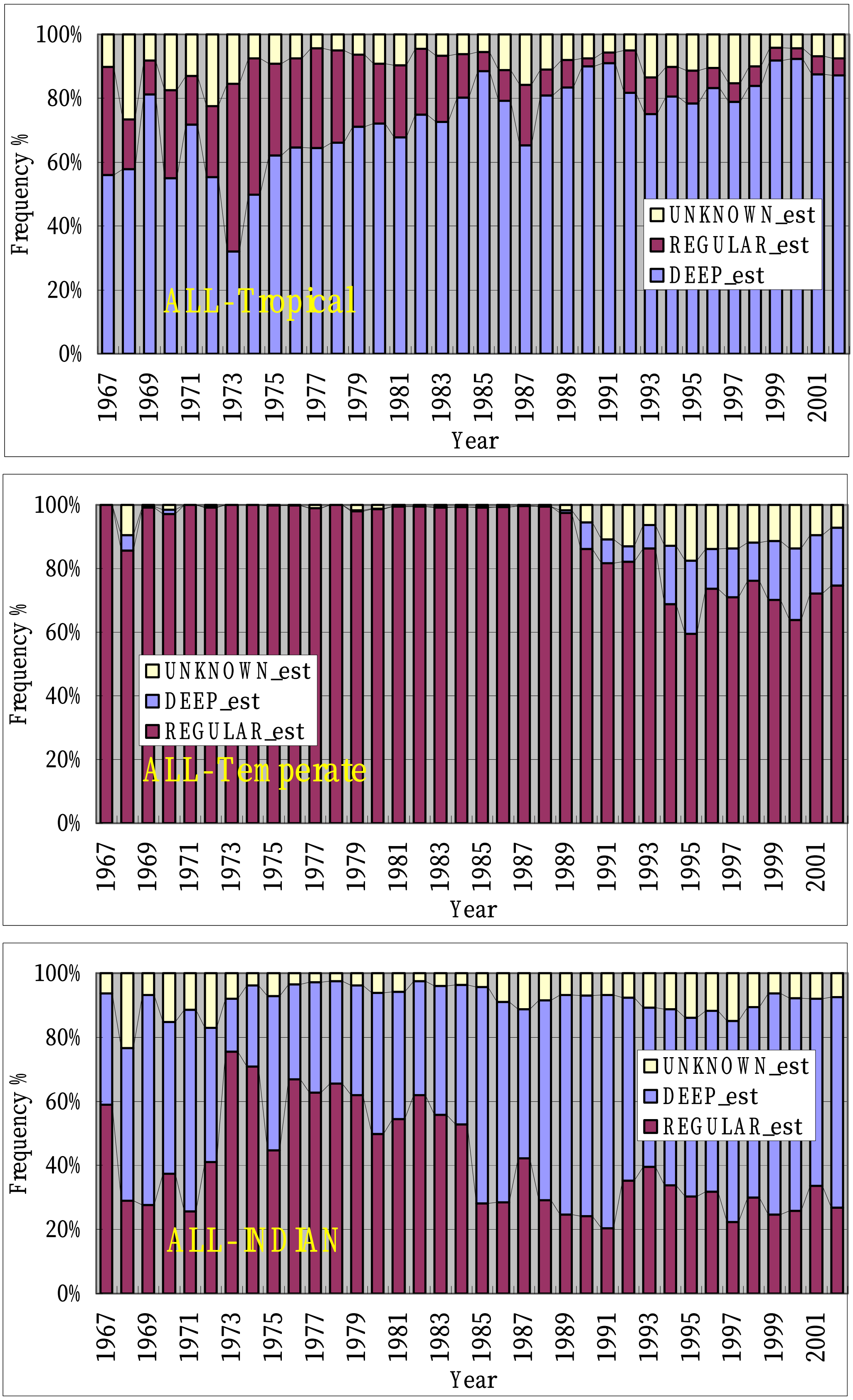


Fig. 3. Annual change in the targeting (DEEP, REGULAR and UNKNOWN) estimated by the criteria of Lee and Nishida (2002) for 1968-2002.

