GLM ANALYSES FOR STANDARDIZATION OF JAPANESE LONGLINE CPUE FOR BIGEYE TUNA IN THE INDIAN OCEAN APPLYING ENVIRONMENTAL FACTORS

Hiroaki OKAMOTO, Naozumi MIYABE and Takayuki MATSUMOTO

National Research Institute of Far Seas Fisheries
5 chome 7-1, Orido, Shimizu, 424-8633, Japan

ABSTRACT

Japanese longline CPUE for bigeye tuna from was standardized by GLM, upto 1999. In this study, in order improve the standardization, new sub-area definition and environmental factors (SST and SOI) were applied in the models. Judging from AIC value, the model including environmental factors showed better fit than that of other models without environmental factors indicating that the application of environmental factors in to the model improved the fit of model significantly. Although the same model was applied to both of number and weight based CPUEs, there was no remarkable difference between the standardized CPUEs derived from them. The model including Year-Area interaction as well as environmental factors was also tested and realized that the inclusion of the Year-Area interaction indicated better fit than without it. After all, the model including environmental factors and Year-Area interaction was determined as the final model because the model showed the least AIC in the models tested and the distribution of standardized residuals was not apart from the normal distribution. Age specific CPUEs were also developed with use of final model and catch at age information prepared by Miyabe (2001) in order to provide possible input data as abundance indices for age structured production model analysis conducted by Nishida et al. (2001).

1. INTRODUCTION

In the analyses to estimate the trend of bigeye abundance in the Indian Ocean, CPUE of Japanese longline for this species has been regarded as one of the reliable data sources. Although Japanese longline CPUE for bigeye has been standardized mainly by GLM analysis, the process of standardization may require further elaboration to account for possible source of variation. In the IOTC meeting on method held on April in 2001, the followings were recommended to improve the CPUE standardization.

If interactions between year effect and other factors are shown to be significant, the model should incorporate them, using an appropriate weighting scheme (e.g. an area-weighted scheme if year-area interactions are significant).

Indices for two size categories should be developed.

Indices should be presented reflecting catch both in weight and number.

The effects of alternative spatial stratification that would better reflect areas with similar fishing practices or ecological characteristics should be explored.

Moreover, Okamoto et al. (2001) suggested that application of environmental factors in the GLM model might be tested to improve the standardization.

The purpose of this study is to improve standardization of Japanese longline CPUE reflecting above recommended issues, and to provide standardized CPUEs as input data for the stock assessment methods (e.g. ASPM or other).

2. MATERIALS AND METHODS

Area definition:

Okamoto and Miyabe (1998) made sub-area definition as Figure 1-a for longline CPUE standardization for bigeye based on the geographical distribution of bigeye CPUE. This sub-area definition had been used until the analysis by Matsumoto (2000). Okamoto *et al*. (2001) showed that geographical distribution of small bigeye (average weight less than 35kg) is obviously different from that of large bigeye (average weight larger or equal to 50kg) based on average weight of bigeye caught in each operation (Figure 2), This result indicates that bigeye in different life stage may have different distribution pattern or longline selectivity is different by area. Considering that the CPUE of small bigeye is generally higher than that of large bigeye (IOTC 2001), it should be desirable that this difference in the distribution of size specific CPUE should be reflected in sub-area definition in the standardization process. Then new sub-area was defined as Figure.

Environmental factors:

As environmental factors, which are available for the period from 1952 to 1999, Sea Surface Temperature (SST) and Southern Oscillation Index (SOI) were applied.

SST:

The SST data, whose resolution is 2-degree latitude and 2-degree longitude by month from 1946 to 2000, was from SAGE (Subarctic Gyre Experiment) compiled by Climate and Marine Department of JAPAN METEOROLOGICAL AGENCY. This original data was first converted to grid data of 1-degree by 1-degree as shown below.

1 Original data is assumed to represent SST at the center of the 2 degree square cell (closed circle in Appendix figure 1-a). .

2 By taking average between the neighboring cells (above and below, left and right), data at the midpoint of two original data were calculated (open circle in Appendix figure 1-b).

3 Averaging between the neighboring same latitudinal data obtained by calculation in 2), the SST at the midpoint between them were obtained (open triangle in Appendix figure 1-c).

   i) Using this 1degree grid SST data made by the above process, representative SST for each 5-degree cell was (open square in Appendix figure 1-d) obtained by taking average SST at four corners (closed square in Appendix figure 1-d) of 5-degree square.

SOI

Monthly SOI data was taken from NOAA (National Oceanic & Atmospheric Administration) and was downloaded from the following site.

ftp://ftp.ncep.noaa.gov/pub/cpc/wd52dg/data/indices/soi

Catch and effort data used:

Catch and effort data from 1952 to 1999 aggregated by year, month, 5-degree square and the number of hooks between floats (NHF), was used for the analysis (1999 data is preliminary). As the NHF information does not exist for the period for 1952 to 1974, NHF was regarded to be 5 in this period. It is known that 5 hooks between floats were typical gear setting introduced to most of the fleet.

In order to provide CPUE in weight, catch number was converted to weight using average weight prepared by 10 degrees latitude and 20 degrees of longitude. For the years between 1970 and 1993, this average weight data were the same data that was employed to calculate annual catch statistics reported to international organization such as FAO. While the average weight data since 1994 were based on total catch in both number and weight recorded in the logbook and its resolution is 5-degree latitude and 10-degree longitude by two months interval. As there is no available average weight data before 1970, those during 1952 to 1969 were assumed to be the same as in 1970.

GLM (General Linear Model):

CPUEs based on the number of catch and on the weight of catch were used.

The number of caught fish / the number of hooks * 1000 (number based CPUE)

Weight of caught fish in kg / the number of hooks * 1000 (weight based CPUE)

The models used for GLM analysis (log normal error structure model) was the followings.

Log (CPUEijkl + const)=

μ+YR(i)+MN(j)+AREA(k)+NHFCL(l)+SST(m) +SOI(n)+MN(j)*AREA(k)+ AREA(k) *NHFCL(l) +AREA(k) *SST(m)+AREA(k) *SOI(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 area,

NHFCL(l) : effect of gear type (class of the number of hooks between floats),

MN (j)*AREA(k) : interaction term between fishing season and area,

AREA(k) *NHFCL(l) : interaction term between area and gear type,

e(ijkl..) : error term.

The number of hooks between floats (NHF) were divided into 3 classes (NHFCL 1: 5-9, NHFCL 2: 10-15, NHFCL 3: 16-21). From the simplest model that includes only Year as main effect, to the full model shown above were run and AIC (Akaike's Information Criteria) was calculated in each model to select the best model. AIC was calculated by the following equation.

$$AIC = n*\log(2\pi\sigma^2) + n + 2(p + 1)$$

Where n: number of data,

σ^2: sum of square of residuals / n

p: number of parameter

Some of these models were applied for both number based and weight based CPUEs and for old and new sub-area definitions.

In addition to the above models, the models in which the Year-Area interaction was added were also conducted. Year effect was obtained by the method reported by Ogura and Shono (1999) that utilizes LSMEAN (least square mean output in SAS) of Year-Area interaction as shown in the following equation.

$$CPUE_i = \Sigma W_j * (\exp(LSMEAN(Year*Area_{ij}))-constant)$$

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.

Age specific CPUE:

By using catch at age information prepared by Miyabe (2001), each age component was calculated by quarter of the year and 10 degrees latitude by 20 degrees longitude. Each CPUE in number in the same strata was multiplied with this age component in order to develop age specific CPUE. Standardization by final model with and without Year-Area interaction using new area was conducted for the years between 1965 and 1999. .

RESULTS AND DISCUSSION

The major points described in this paper are followings.

1 AIC values were compared to select the best model (without Year-Area interaction).
2 Trends of standardized CPUE were investigated in each sub-area based on old and new sub-area definitions.
3 The effect of applying environmental factors into the model was evaluated and CPUE trend was compared between number- and weight-based CPUEs.
4 Year-Area interaction was added into the model, which also includes environmental factors.
5 Using the catch at age information and final model selected, age specific CPUEs were calculated and their trends were compared between age and area.

Comparison of goodness of fit among models:

In order to select the best model in GLM to standardize Japanese longline CPUE, eleven stepwise models were run using new tropical area from 1952 to 1999 and the AIC values derived from each model were compared (Table 1). The model used in the previous studies (Okamoto and Miyabe 1998, Okamoto and Miyabe 1999, Matsumoto 2000) was seventh model from the top in the Table 1 (i.e. Year + Month + Area + NHFCL + Month*AREA + AREA*NHFCL). This model is called for convenience as the basic model in this paper. In the models tested, the last model (Year + Month + Area + NHFCL + SST + SOI + Month*Area + Area*NHFCL + Area*SST + Area*SOI) showed the smallest AIC value indicating best fit. Figure. 3 shows the trend of standardized CPUEs and nominal CPUE expressed relatively. It is easily known that factor which affect most on the total trend of CPUE is NHFCL. The CPUE trends that derived from the first three models without NHFCL are not so different from the trend of nominal CPUE and those from latter six models with NHFCL are similar to the fifth model in which Year, Month, Area and NHFCL are simply included without any interaction. Although the last model showed best fit as described above, in order to compare with the results in the past studies, three models, seventh model (basic model), tenth model (basic +SST +Area*SST) and eleventh model (basic +SST +SOI +Area*SST +Area*SOI), were tested after this. Moreover, the model in which Year-Area interaction was added to the last model (basic +SST +SOI +Area*SST +Area*SOI) were tested separately in the latter part of this paper.

CPUE trends in each sub-area:

Trends of standardized CPUE in each sub-area were observed for old (Figure 4) and new area definitions (Figure 5). In order to keep consistency with the previous studies the basic model are used in this analysis. Results of ANOVA and distributions of the standard residual in each analysis were shown in Appendix Table 1 and Appendix Figure 2, respectively. Remarkable difference in CPUE trend was not detected between old and new area definitions. CPUEs in the three tropical areas including western (sub-areas 1 and 3), central (sub-areas 2 and 4) and eastern (sub-area 5) tropical areas, which are the main fishing grounds for bigeye, were relatively higher than those in two south areas including western (sub-area 6) and eastern (sub-area 7) areas. Tropical areas showed similar CPUE trend each other. That is, CPUE declined steadily from early 1950s to 1976, sudden jump in 1977 and 1978, and declined again from middle of 1980s to the latest year, though the latter declining trend is more obvious in western tropical than in the eastern tropical. On the other hand, CPUE before 1976 in the south areas showed increasing trend (western south) or stable (western south), and declining trend after the middle 1980s was not obvious or even showed increasing trend from 1986 to 1994 in eastern south area. The same analysis was done on all tropical (sub-areas 1, 2, 3, 4 and 5), all south (sub-area 6 and 7) and all Indian (sub-area 1, 2, 3, 4, 5, 6 and 7) using old and new area definition (Figure 6). Being offset by the declining CPUE trend in tropical area by opposite trend in south area, the declining trend in all Indian is much less than all tropical area.

Applying environmental factors:

Before the inclusion of the environmental factors in the GLM analysis, relationship between CPUE (log-CPUE) and Sea Surface Temperature (SST) in each area was briefly studied (Figure 7). Relationships between them are similar among three tropical areas (western, central and eastern tropical areas) and among two south areas (western and eastern south areas). In the tropical areas, most efforts distributed in the temperature range from 24°C to 30°C, in which the CPUE increased slightly although it declined a little in the east tropical area at higher temperature than 28°C. In the south areas, most effort distributed in the temperature range from 16°C to 28°C, in which the CPUE decreased slightly. Roughly speaking, relationship between CPUE and temperature is nearly linear in any area. As far as judging on the AIC from both models including SST or SST^2 (Table 1), the model with SST showed better fit than that with SST^2. Although it might be natural to assume non-linear relationship between CPUE and SST, the linear relationship would be enough to express the relationship with this relatively narrow temperature range in each area. Standardized CPUEs using basic model, model with SST and Area-SST interaction and model with SST, SOI, Area-SST and Area-SOI interaction for all tropical, all south and all Indian were shown in Figure 8. There is not remarkable difference in CPUE trends detectable visually between models in each area. However, CPUEs derived from model including SST and from model including SST and SOI have almost same trends, but they are slightly lower than that derived from basic model in the period from 1979 to 1988 in all tropical area (Figure 9). In summary, gap in CPUE level before 1976 and after 1979 was slightly relieved by applying environmental factors in the model although environmental factors did not account for the large fluctuation of CPUE during 1977 to 1978 at all. Results of F-test of each factor in GLM using above models were shown in Table 2. Even though effect terms in all models were significant, mean square of SOI was smaller than that of other factors, while mean square of SST is the largest among all. Distributions of the standard residual (Appendix Figure 3) were not apart from the normal distribution though all of them skewed to right (larger residual) to some extent. Same analyses were done for weight based CPUE. The trends of standardized CPUE based on catch in weight were very similar to those of number based CPUE (Figures 10 and 11). Distributions of the standard residuals in weight based CPUE (Appendix Figure 4) were also not apart from the normal distribution. In Figure 12, the relative CPUEs based on catch in number and weight were compared for all tropical, all south and all Indian areas. Any remarkable difference was not detected between CPUEs based on number and weight in any area. Results of ANOVA in these analyses were listed in Appendix table 1. In this paper, further analyses were conduced on only number based CPUE after this.

Model including Year-Area interaction:

Standardized relative CPUEs using the model at the bottom in Table 1 and the same model but with Year-Area interaction were shown in Figure 13 for all tropical and all Indian areas (data of this figure was listed in Appendix table 2). In these analyses, starting year was not 1952 but 1955 because there are missing observation in term of Year-Area interaction before 1955. Main difference between two models in all tropical area is that the declining trend in CPUE after 1991(after 1997 in special) is steeper in model without Year-Area interaction. In the All Indian area, the declining trend from 1955 to 1959 and from 1996 to 1999 is steeper in the model without Year-Area interaction, and as a result, CPUE derived from the model with the interaction has planer trend than that of the other model. Results of ANOVA and AIC for these analyses were shown in Table 3. In both areas, the AIC from the model with Year-Area interaction was remarkably lower than that from the model without the interaction. Results of F-test of each effect term in the model including Year-Area interaction was shown for all tropical and all Indian in Table 4. Distributions of the standardized residual of the model with Year-Area interaction were not so different from normal distribution (Figure 14). Then the model (Year + Month + Area + NHFCL +SST + SOI + Year*Area + Month*Area + Area*NHFCL + Area*SST + Area*SOI) was determined as final model in this study.