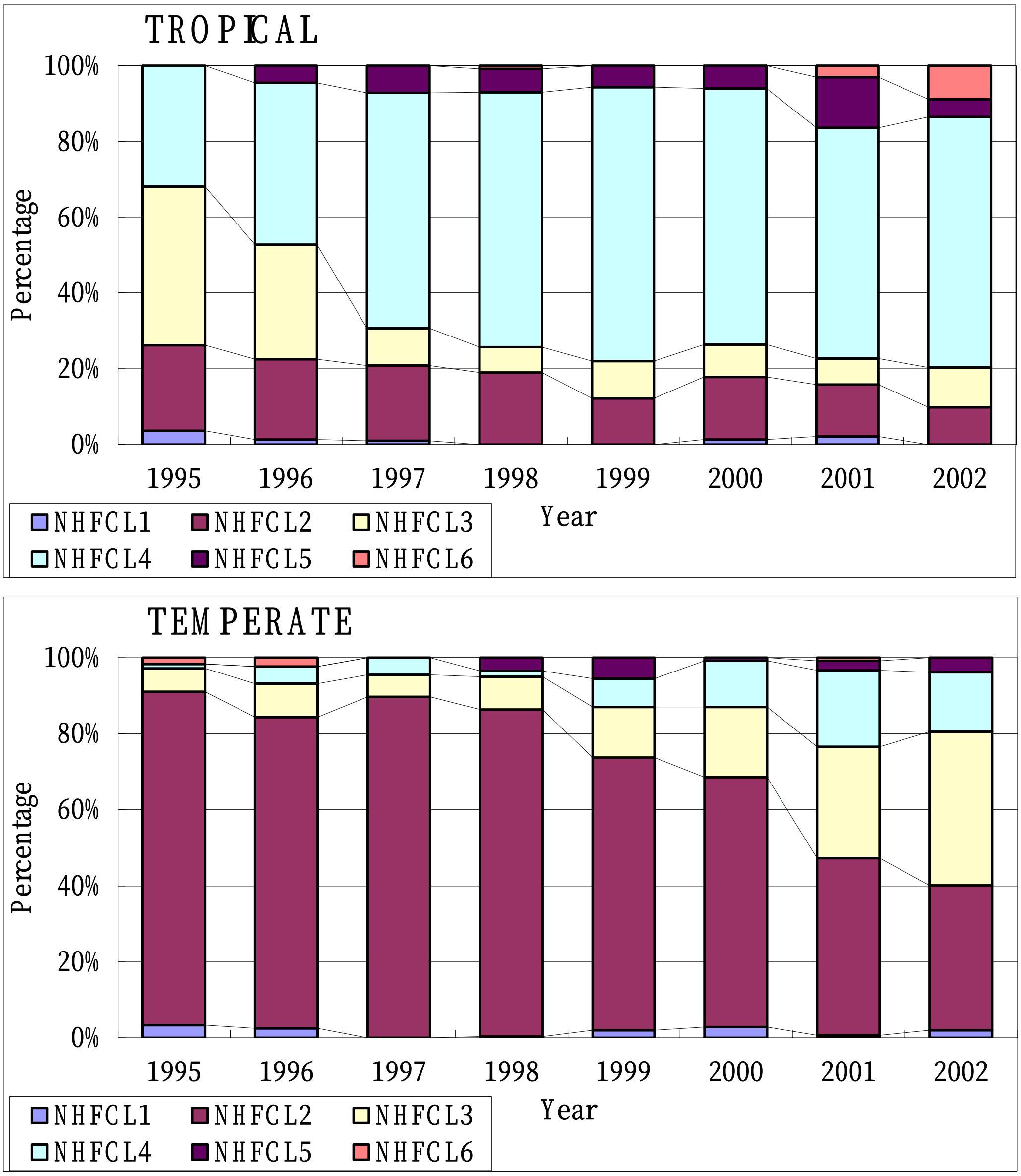


Fig. 4. Annual change in the number of hooks between float (NHF) for 1995-2002 classified into six categories, NHFCL_1: NHF 5-7, NHFCL_2: NHF 8-10, NHFCL_3: NHF 11-13, NHFCL_4: NHF 14-16, NHFCL_5: NHF 17-19, NHFCL_6: NHF 20-21.