Then which area's CPUE can reflect the change in total bigeye biomass in the Indian Ocean, all tropical or all Indian? This question was already discussed in the previous studies (Okamoto and Miyabe 1989, Okamoto and Miyabe 1999). In those papers, it was suggested that it might be more reasonable to grasp the trend of adult bigeye stock by the analysis restricting its area to the tropical region because of the following reasons. The change in bigeye catch and the change in frequency of NHF used in the area indicate that the target species in the south area seemed to change considerably in 1990s. In this area, main fishing ground for southern bluefin tuna is included. The catch of southern bluefin has regulated by quota by three countries, and the fishing season of southern bluefin for Japanese longliners has also been regulated by Japanese Fishery Agency since 1989. Therefore, Japanese longliners change their target quickly from southern bluefin to bigeye when the fishing for southern bluefin is closed and bigeye to southern bluefin when it is opened. Fluctuated and unstable CPUE trend in eastern south area particularly in recent years might suggest that this effect of the rapid change in targeting could not be standardized sufficiently. Available information indicated that considerable amount of fish exists in the southern temperate waters. They are mostly pre-adult but include certain amount of adult fish as well.

Above suggestion would be reasonable still now, although it is desirable to include all bigeye catch and effort data in proper way in order to estimate the change of total bigeye abundance in the Indian Ocean.

Age specific CPUE:

Using catch at age data prepared by Miyabe (2001), age specific CPUE were calculated for the period from 1965 to 1999 and standardized by the final model for all tropical and all Indian area (Figure 15 and 16, respectively). As CPUE in each age fluctuates so much, it is hard to grasp its trend. However, as ages 2 and 3, 4 and 5, and 6 through 8 seems to show relatively similar trends, each ages of similar trend was combined as age group in both areas. In Figure 17, standardized CPUE of each age group for all tropical and all Indian was shown. In both areas, age group 6-8 was kept in same level or decreasing slightly, while CPUE of age group 4-5 declined after 1994 and kept in low level thereafter (data was listed in Appendix table 3). CPUE of age group 2-3 in all tropical area declines gradually after 1981 and the declining trend was steeper after 1990, while that in all Indian showed steady and gradual declining trend after 1981 through 1999. If the age specific CPUE reflects the real change in abundance of each age, the change in CPUE of younger age should be traceable in that of older age with time lag of several years. In all tropical area, as a matter of fact, peaks of age group 2-3 in 1982, 1986 and 1990 seems to be traceable as peaks of age group 4-5 in 1983, 1987 and 1993, respectively. However, these peaks can not be traced to age group 6-8, and it is hard to trace other peaks of age group 2-3 to older age groups in both of all tropical and all Indian areas. These results might suggest that the information of catch at age does not reflect enough the change in abundance of each age, partially because of shortage in time and space coverage of size data. As described in the introduction, sudden high CPUE in 1977 and 1978 has been observed still in the standardized longline CPUE for bigeye (Okamoto et al. 2001). This jump of CPUE was reflected as extraordinary high peak in the same period in 4-5 age group of both areas (Figure 17). Although the reliability of size specific CPUE is obscure, if the age specific CPUEs reflect the age specific abundance to some extent and if the high peak of CPUE was caused by enormous increase of recruitment in this period, the high peak in 4-5 age group should be traced to younger or older age group. But it is not observed any sigh of relevant high CPUE in both age groups at all. This fact may indicate that the high CPUE was not caused by the change in the recruitment abundance unless the reliability of age specific CPUE is too low to estimate i

REFERENCES

IOTC (2001): Report of the IOTC ad hoc working party on methods. IOTC/WPM/Report, 21p.

MATSUMOTO, T. (2000): Standardized CPUE for bigeye caught by Japanese longline fishery in the Indian Ocean, 1952-1999. IOTC/WPTT/00/08, 10p.

MIYABE, N. (2001): Estimation of selectivity at age for bigeye tuna in the Indian Ocean. IOTC/WPTT/01/xx, 13p.

NISHIDA, T., N. MIYABE, H. SHONO, T. MATSUMOTO AND C. HSU (2001): ASPM analyses for the bigeye tuna resources in the Indian Ocean. IOTC/WPTT/01/xx, p.

OGURA, M. AND H. SHONO (1999): Factors affecting the fishing effort of the Japanese distant water pole and line vessel and the standardization of that skipjack CPUE, Part B. SCTB 12/SKJ-4, 16p.

OKAMOTO, H. AND N. MIYABE (1998): Updated standardized CPUE of bigeye caught by the Japanese longline fishery in the Indian Ocean. IPTP/TWS/98/2/9, 10p.

OKAMOTO, H. AND N. MIYABE (1999): Standardized CPUE of bigeye caught by the Japanese longline fishery in the Indian Ocean, up to 1998. IOTC/ WPTT/99/06, 8p.

OKAMOTO, H., N. MIYABE AND D. INAGAKE (2001): Interpretation of high catch rates of bigeye tuna in 1977 and 1978 observed in the Japanese longline fishery in the Indian Ocean. IOTC/WPM/01/01, 25p.

Table 1. Results of AIC from the General Linear Model for bigeye in the all tropical area (sub-areas 1, 2, 3, 4 and 5) in the Indian Ocean, 1952-199

MODEL	n	p	error S.S.	s^2	AIC
Y	29135	47	17199.995	0.590	67422.47
Y+M	29135	58	16959.183	0.582	67033.68
Y+M+A	29135	62	16555.626	0.568	66340.01
Y+M+A+M*A	29135	106	16291.373	0.559	65959.22
Y+M+A+H	29135	64	16203.571	0.556	65717.77
Y+M+A+H+M*A	29135	108	15955.363	0.548	65356.02
Y+M+A+H+M*A+A*H	29135	116	15733.703	0.540	64964.43
Y+M+A+H+S+M*A+A*H	29135	117	15472.613	0.531	64478.90
Y+M+A+H+S+S^2+M*A+A*H	29135	118	15425.552	0.529	64392.15
Y+M+A+H+S^2+M*A+A*H+A*S^2	29135	121	15355.857	0.527	64266.21
Y+M+A+H+S+M*A+A*H+A*S	29135	121	15347.726	0.527	64250.78
Y+M+A+H+S+So+M*A+A*H+A*S+A*So	29135	126	15322.323	0.526	64212.52

Table 2. Results of F-test of each effect term in GLM using each model for all tropical area.

Source	Degree of Freedum	Sum of Square	Mean Square	F Value	Pr > F
YR+MN+AREA+NHFCL+MN*AREA+AREA*NHFCL					
YEAR	47	933.927	19.871	41.39	0.0001
MONTH	11	68.521	6.229	12.97	0.0001
AREA	4	499.538	124.884	260.10	0.0001
NHFCL	2	140.878	70.439	146.71	0.0001
MN*AREA	44	322.122	7.321	15.25	0.0001
AREA*NHFCL	8	292.480	36.560	76.15	0.0001
YR+MN+AREA+NHFCL+SST+MN*AREA+AREA*NHFCL+AREA*SST					
YEAR	47	1009.670	21.482	40.61	0.0001
MONTH	11	289.310	26.301	49.72	0.0001
AREA	4	127.390	31.847	60.20	0.0001
NHFCL	2	193.435	96.717	182.83	0.0001
SST	1	335.608	335.608	634.43	0.0001
MN*AREA	44	282.596	6.423	12.14	0.0001
AREA*NHFCL	8	279.584	34.948	66.06	0.0001
AREA*SST	4	124.887	31.222	59.02	0.0001
YR+MN+AREA+NHFCL+SST^2+MN*AREA+AREA*NHFCL+AREA*SST^2					
YEAR	47	1013.150	21.556	40.73	0.0001
MONTH	11	289.794	26.345	49.78	0.0001
AREA	4	131.220	32.805	61.98	0.0001
NHFCL	2	194.221	97.110	183.48	0.0001
SST^2	1	332.800	332.800	628.78	0.0001
MN*AREA	44	281.440	6.396	12.09	0.0001
AREA*NHFCL	8	281.269	35.159	66.43	0.0001
AREA*SST^2	4	125.032	31.258	59.06	0.0001
YR+MN+AREA+NHFCL+SST+SOI+MN*AREA+AREA*NHFCL+AREA*SST+AREA*SOI					
YEAR	47	985.898	20.977	39.71	0.0001
MONTH	11	292.853	26.623	50.40	0.0001
AREA	4	136.286	34.071	64.50	0.0001
NHFCL	2	192.223	96.111	181.96	0.0001
SST	1	330.747	330.747	626.17	0.0001
SOI	1	2.885	2.885	5.46	0.0194
MN*AREA	44	291.491	6.625	12.54	0.0001
AREA*NHFCL	8	271.050	33.881	64.14	0.0001
AREA*SST	4	134.168	33.542	63.50	0.0001
AREA*SOI	4	20.376	5.094	9.64	0.0001

Table 3. Result of ANOVA and AIC from the General Linear Model for bigeye in the tropical (AREA 1, 2, 3, 4 and 5), and all area (AREA 1-7) in the Indian Ocean, 1955-1999.

Type of AREA&YR	Type of CPUE	AREA	Source	D. F.	S.S.	M.S.	F	Pr > F	R-Square	AIC
YR+MN+AREA+NHFCL+SST+SOI+MN*AREA+AREA*NHFCL+AREA*SST+AREA*SOI										
NEW 5599	Number	ALL TROP.	Model	123	3119.37	25.361	47.97	0.0001	0.1708	63422.70
NEW 5599	Number	ALL INDIAN	Model	155	14020.66	90.456	135.73	0.0001	0.3098	114524.33
YR+MN+AREA+NHFCL+SST+SOI+YR*AREA+MN*AREA+AREA*NHFCL+AREA*SST+AREA*SOI										
NEW 5599	Number	ALL TROP.	Model	299	3845.23	12.860	25.39	0.0001	0.2106	62361.72
NEW 5599	Number	ALL INDIAN	Model	419	15777.25	37.655	59.53	0.0001	0.3486	112330.53

Table 4. Results of F-test of each effect term in GLM of final model including year-area interaction for all tropical and all indian areas using number based CPUE from 1955 to 1999.

Source	Degree of Freedum	Sum of Square	Mean Square Square	F Value	Pr > F
YR+MN+AREA+NHFCL+SST+SOI+YR*AREA+MN*AREA+AREA*NHFCL+AREA*SST+AREA*SOI					
All Tropical:					
YR	44	824.1092	18.72975518	36.98	0.0001
MN	11	283.6464	25.78603306	50.91	0.0001
AREA	4	134.8174	33.70434305	66.55	0.0001
NHFCL	2	135.252	67.62601736	133.52	0.0001
SST	1	331.8134	331.8134338	655.14	0.0001
SOI	1	5.560278	5.56027847	10.98	0.0009
YR*AREA	176	725.8566	4.12418503	8.14	0.0001
MN*AREA	44	322.7609	7.33547448	14.48	0.0001
AREA*NHFCL	8	87.29929	10.91241166	21.55	0.0001
SST*AREA	4	134.0188	33.5047023	66.15	0.0001
SOI*AREA	4	13.77135	3.44283674	6.8	0.0001
All Indian:					
YR	44	566.3526	12.87165104	20.35	0.0001
MN	11	422.7402	38.43092597	60.76	0.0001
AREA	6	753.9369	125.6561486	198.66	0.0001
NHFCL	2	185.7629	92.88143878	146.84	0.0001
SST	1	443.8214	443.8214194	701.66	0.0001
SOI	1	9.457073	9.45707316	14.95	0.0001
YR*AREA	264	1756.591	6.65375366	10.52	0.0001
MN*AREA	66	1365.083	20.68307504	32.7	0.0001
AREA*NHFCL	12	145.4003	12.11669469	19.16	0.0001
SST*AREA	6	1061.821	176.9701843	279.78	0.0001
SOI*AREA	6	16.68749	2.78124796	4.4	0.0002

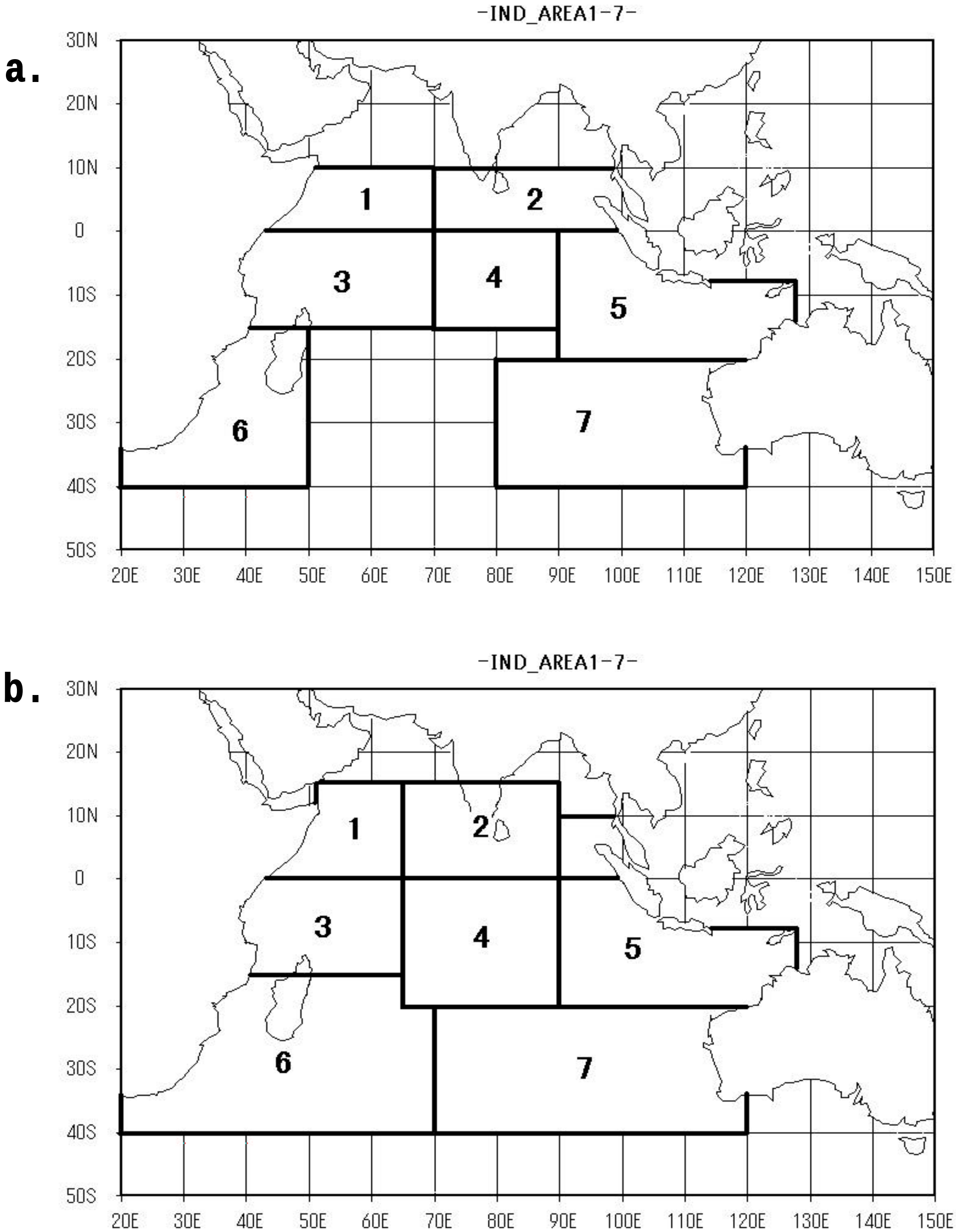


Figure 1. Old (a) and new (b) sub-area definitions used in this analyses.