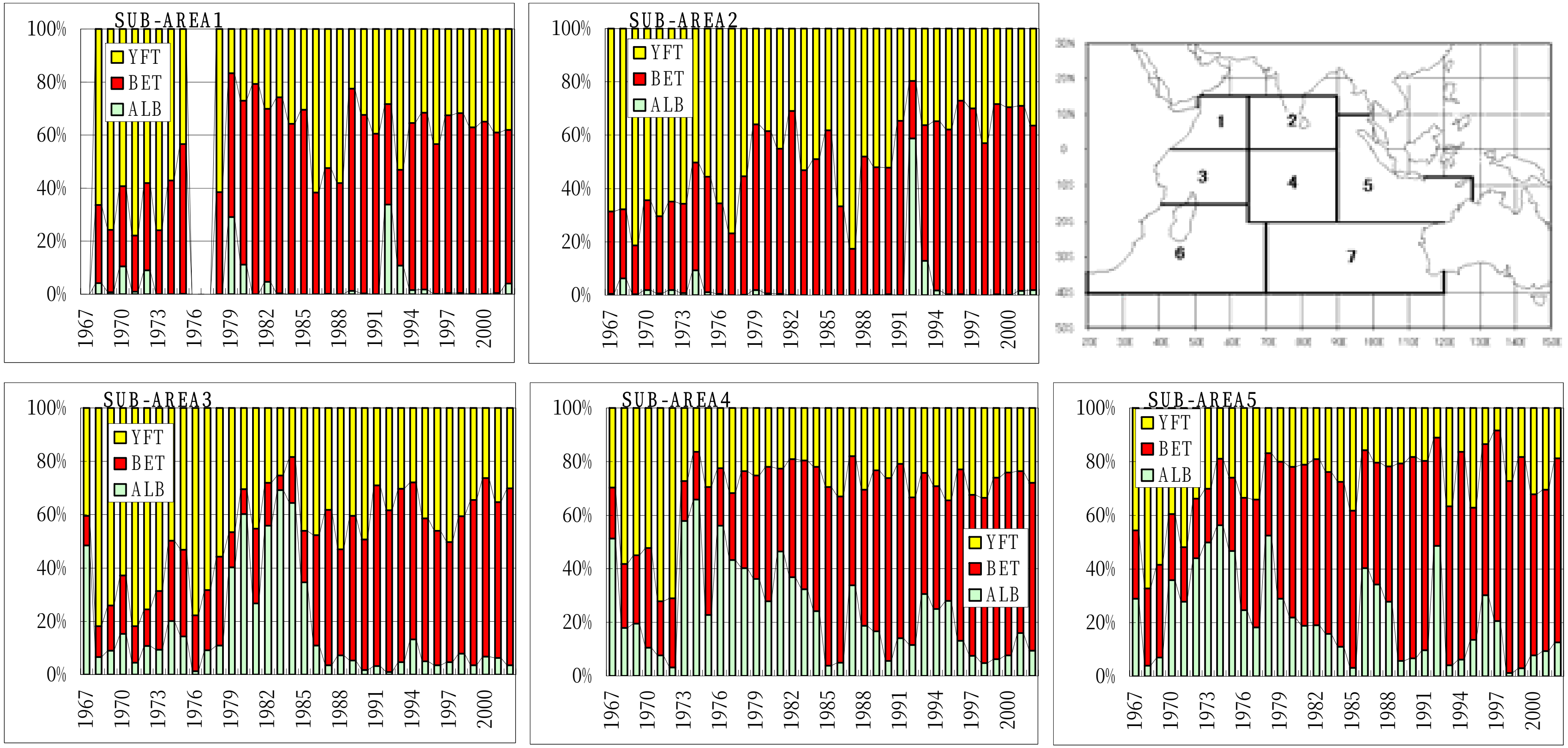


Fig. 5. Historical change in species composition in each tropical subareas. Subarea definition used in Okamoto et al. (2004) for Japanese longline were used.