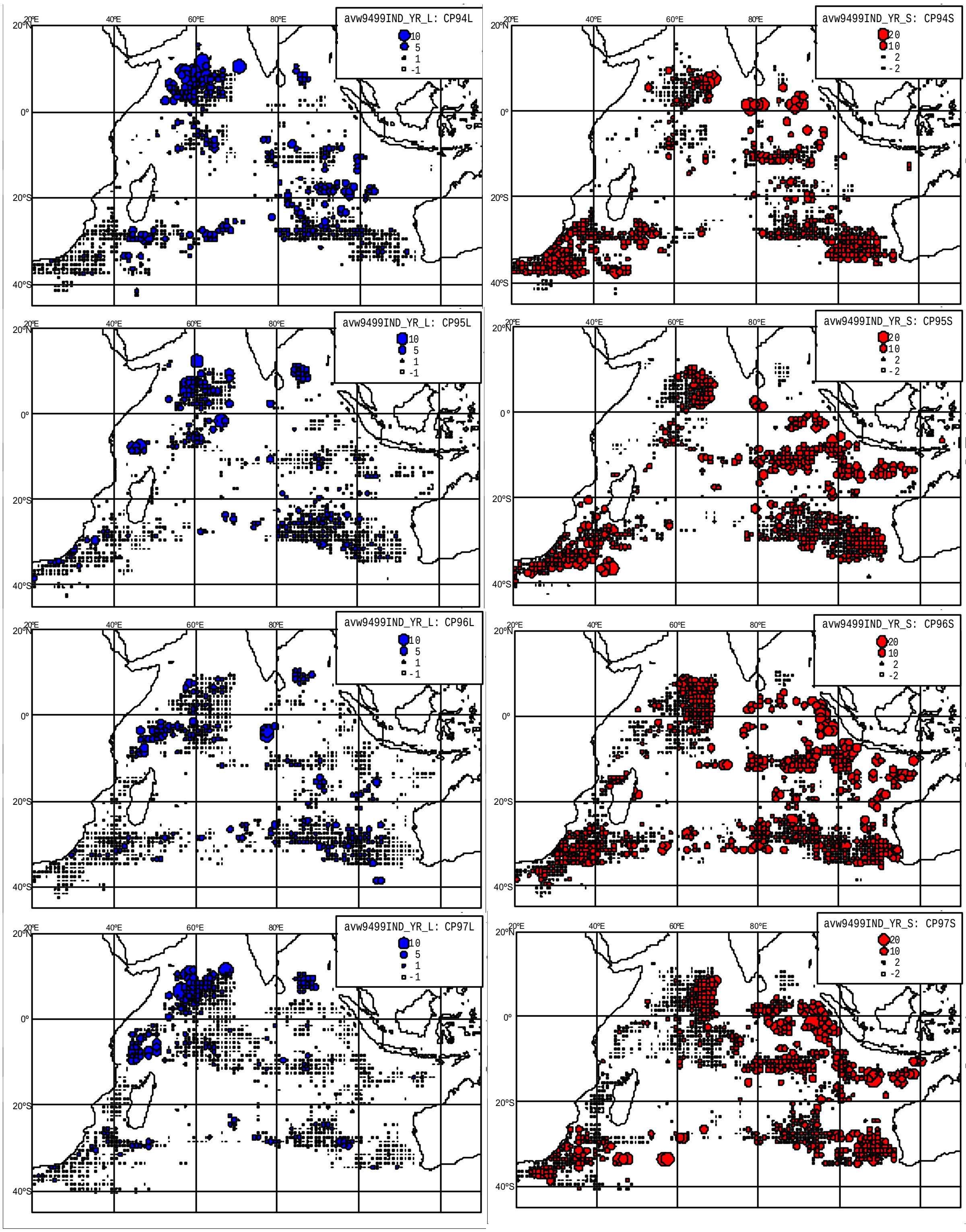


*Figure 2. Geographical distributions of annual size specific CPUE (No. of fish /hooks*1000) from 1994 to 1999. Left row shows CPUE of large fish (average weight is greater or equal than 50 kg), right row shows that of small fish (average weight is less than 35 kg).*

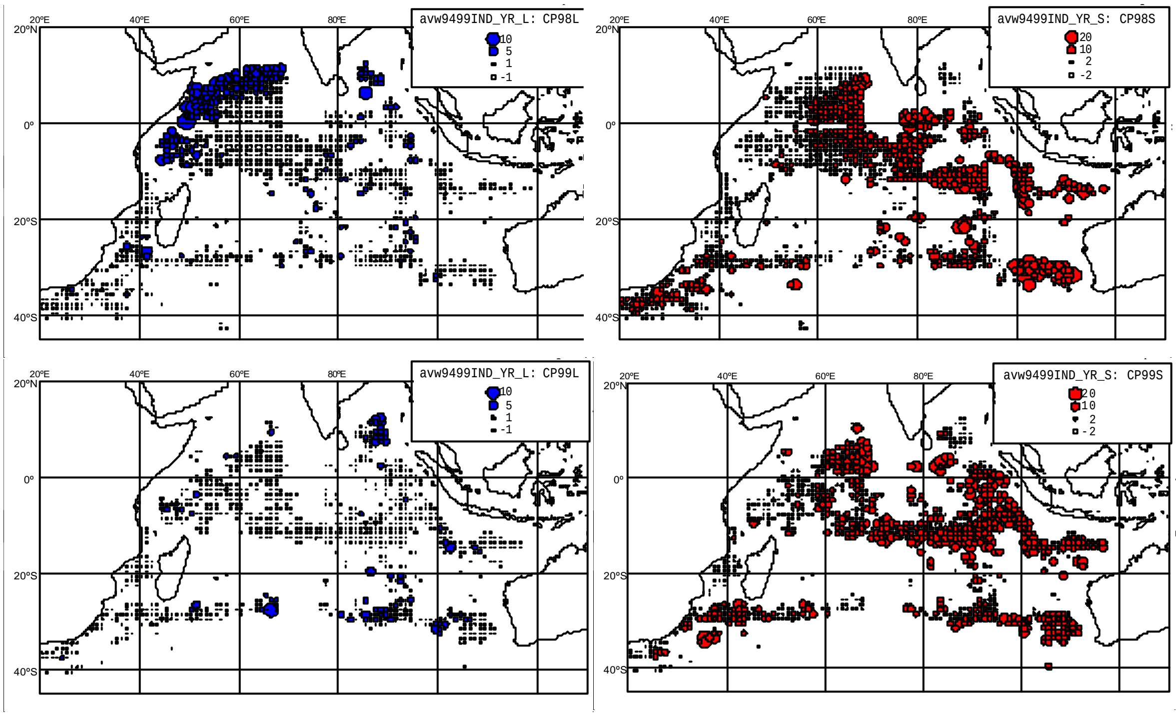


Figure 2. Continued.

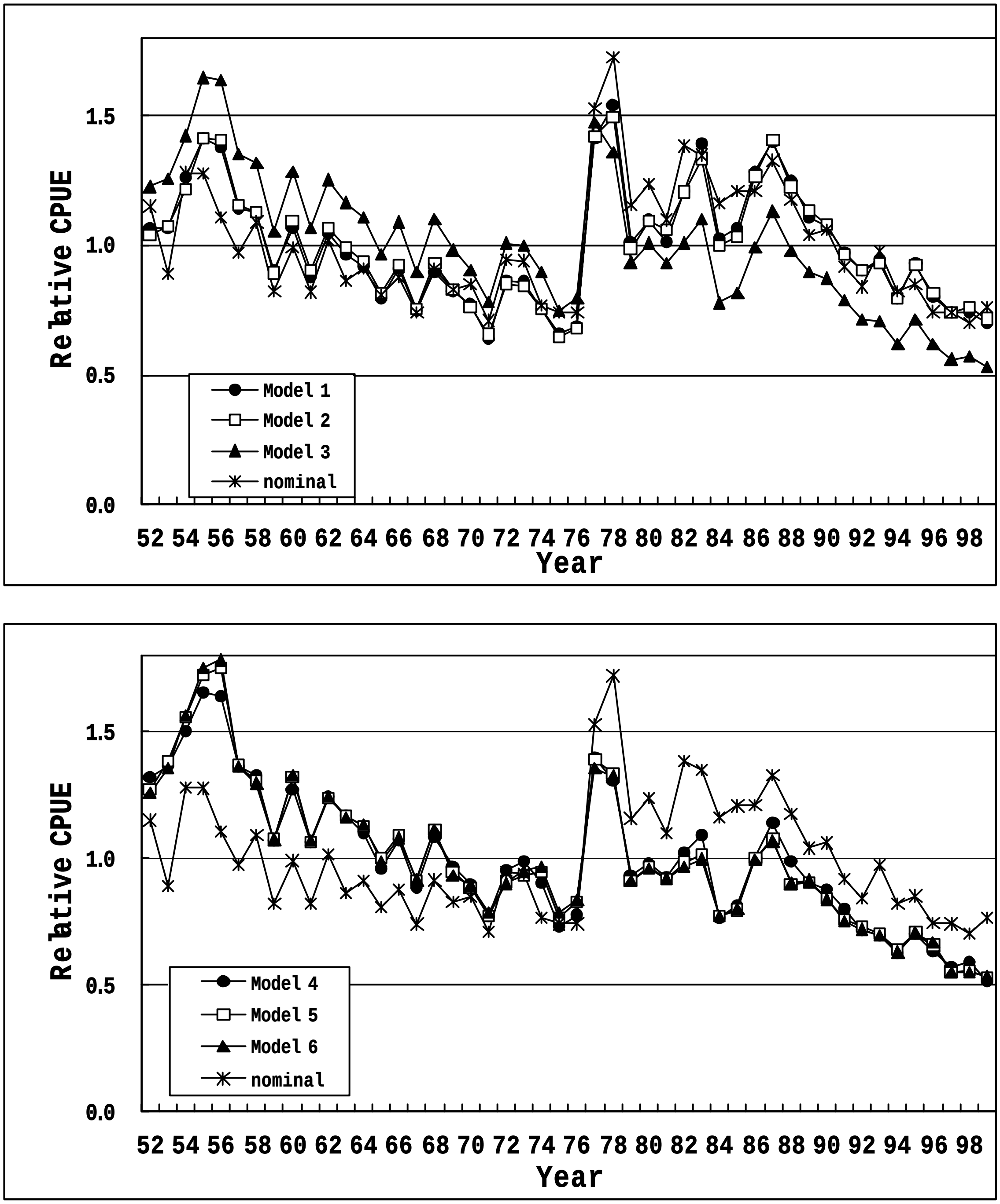


Figure 3. Comparison of relative CPUEs (number based CPUE) derived from various GLM model for all tropical.