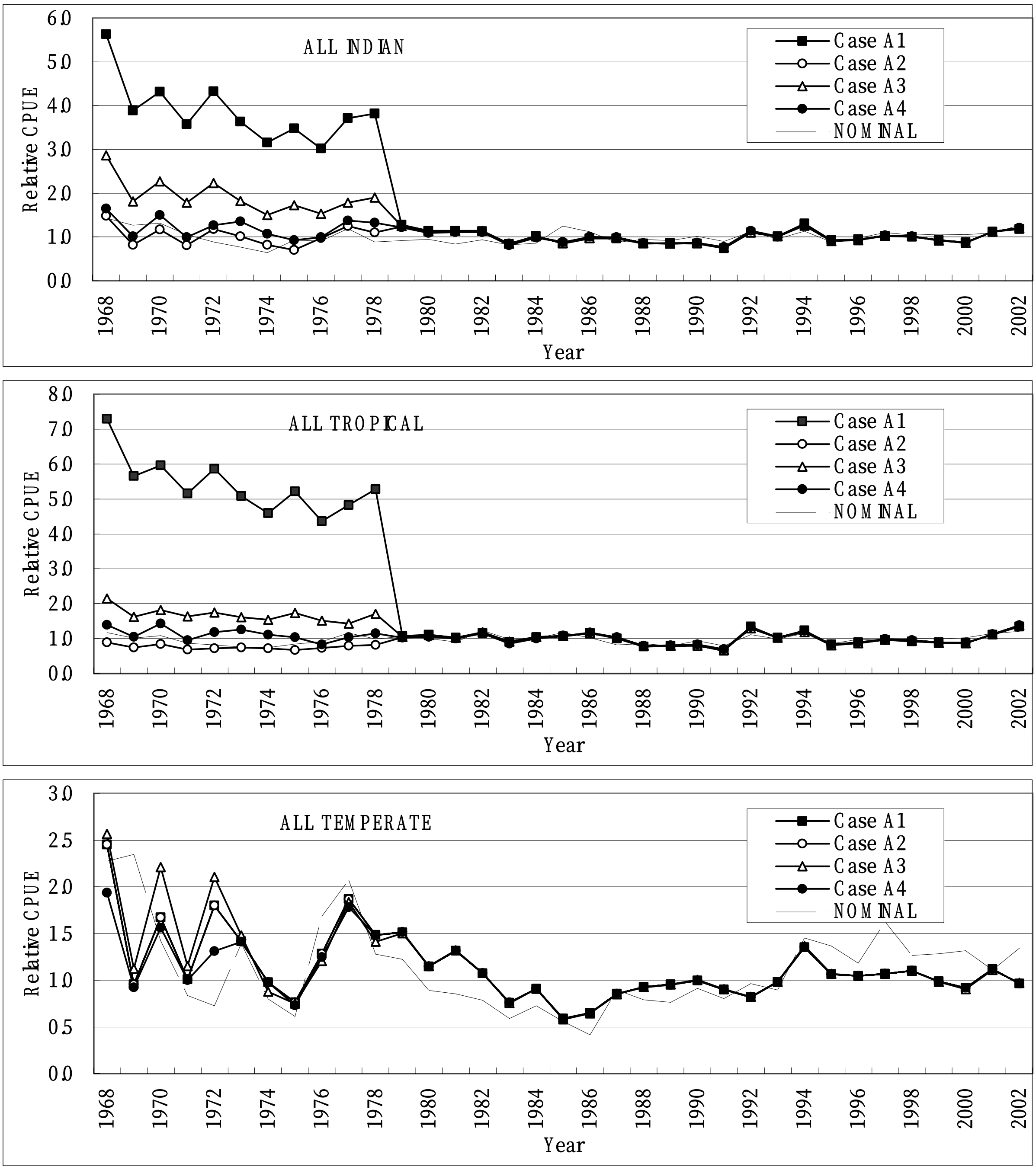


Fig. 6. Annual trends of standardized CPUE derived from four cases of CASE A were overlaid. Each CPUE was expressed relatively as average during 1979-2002 is 1.0.

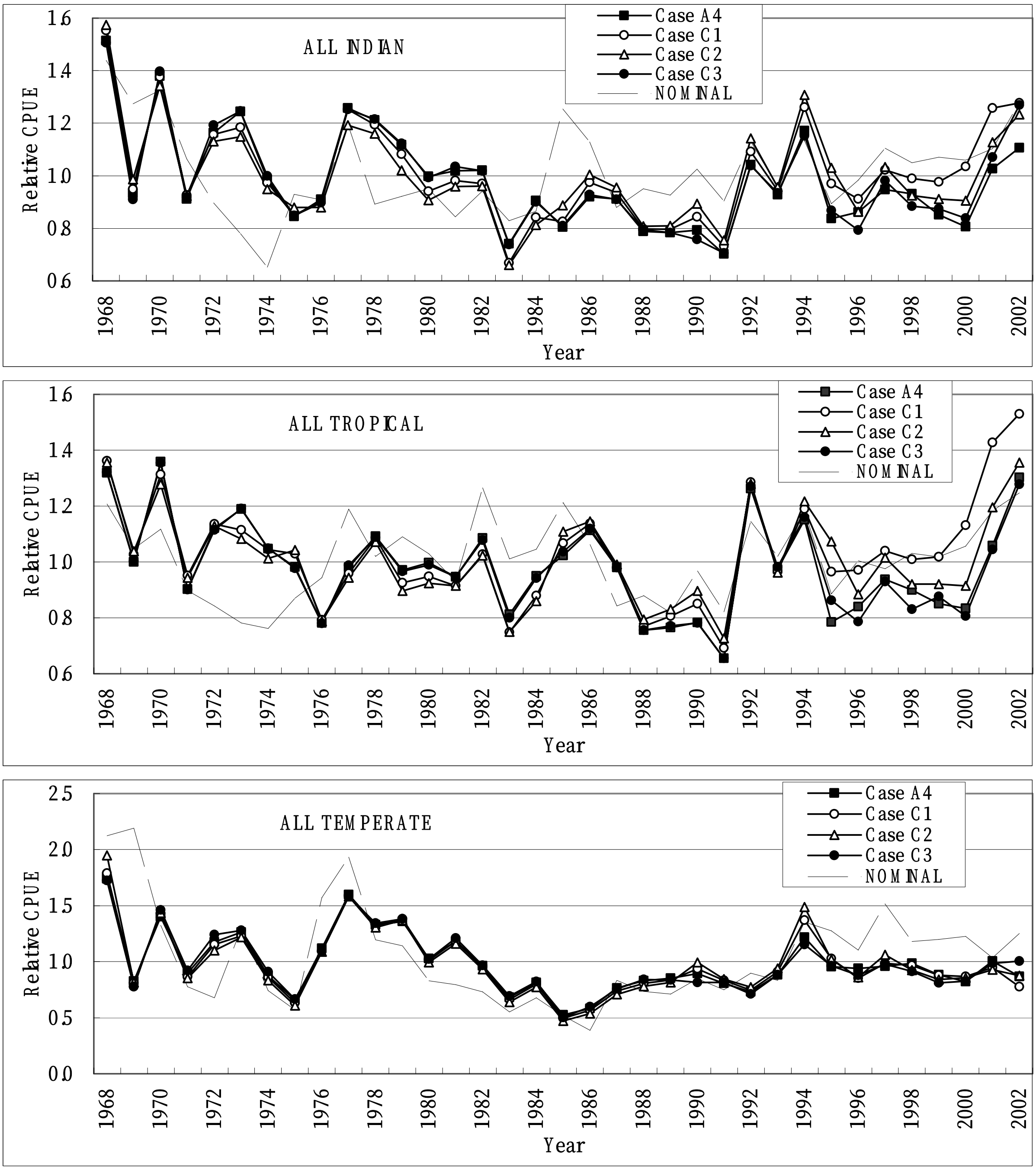


Fig. 7. Annual trends of standardized CPUE derived from four cases of CASE C and CACE A4 were overlaid. Each CPUE was expressed relatively as average during 1968-1994 is 1.0.

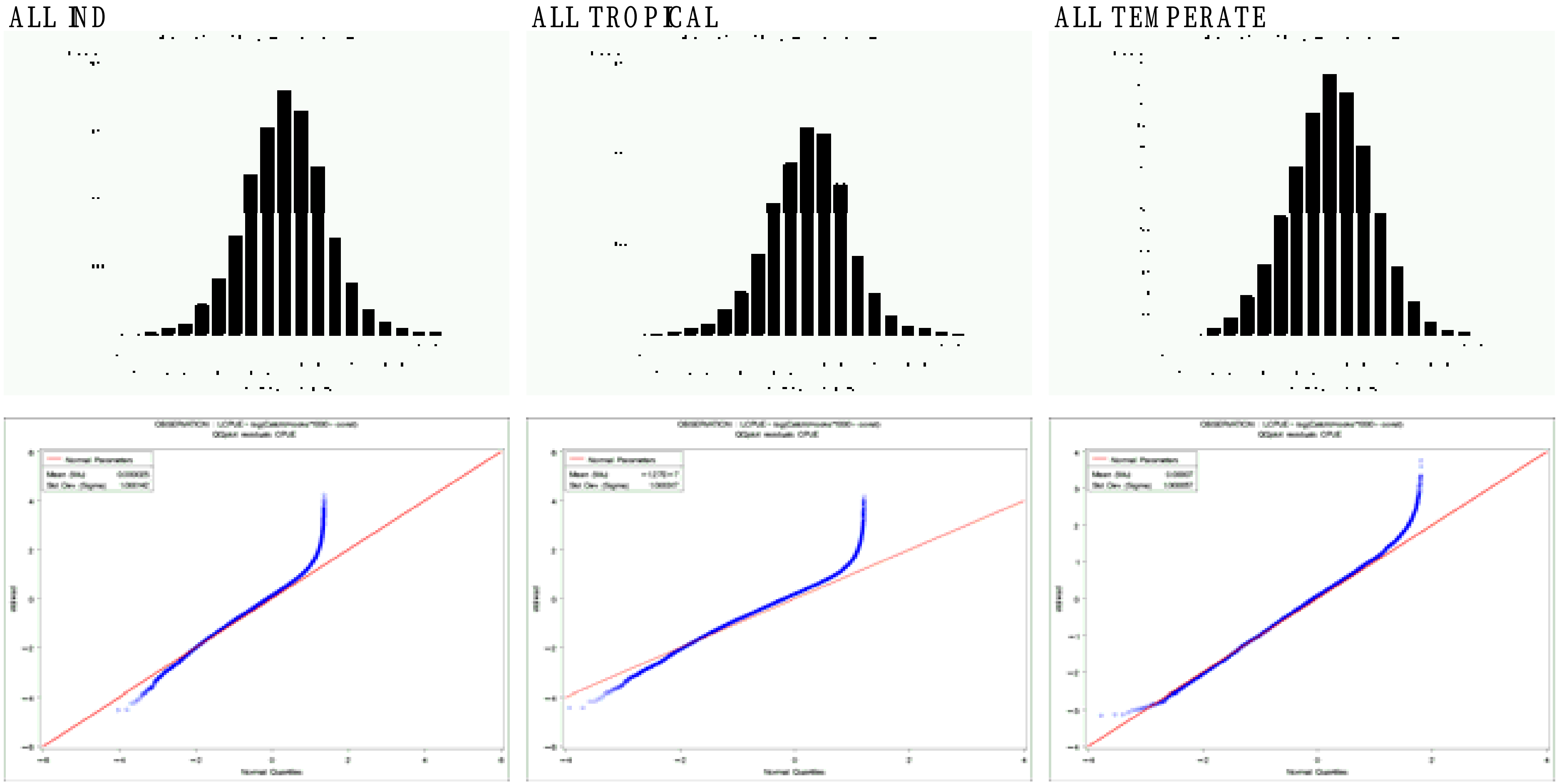


Fig. 8. Standardized residuals derived from CASE C2 expressed in histograms and QQ plots.