Model 1: Year

Model 2: Year+Month+Area

Model 3 Year+Month+Area+NHFCL

Model 4: Year+Month+Area+NHFCL+Month*Area+Area*NHFCL

Model 5: Year+Month+Area+NHFCL+SST+Month*Area+Area*NHFCL+Area*SST

Model 6: Year+Month+Area+NHFCL+SST+SOI+Month*Area+Area*NHFCL+Area*SST+Area*SOI

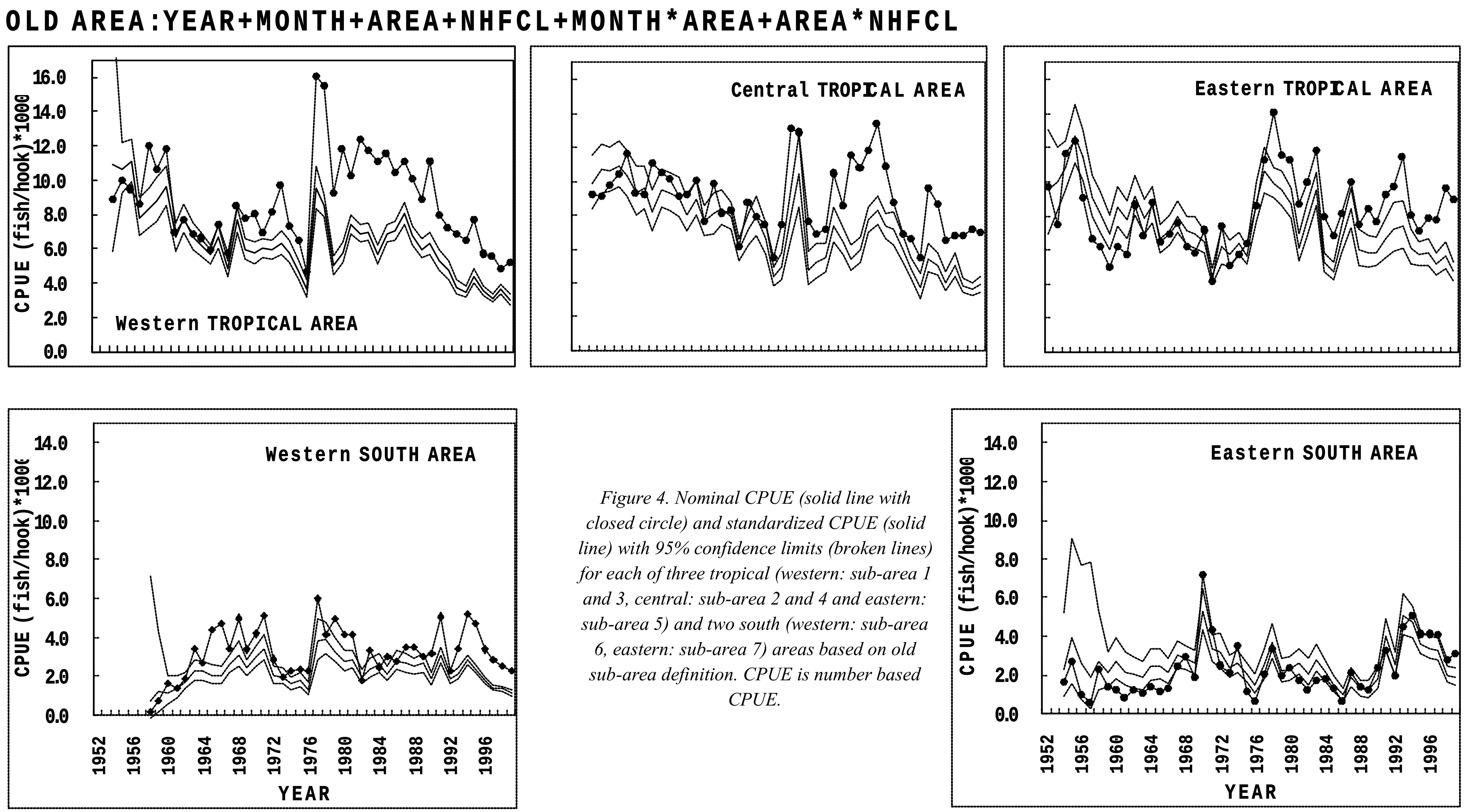


Figure 4. Nominal CPUE (solid line with closed circle) and standardized CPUE (solid line) with 95% confidence limits (broken lines) for each of three tropical (western: sub-area 1 and 3, central: sub-area 2 and 4 and eastern: sub-area 5) and two south (western: sub-area 6, eastern: sub-area 7) areas based on old sub-area definition. CPUE is number based CPUE.

NEW AREA:YEAR+MONTH+AREA+NHFCL+MONTH*AREA+AREA*NHFCL

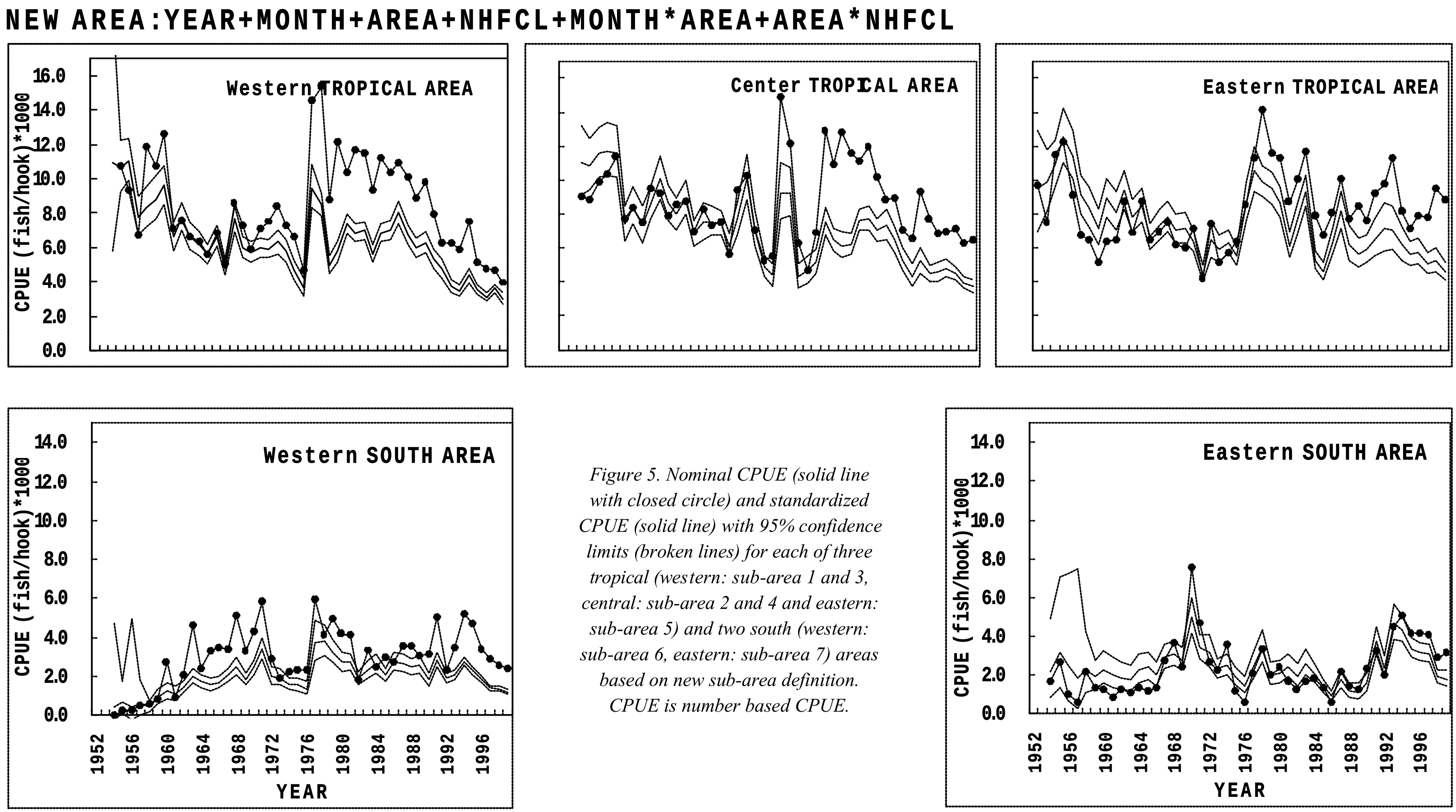


Figure 5. Nominal CPUE (solid line with closed circle) and standardized CPUE (solid line) with 95% confidence limits (broken lines) for each of three tropical (western: sub-area 1 and 3, central: sub-area 2 and 4 and eastern: sub-area 5) and two south (western: sub-area 6, eastern: sub-area 7) areas based on new sub-area definition. CPUE is number based CPUE.

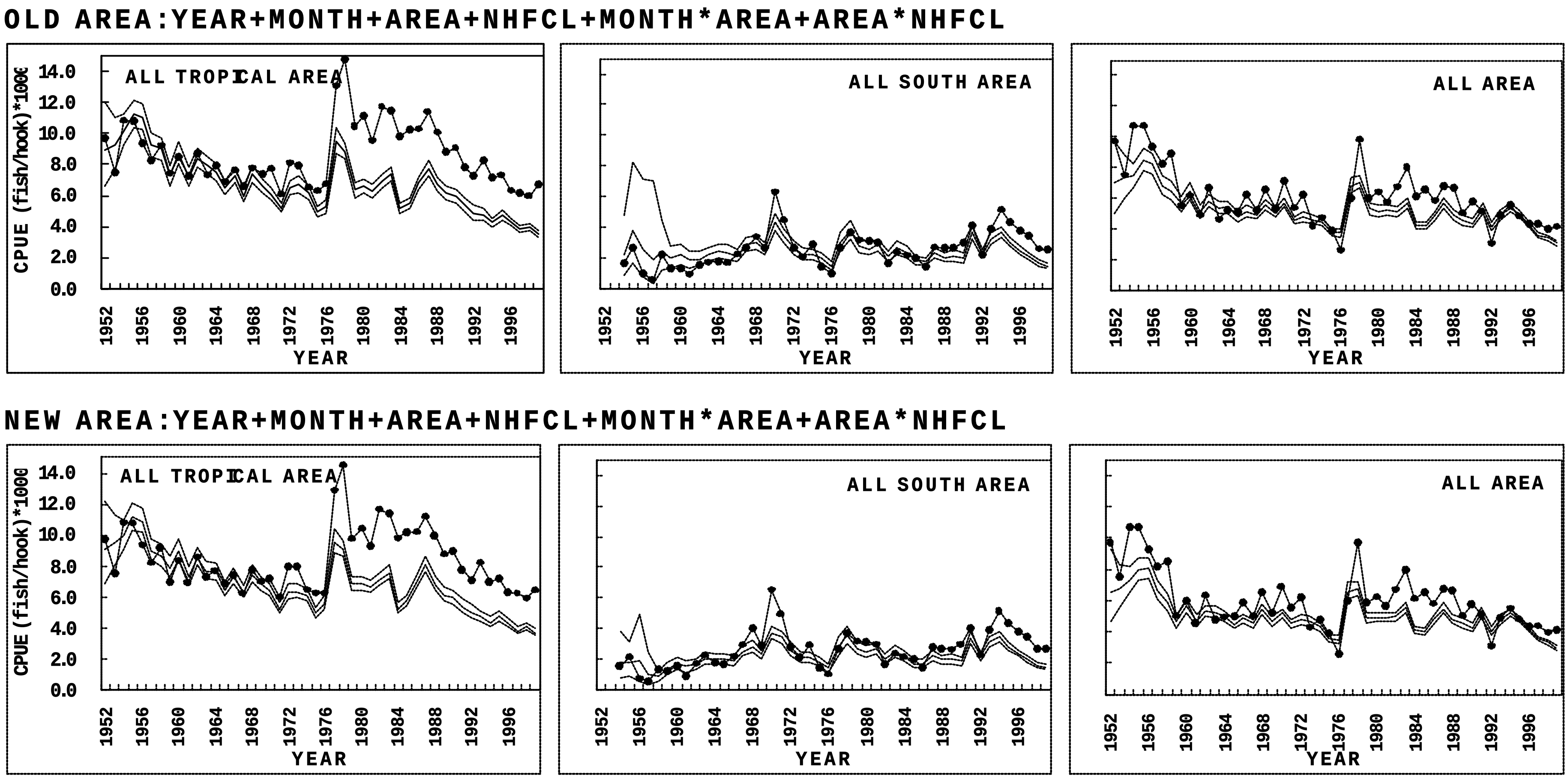


Figure 6. Nominal CPUE (solid line with closed circle) and standardized CPUE (solid line) with 95% confidence limits (broken lines) for each of all tropical (sub-area 1 through 5) and all south (sub-area 6 and 7) areas based on old (upper) and new (lower) sub-area definitions. CPUE is number based CPUE.

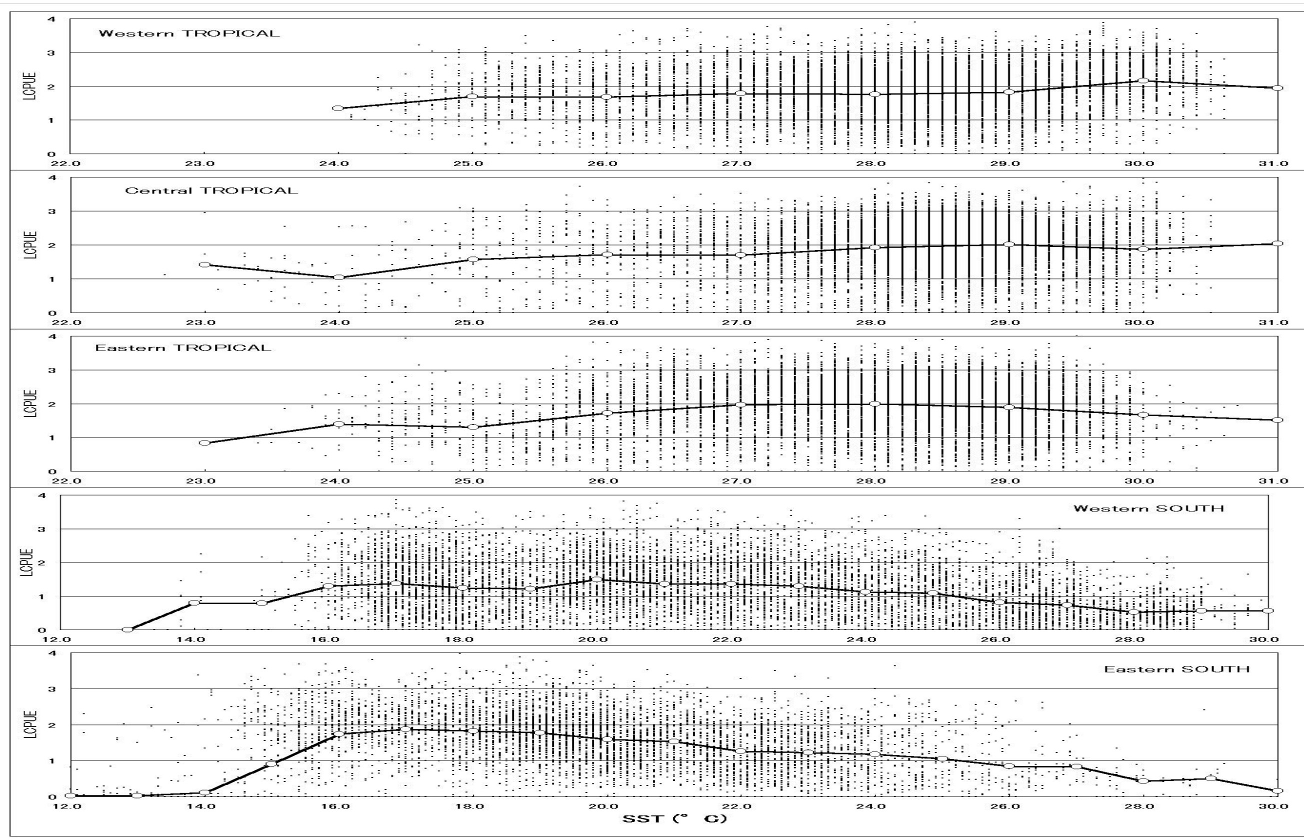


Figure 7. Relationship between SST and logarithmic CPUE in three tropical and two south areas in the Indian Ocean.