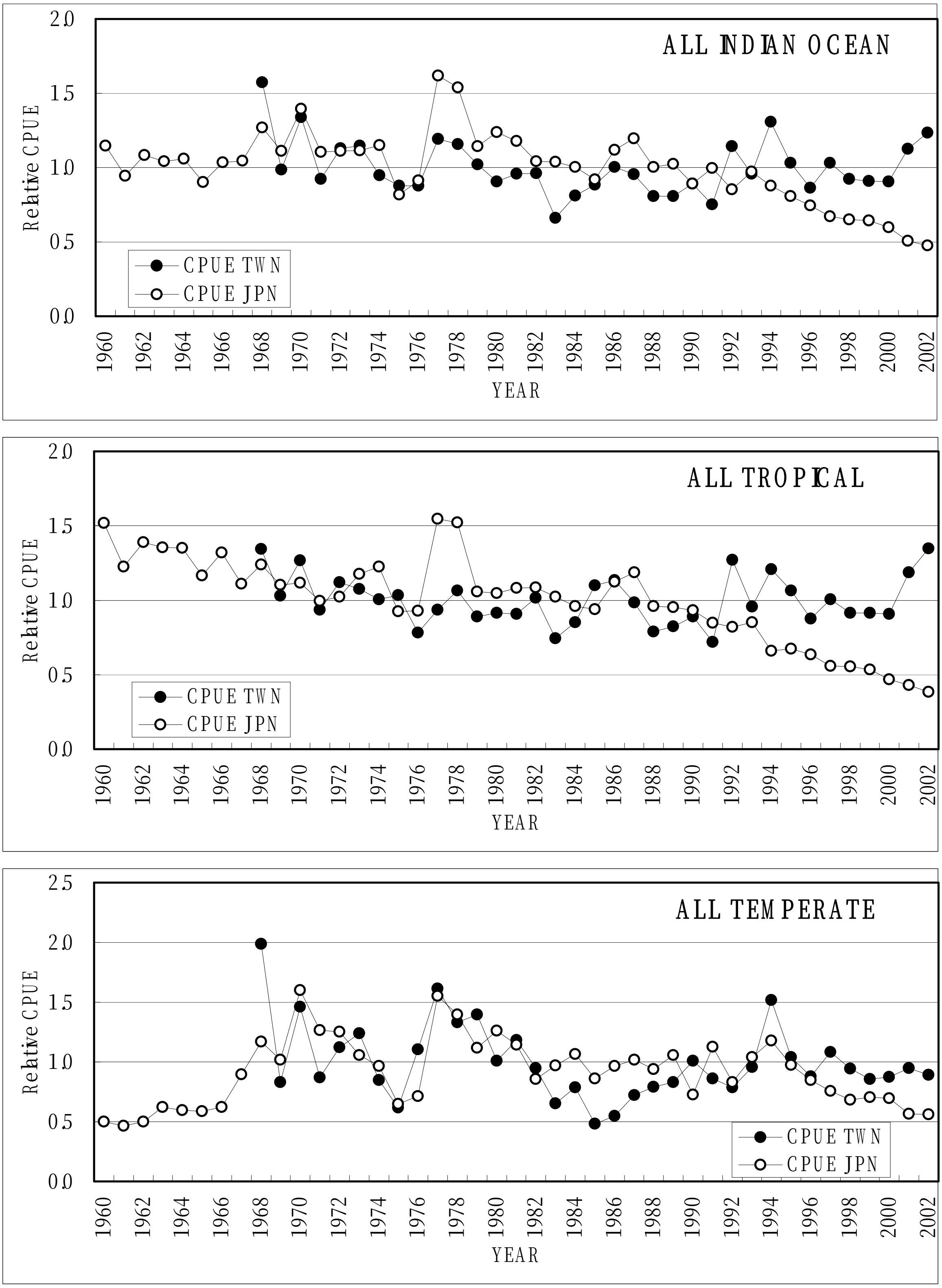


Fig. 9. Standardized CPUE (1968-2002) derived from CASE C2 with standardized Japanese longline CPUE expressed in relative scale as average for 1968-2002 is 1.0.

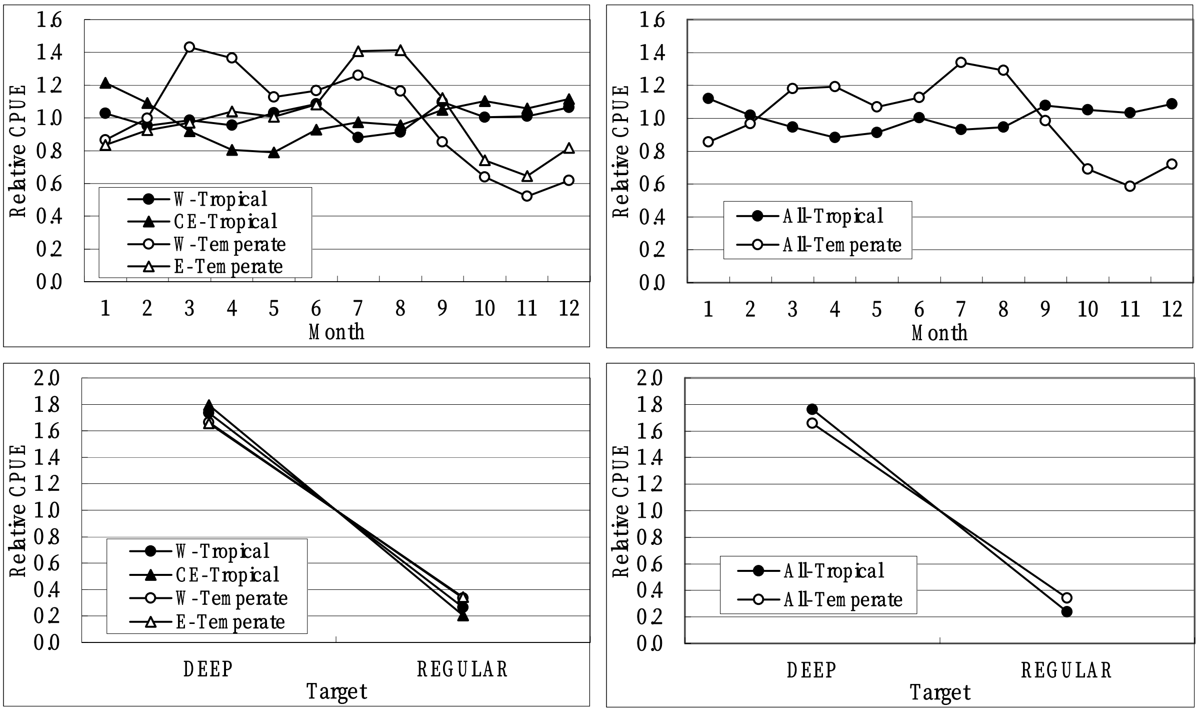


Fig. 10. Standardized CPUE trend of season (month) and targeting derived from LSMEANS (least square means) of GLM for 1979-1994.

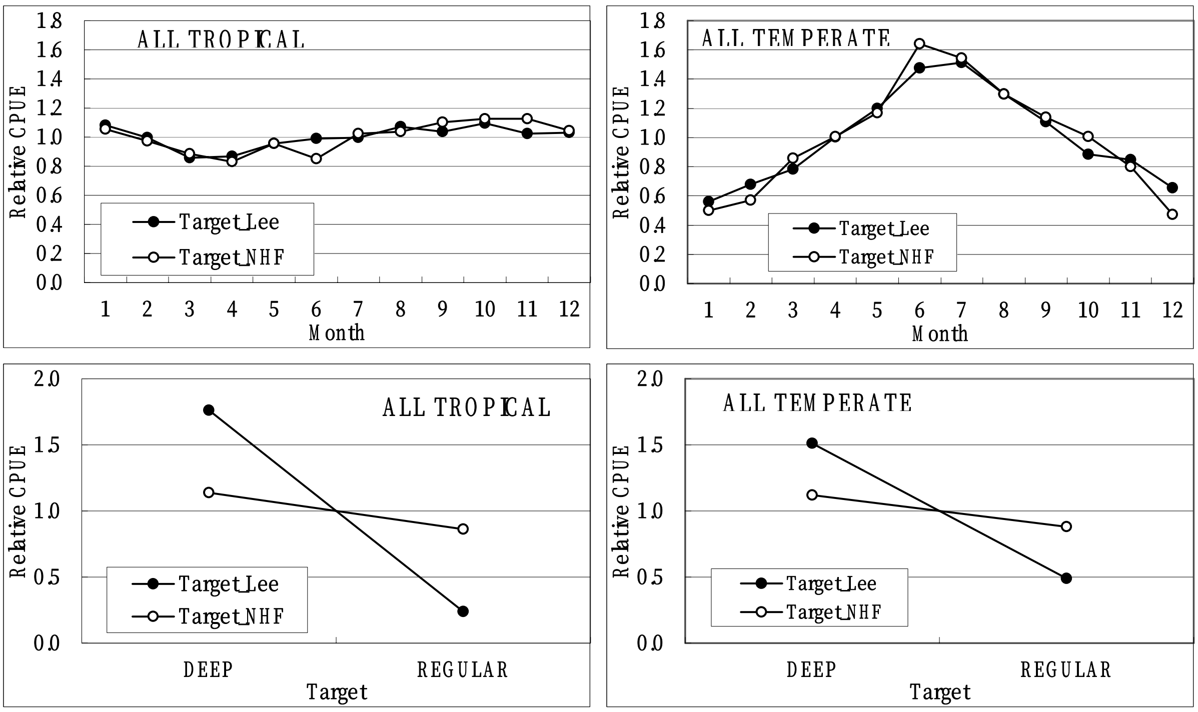


Fig. 11. Comparison of the CPUE of month and targeting between two sorts of targeting estimation for 1995-2002, targeting (DEEP and REGULAR) estimated by L-N method and that estimated from actual NHF information.