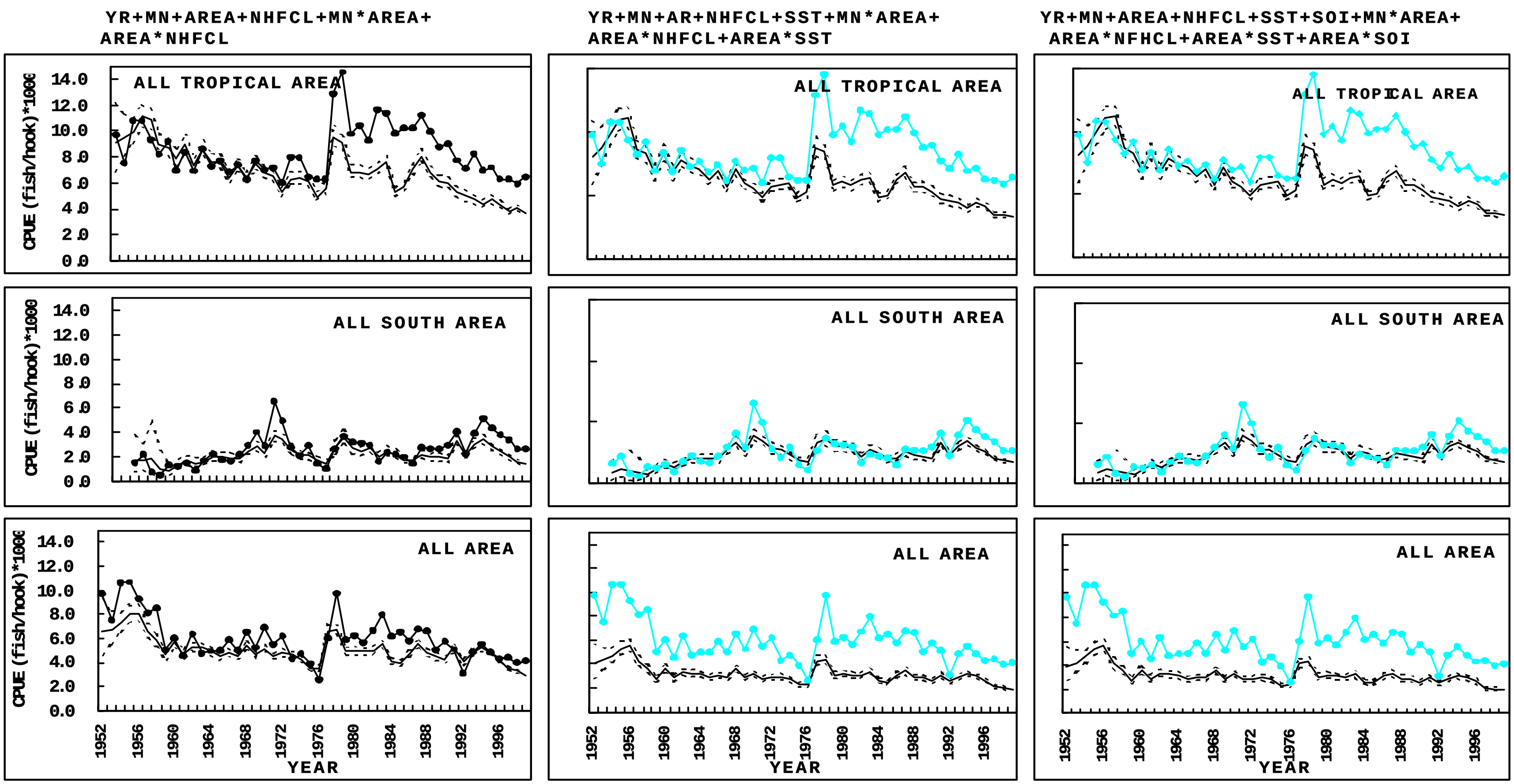


Figure 8. Nominal CPUE (solid line with closed circle) and standardized CPUE (solid line) with 95% confidence limits (broken lines) for each of all tropical (sub-area 1 through 5), all south (sub-area 6 and 7) and all Indian areas for number based CPUE using three types of model

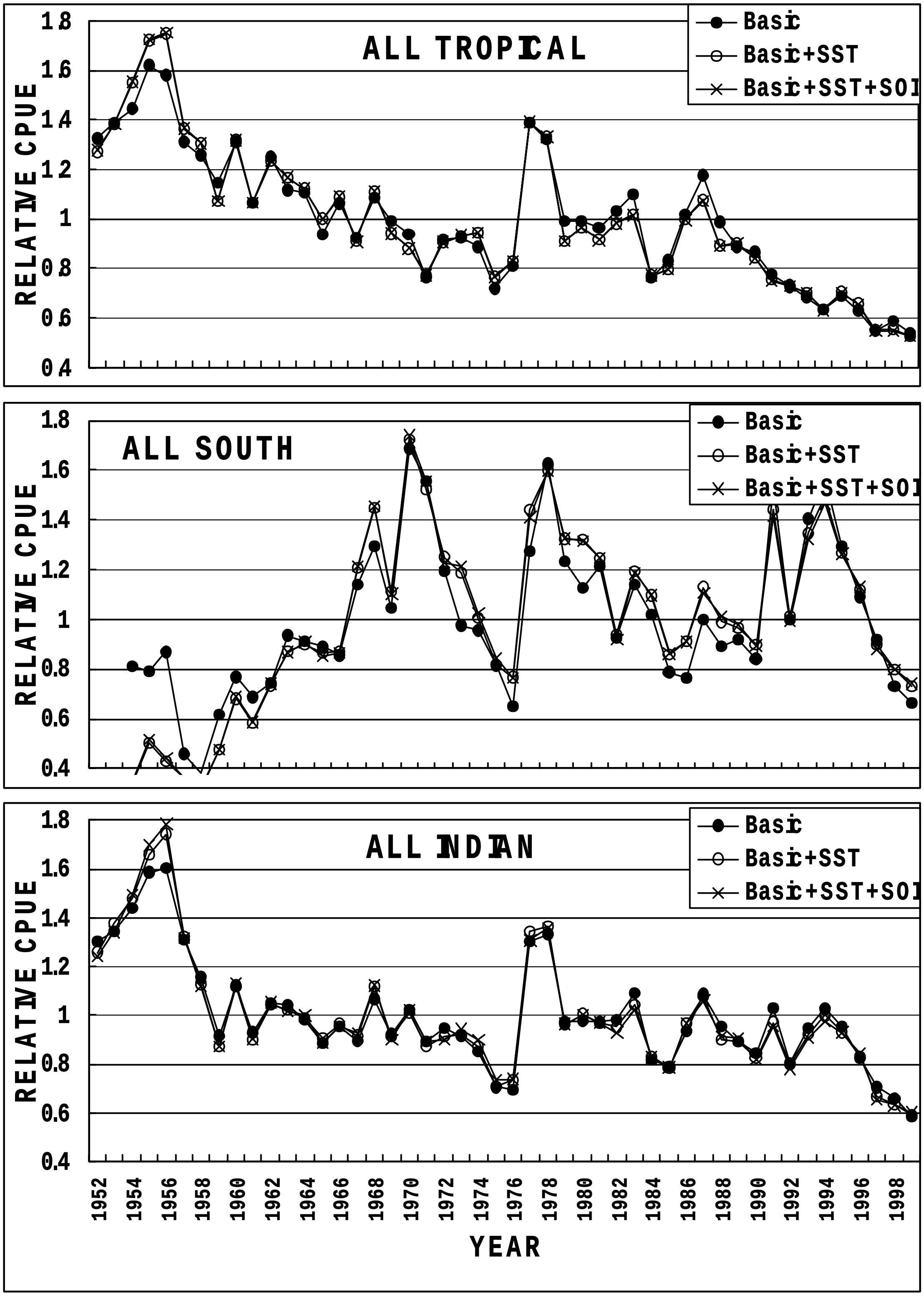


Figure 9. Relative CPUE (number based CPUE) for all tropical, all south and all Indian areas using three types of models.

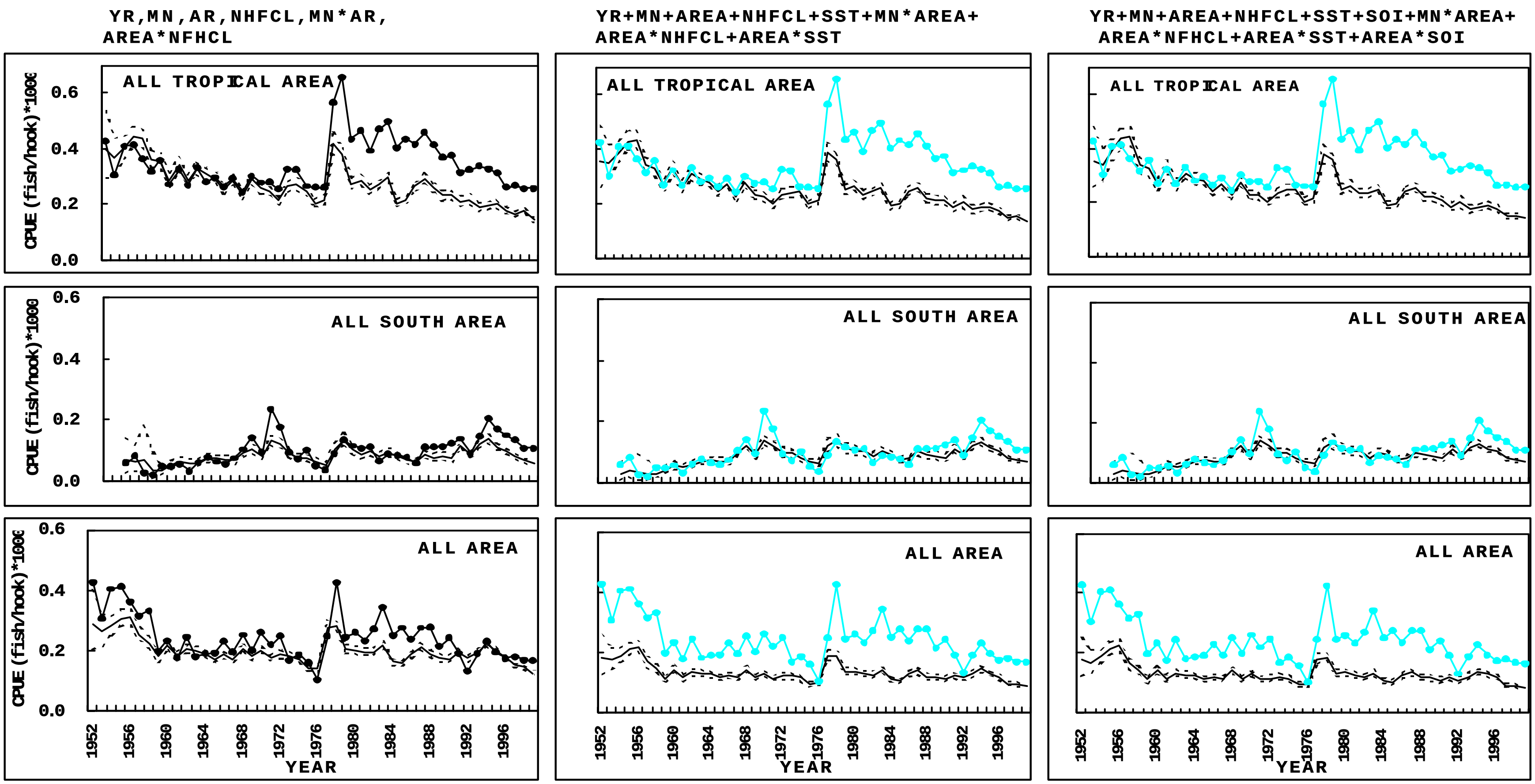


Figure 10. Nominal CPUE (solid line with closed circle) and standardized CPUE (solid line) with 95% confidence limits (broken lines) for each of all tropical (sub-area 1 through 5), all south (sub-area 6 and 7) and all Indian areas for weight based CPUE using three types of model.

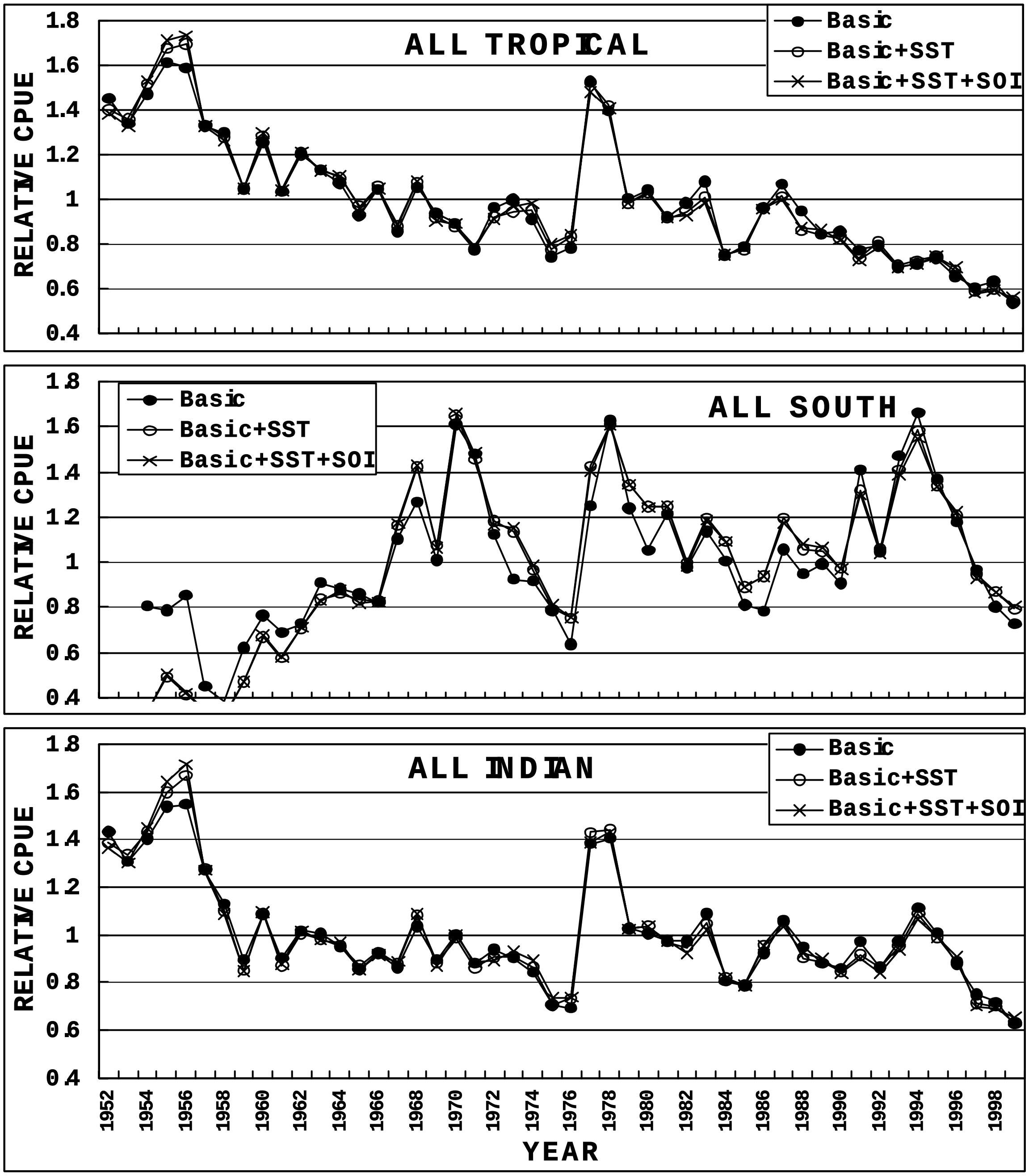


Figure 11. Relative CPUE (weight based CPUE) for all tropical, all south and all Indian areas using three types of models.