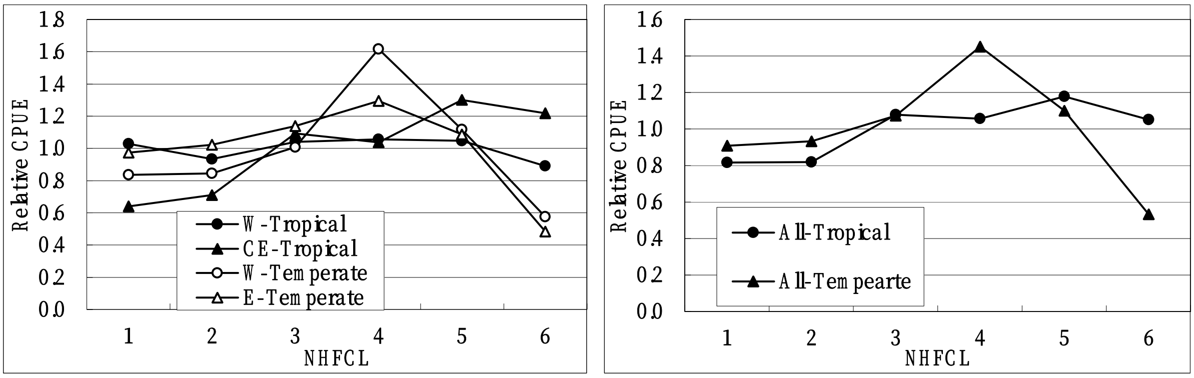


Fig. 12. Standardized relative CPUE of NHFCL derived from GLM for 1995-2002 (NHFCL_1: NHF 5-7, NHFCL_2: NHF 8-10, NHFCL_3: NHF 11-13, NHFCL_4: NHF 14-16, NHFCL_5: NHF 17-19, NHFCL_6: NHF 20-21)

Appendix Table: Annual value of standardized Bigeye CPUE derived from CASE C2 in All, Tropical and Temperate Indian Ocean for 1968-2002 expressed in relative scale in which the average from 1968 to 2002 is 1.0.

	1968-2002				1968-2000		
Year	ALL IND	TROP.	TEMP.		ALL IND	TROP.	TEMP.
	Relative CPUE	Relative CPUE	Relative CPUE		Relative CPUE	Relative CPUE	Relative CPUE
1968	1.573	1.346	1.986		1.551	1.345	1.918
1969	0.986	1.030	0.830		0.981	1.032	0.836
1970	1.340	1.268	1.461		1.400	1.308	1.514
1971	0.922	0.936	0.870		0.937	0.938	0.908
1972	1.129	1.119	1.121		1.167	1.132	1.189
1973	1.148	1.073	1.239		1.205	1.125	1.266
1974	0.949	1.004	0.848		0.986	1.044	0.863
1975	0.878	1.034	0.619		0.882	1.047	0.633
1976	0.878	0.782	1.107		0.895	0.797	1.100
1977	1.192	0.936	1.612		1.222	0.960	1.613
1978	1.159	1.064	1.329		1.190	1.091	1.330
1979	1.020	0.889	1.396		1.061	0.925	1.403
1980	0.906	0.916	1.011		0.940	0.950	1.014
1981	0.957	0.908	1.181		0.980	0.933	1.189
1982	0.960	1.015	0.950		0.980	1.047	0.945
1983	0.660	0.744	0.653		0.682	0.766	0.660
1984	0.811	0.852	0.787		0.839	0.884	0.797
1985	0.886	1.100	0.481		0.873	1.094	0.485
1986	1.003	1.136	0.546		0.999	1.144	0.555
1987	0.955	0.983	0.722		0.961	0.997	0.732
1988	0.807	0.788	0.793		0.809	0.790	0.803
1989	0.808	0.823	0.830		0.811	0.824	0.833
1990	0.893	0.889	1.010		0.864	0.868	0.962
1991	0.753	0.721	0.861		0.741	0.708	0.852
1992	1.142	1.270	0.785		1.129	1.279	0.762
1993	0.957	0.955	0.956		0.964	0.973	0.947
1994	1.307	1.208	1.515		1.295	1.214	1.446
1995	1.030	1.065	1.037		1.039	1.099	1.022
1996	0.862	0.876	0.877		0.857	0.894	0.827
1997	1.032	1.007	1.081		1.041	1.027	1.058
1998	0.924	0.913	0.943		0.920	0.925	0.899
1999	0.911	0.913	0.856		0.902	0.917	0.823
2000	0.904	0.907	0.872		0.896	0.923	0.817
2001	1.127	1.185	0.946				
2002	1.233	1.346	0.891				