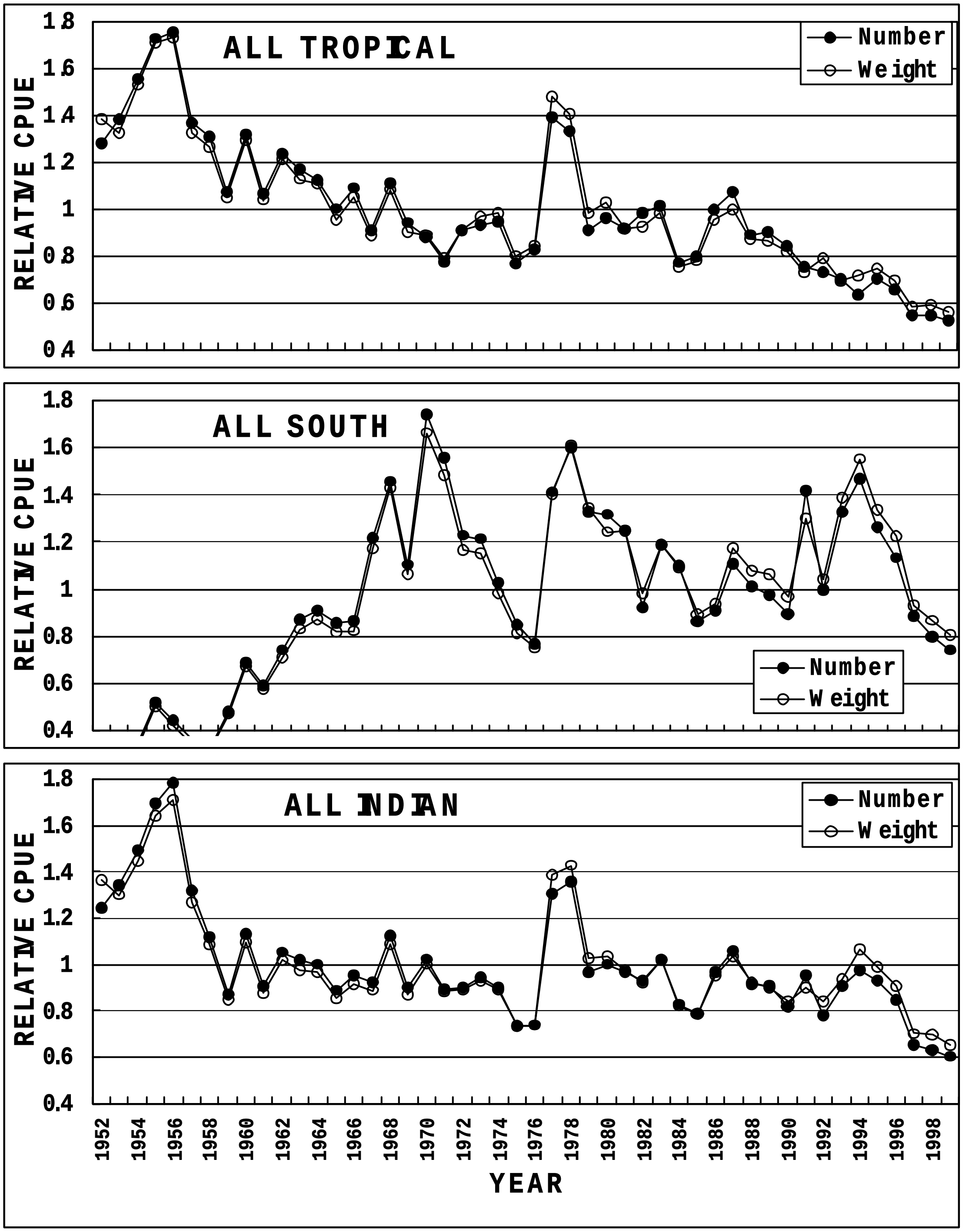
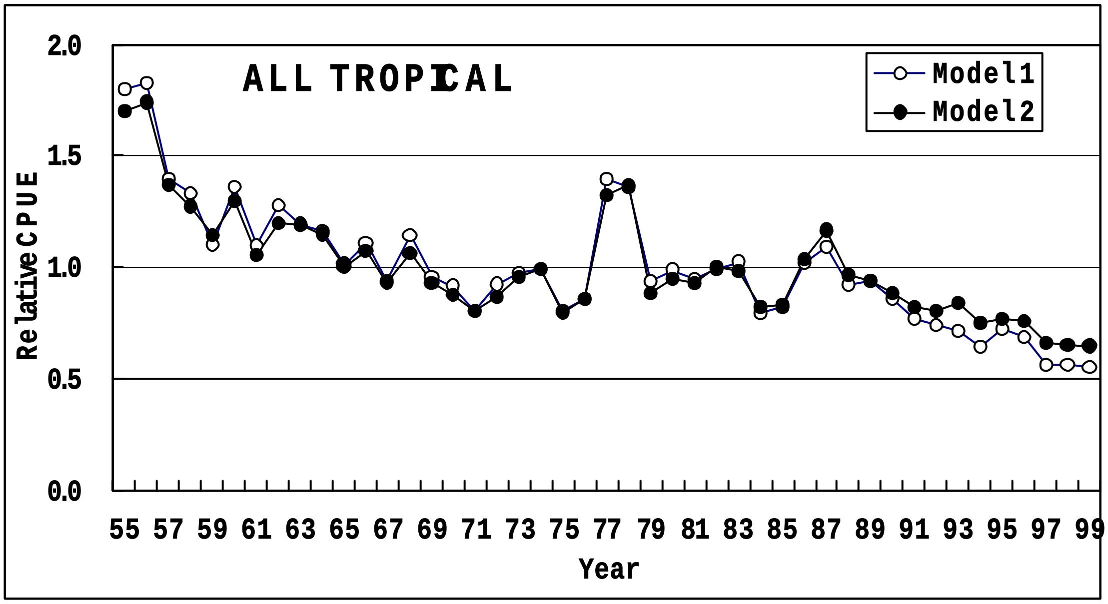


*Figure 12. Relative CPUE (number and weight based CPUEs) for all tropical, all south and all Indian areas. Used model is YR+MN+AREA+NHFCL+SST+SOI+MN*AREA+ AREA*NFHCL+AREA*SST+AREA*SOI.*



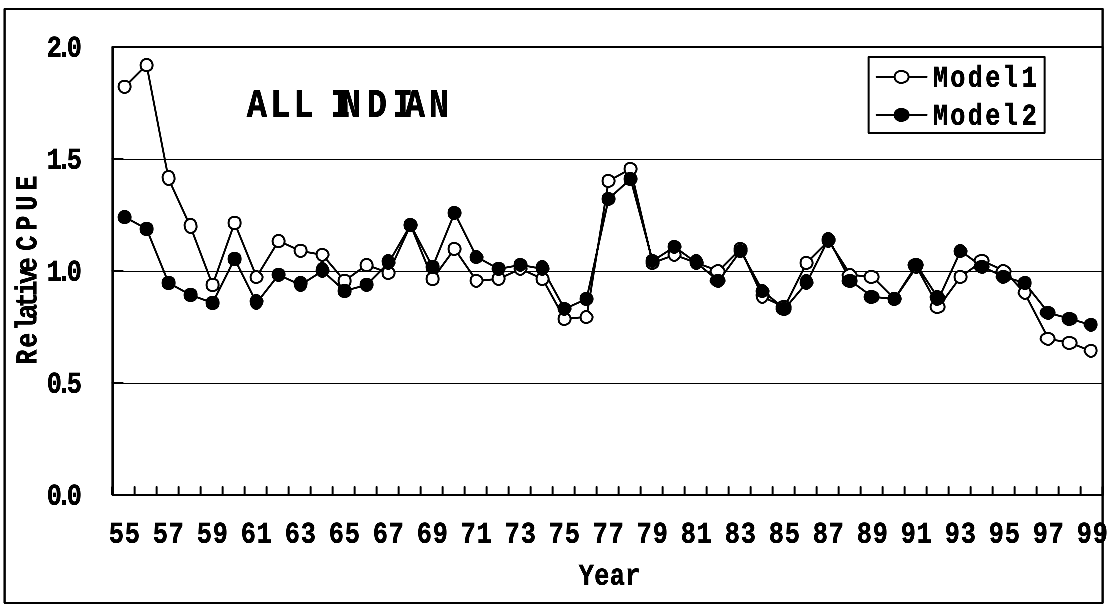


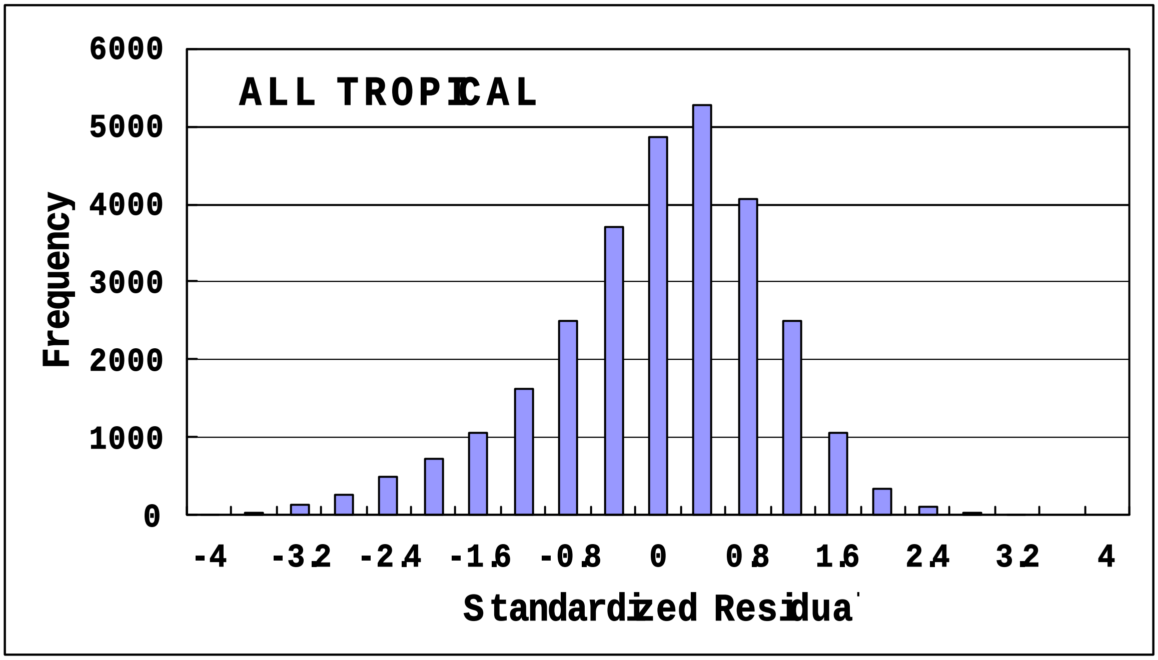
Figure 13. Comparison of standardized CPUE (Number base) between models with (Model 2) and without (Model 1) Year-Area interaction.

*MODEL 1: YR+MN+AREA+NHFCL+SST+SOI+MN*AREA +AREA*NHFCL*

*+AREA*SST +AREA+SOI*

*MODEL 2: YR+MN+AREA+NHFCL+SST+SOI+**<u>YR*AREA</u>**+MN*AREA*

*+AREA*NHFCL +AREA*SST +AREA+SOI*



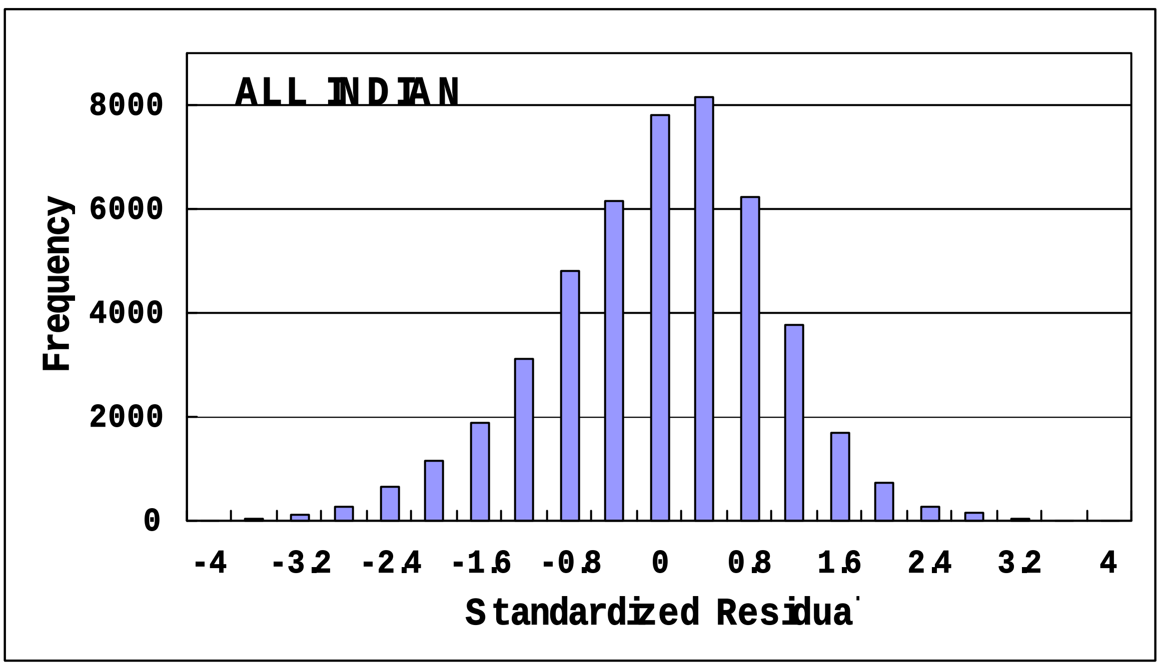


Figure 14. Overall histogram of standardized residuals from GLM analyses using the model including Year-Area interaction for all tropical (upper) and all Indian areas (lower).

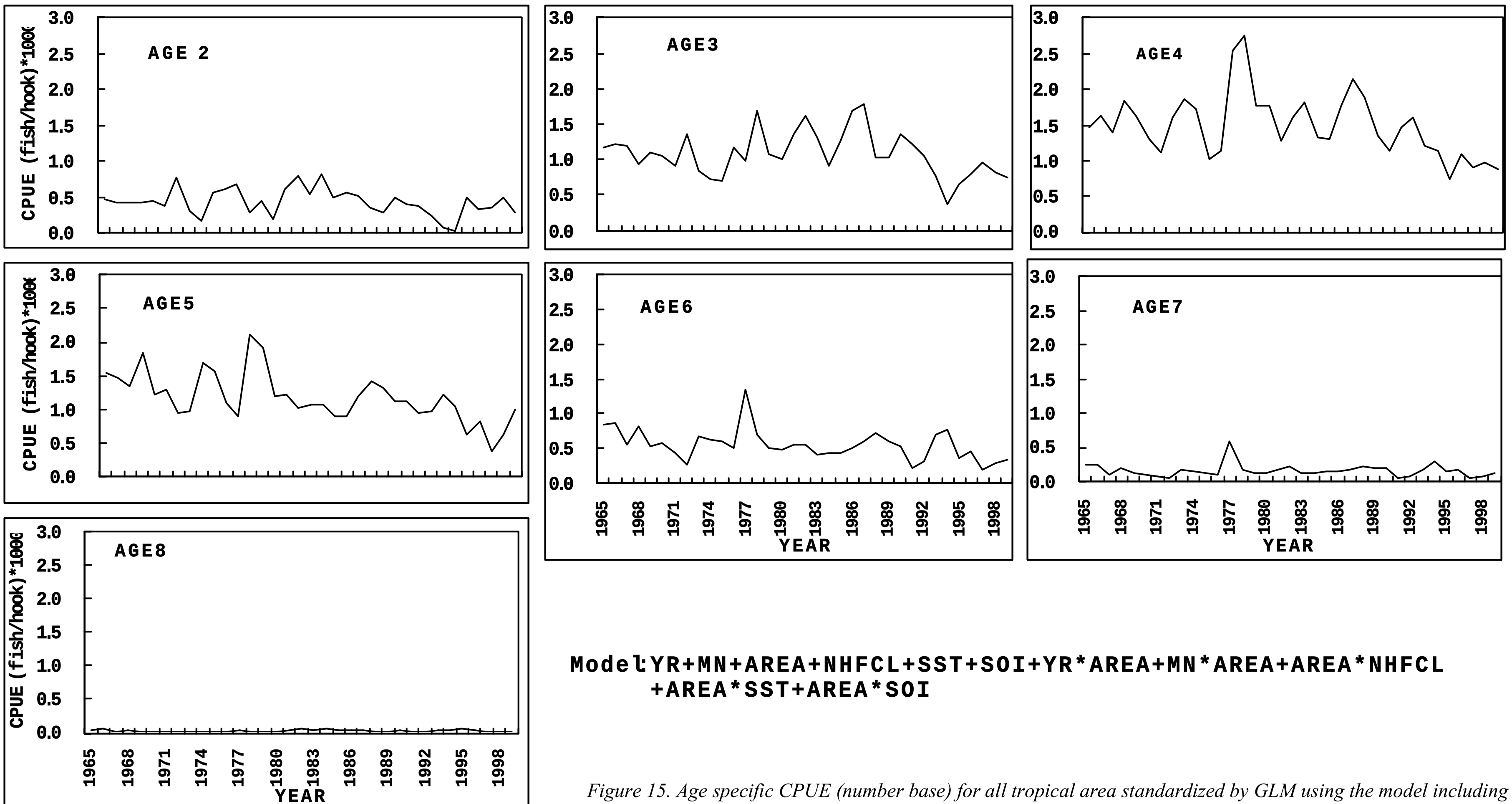


Figure 15. Age specific CPUE (number base) for all tropical area standardized by GLM using the model including Year-Area interaction.

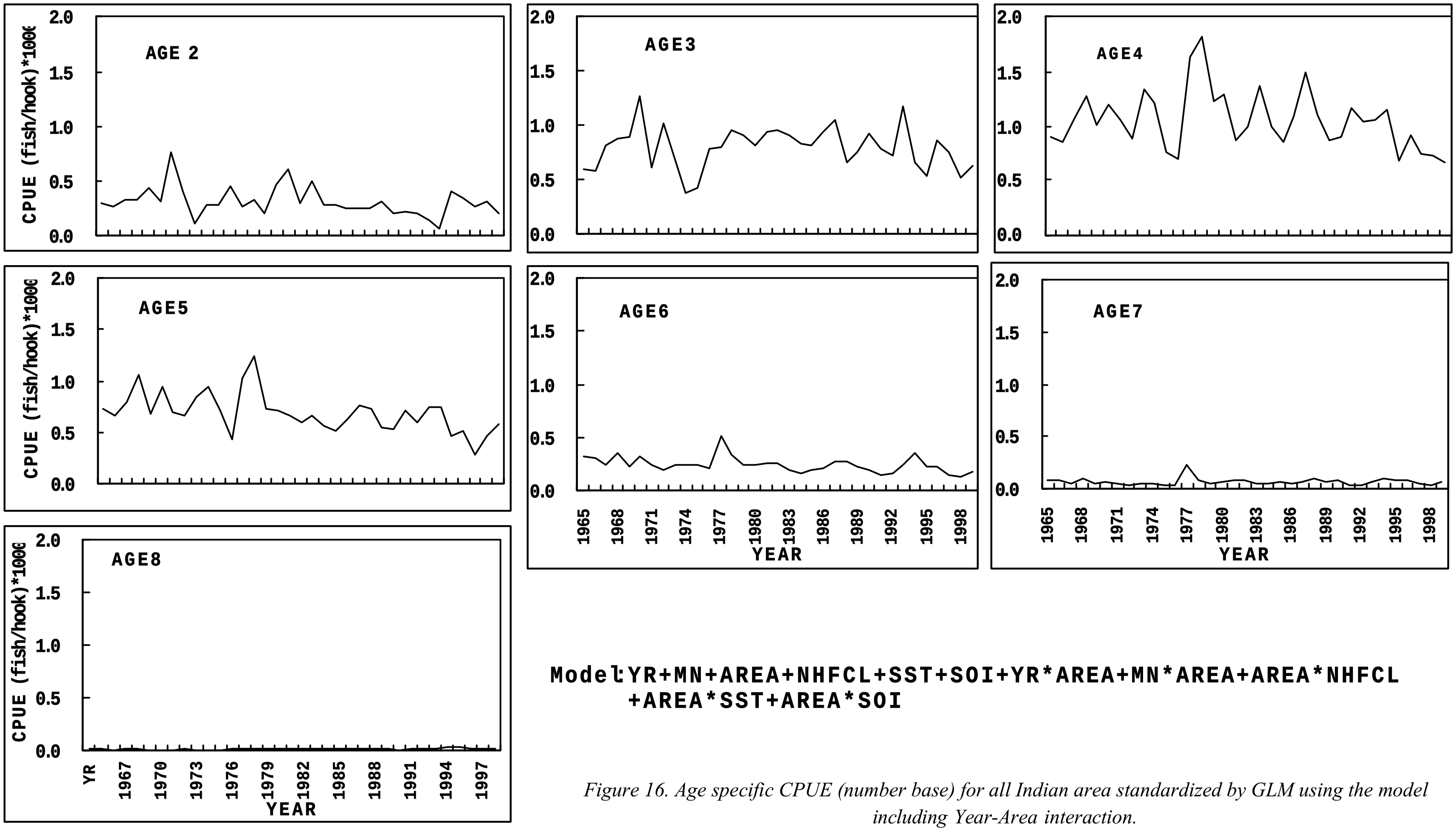
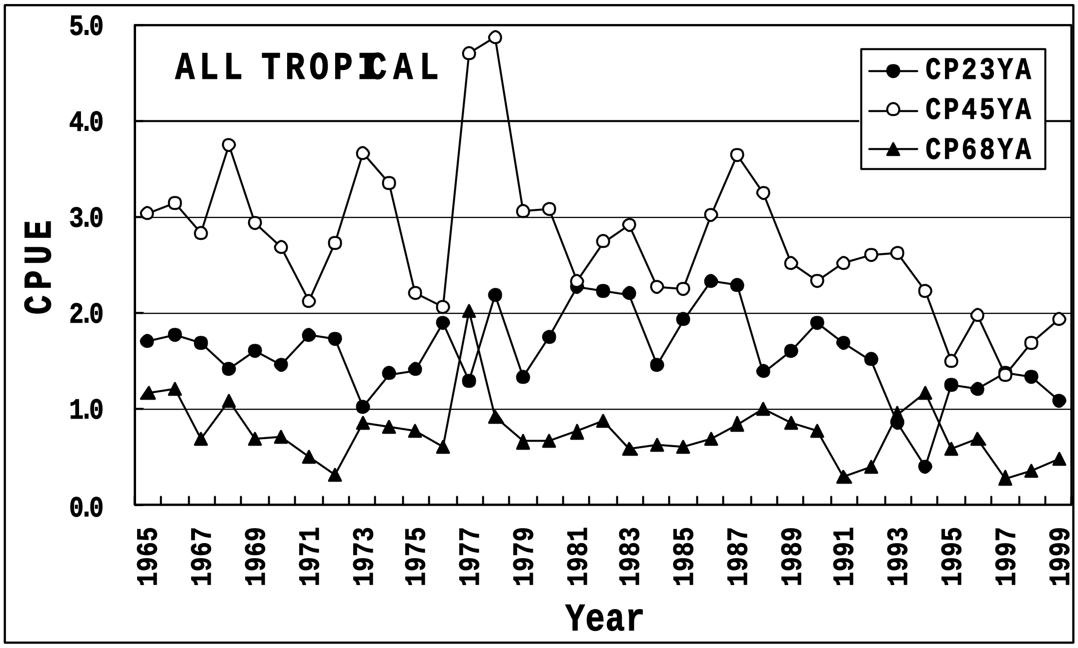


Figure 16. Age specific CPUE (number base) for all Indian area standardized by GLM using the model including Year-Area interaction.



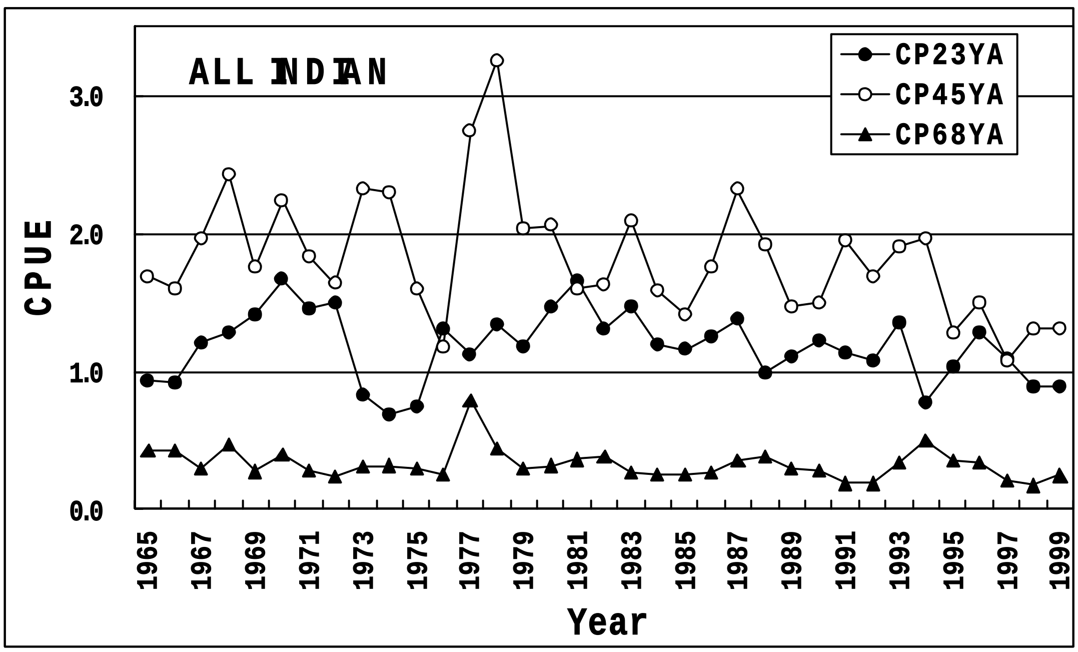


Figure 17. Standardized CPUE for each age group (age 2-3, 4-5, and 6-8) in all tropical (upper) and all Indian (lower) areas.

*Model: YR+MN+AREA+NHFCL+SST+SOI+YR*AREA+MN*AREA+AREA*NHFCL+AREA*SST*

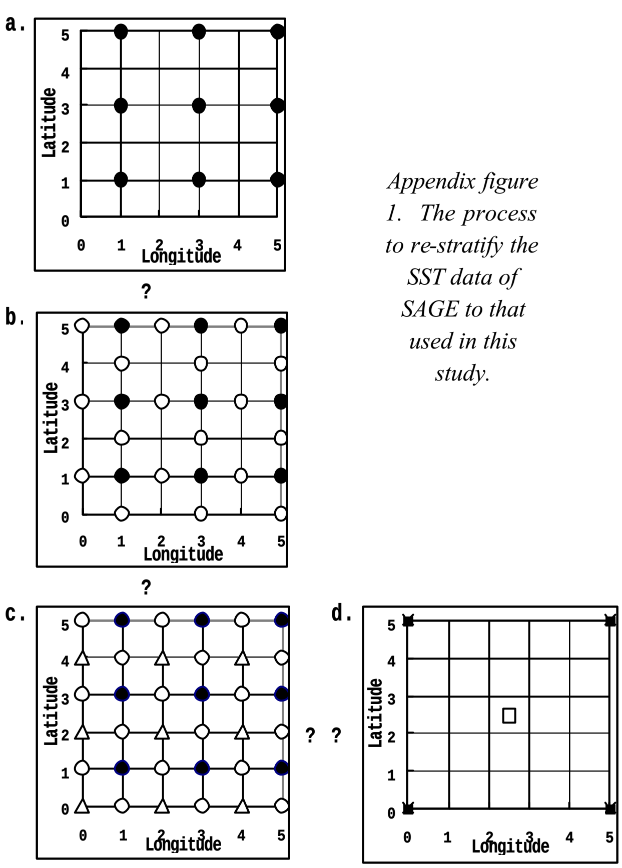
+AREA+SOI

Appendix table 1. Result of ANOVA from the General Linear Model for bigeye in the tropical (AREA 1, 2, 3, 4 and 5) south (AREA 6 and 7) and all area(AREA 1-7) in the Indian Ocean, 1952-1999.

Type of AREA	Type of CPUE	AREA	Source of Variation	D.F.	S. S.	Mean Square	F Value	Pr > F	R-Square
YR + MN + AREA + NHFCL + MN*AREA + AREA*NHFCL									
OLD	Number	Western TROPICAL	Model	72	1624.58	22.564	53.11	0.0001	0.2439
NEW	Number	Western TROPICAL	Model	71	1334.80	18.800	41.52	0.0001	0.2374
OLD	Number	Center TROPICAL	Model	72	438.27	6.087	14.69	0.0001	0.1384
NEW	Number	Center TROPICAL	Model	72	711.71	9.885	17.90	0.0001	0.1165
OLD	Number	Eastern TROPICAL	Model	58	2300.17	39.658	32.15	0.0001	0.1943
NEW	Number	Eastern TROPICAL	Model	60	1003.94	16.732	29.44	0.0001	0.1543
OLD	Number	Western SOUTH	Model	54	1538.44	28.490	30.87	0.0001	0.1598
NEW	Number	Western SOUTH	Model	58	1934.81	33.359	35.81	0.0001	0.1715
OLD	Number	Eastern SOUTH	Model	58	2300.17	39.658	32.15	0.0001	0.1943
NEW	Number	Eastern SOUTH	Model	58	2361.30	40.712	33.56	0.0001	0.1933
OLD	Number	ALL TROPICAL	Model	106	2374.77	22.403	49.08	0.0001	0.1488
NEW	Number	ALL TROPICAL	Model	116	2861.02	24.664	51.37	0.0001	0.1770
OLD	Number	ALL SOUTH	Model	72	3439.89	47.776	43.44	0.0001	0.1591
NEW	Number	ALL SOUTH	Model	72	3859.77	53.608	48.86	0.0001	0.1620
OLD	Number	ALL INDIAN	Model	144	11929.14	82.841	127.65	0.0001	0.2933
NEW	Number	ALL INDIAN	Model	145	12295.42	84.796	132.35	0.0001	0.3023
New	Weight	ALL TROPICAL	Model	116	2653.85	22.878	41.68	0.0001	0.1428
New	Weight	ALL SOUTH	Model	72	3825.76	53.136	48.38	0.0001	0.1607
New	Weight	ALL INDIAN	Model	144	12857.56	89.289	128.53	0.0001	0.2814
YR+MN+AREA+NHFCL+SST+MN*AREA+AREA*NHFCL+AREA*SST									
NEW	Number	ALL TROPICAL	Model	121	3114.21	25.737	48.65	0.0001	0.1687
NEW	Number	ALL SOUTH	Model	74	5929.49	80.128	81.47	0.0001	0.2489
NEW	Number	ALL INDIAN	Model	151	14060.19	93.114	139.91	0.0001	0.3090
NEW	Weight	ALL TROPICAL	Model	121	3020.26	24.961	46.08	0.0001	0.1612
NEW	Weight	ALL SOUTH	Model	74	5936.73	80.226	81.66	0.0001	0.2493
NEW	Weight	ALL INDIAN	Model	151	14729.06	97.543	147.01	0.0001	0.3196
YR+MN+AREA+NHFCL+SST^2+MN*AREA+AREA*NHFCL+AREA*SST^2									
NEW	Number	ALL TROPICAL	Model	121	3106.08	25.670	48.50	0.0001	0.1682
YR+MN+AREA+NHFCL+SST+SOI+MN*AREA+AREA*NHFCL+AREA*SST+AREA*SOI									
NEW	Number	ALL TROPICAL	Model	126	3139.62	24.918	47.17	0.0001	0.1701
NEW	Number	ALL SOUTH	Model	76	5932.67	78.061	79.38	0.0001	0.2490
NEW	Number	ALL INDIAN	Model	158	14097.48	89.225	134.21	0.0001	0.3098
NEW	Weight	ALL TROPICAL	Model	126	3050.81	24.213	44.78	0.0001	0.1628
NEW	Weight	ALL SOUTH	Model	76	5940.38	78.163	79.57	0.0001	0.2495
NEW	Weight	ALL INDIAN	Model	158	14773.02	93.500	141.09	0.0001	0.3206

Appendix table 3. Data of standardized CPUE used for Figure 17.

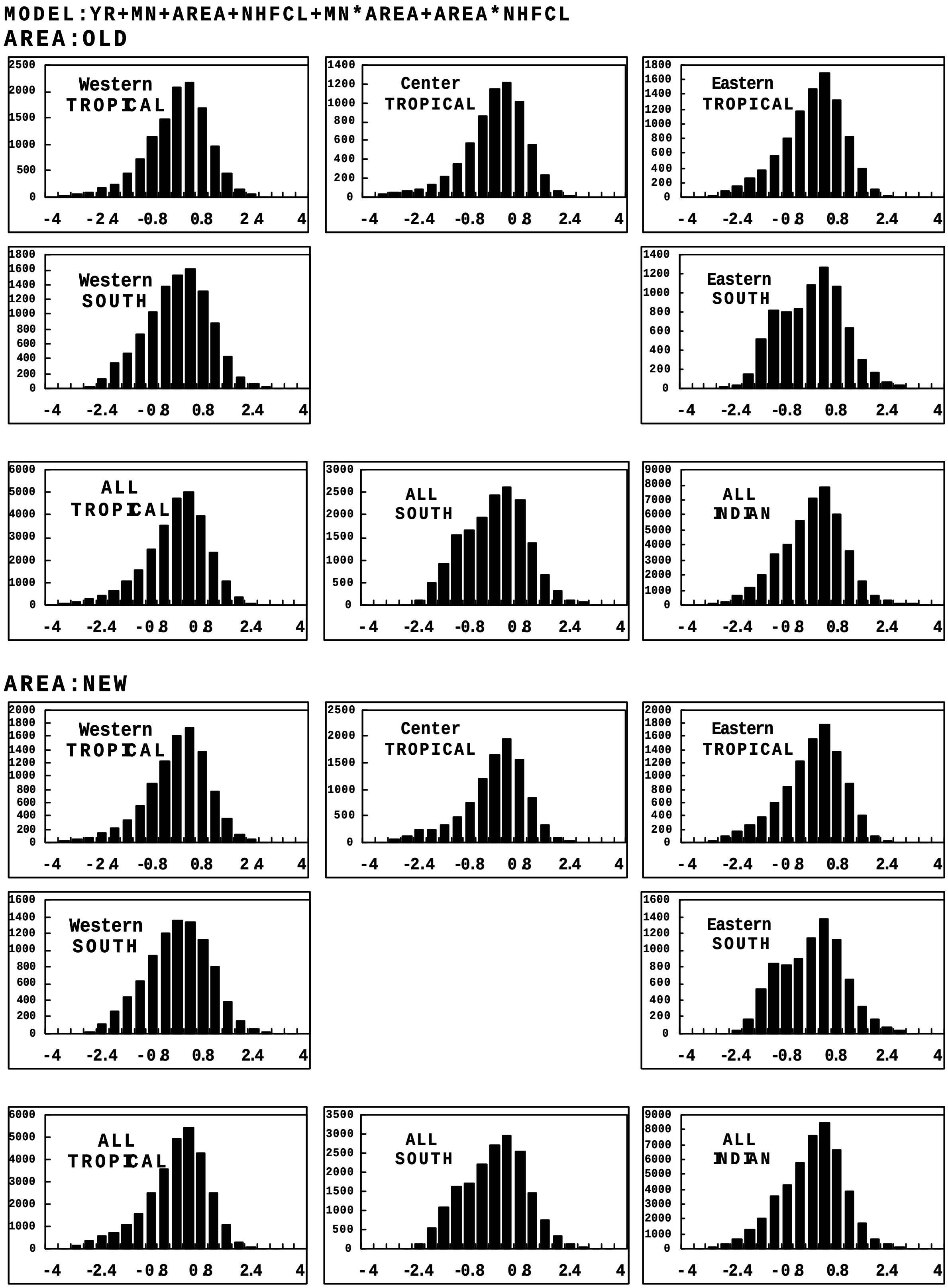
Year	ALL TROPICAL Age 2-3	ALL TROPICAL Age 4-5	ALL TROPICAL Age 6-8	ALL INDIAN Age 2-3	ALL INDIAN Age 4-5	ALL INDIAN Age 6-8
1965	1.700	3.034	1.174	0.933	1.689	0.423
1966	1.781	3.147	1.212	0.918	1.602	0.431
1967	1.688	2.829	0.694	1.203	1.967	0.299
1968	1.418	3.754	1.086	1.287	2.436	0.475
1969	1.611	2.947	0.682	1.411	1.754	0.273
1970	1.465	2.680	0.718	1.667	2.241	0.391
1971	1.766	2.120	0.509	1.454	1.836	0.278
1972	1.738	2.727	0.326	1.498	1.637	0.235
1973	1.024	3.662	0.867	0.829	2.325	0.304
1974	1.366	3.354	0.823	0.691	2.305	0.316
1975	1.408	2.210	0.774	0.752	1.600	0.295
1976	1.905	2.064	0.613	1.306	1.173	0.255
1977	1.294	4.704	2.024	1.127	2.743	0.789
1978	2.188	4.866	0.928	1.345	3.254	0.438
1979	1.327	3.056	0.662	1.185	2.035	0.293
1980	1.753	3.083	0.666	1.464	2.060	0.317
1981	2.281	2.326	0.765	1.656	1.597	0.361
1982	2.231	2.740	0.880	1.308	1.633	0.385
1983	2.199	2.922	0.589	1.477	2.092	0.266
1984	1.462	2.279	0.630	1.200	1.591	0.256
1985	1.930	2.256	0.603	1.159	1.415	0.249
1986	2.329	3.029	0.695	1.259	1.759	0.268
1987	2.287	3.654	0.846	1.376	2.321	0.357
1988	1.388	3.260	0.997	0.985	1.921	0.380
1989	1.607	2.516	0.862	1.112	1.469	0.298
1990	1.904	2.340	0.771	1.226	1.495	0.283
1991	1.693	2.519	0.288	1.134	1.957	0.188
1992	1.512	2.612	0.399	1.077	1.696	0.186
1993	0.862	2.626	0.952	1.355	1.907	0.341
1994	0.404	2.229	1.168	0.777	1.966	0.494
1995	1.254	1.496	0.583	1.032	1.277	0.350
1996	1.206	1.975	0.690	1.285	1.500	0.335
1997	1.375	1.356	0.285	1.097	1.079	0.207
1998	1.343	1.688	0.363	0.889	1.309	0.171
1999	1.093	1.931	0.488	0.892	1.313	0.245



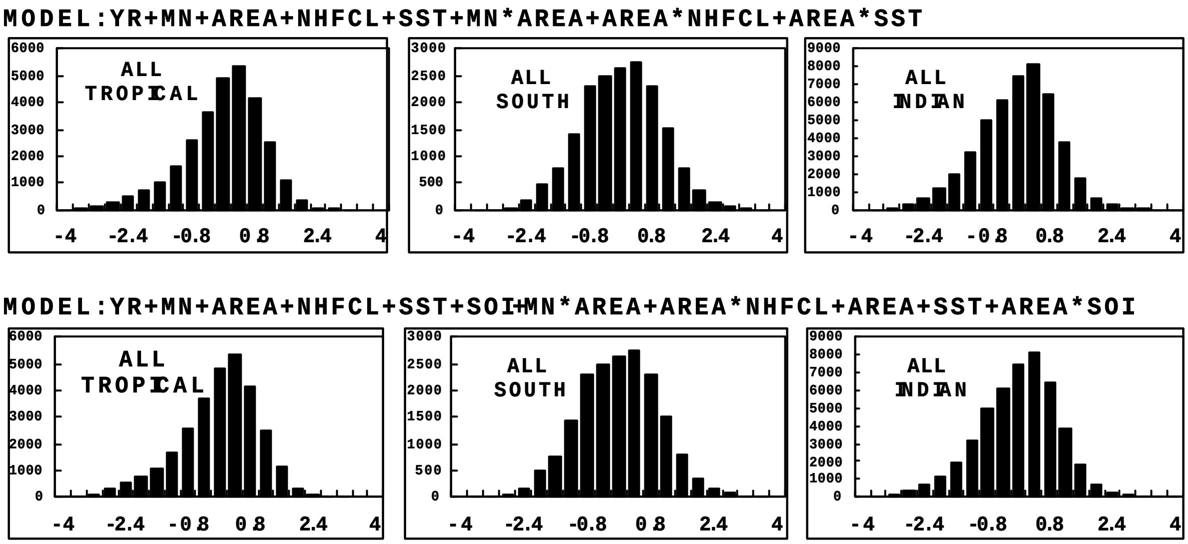
Appendix figure 1. The process to re-stratify the SST data of SAGE to that used in this study.

Appendix table 2. Data of relative CPUE used for Figure 13.

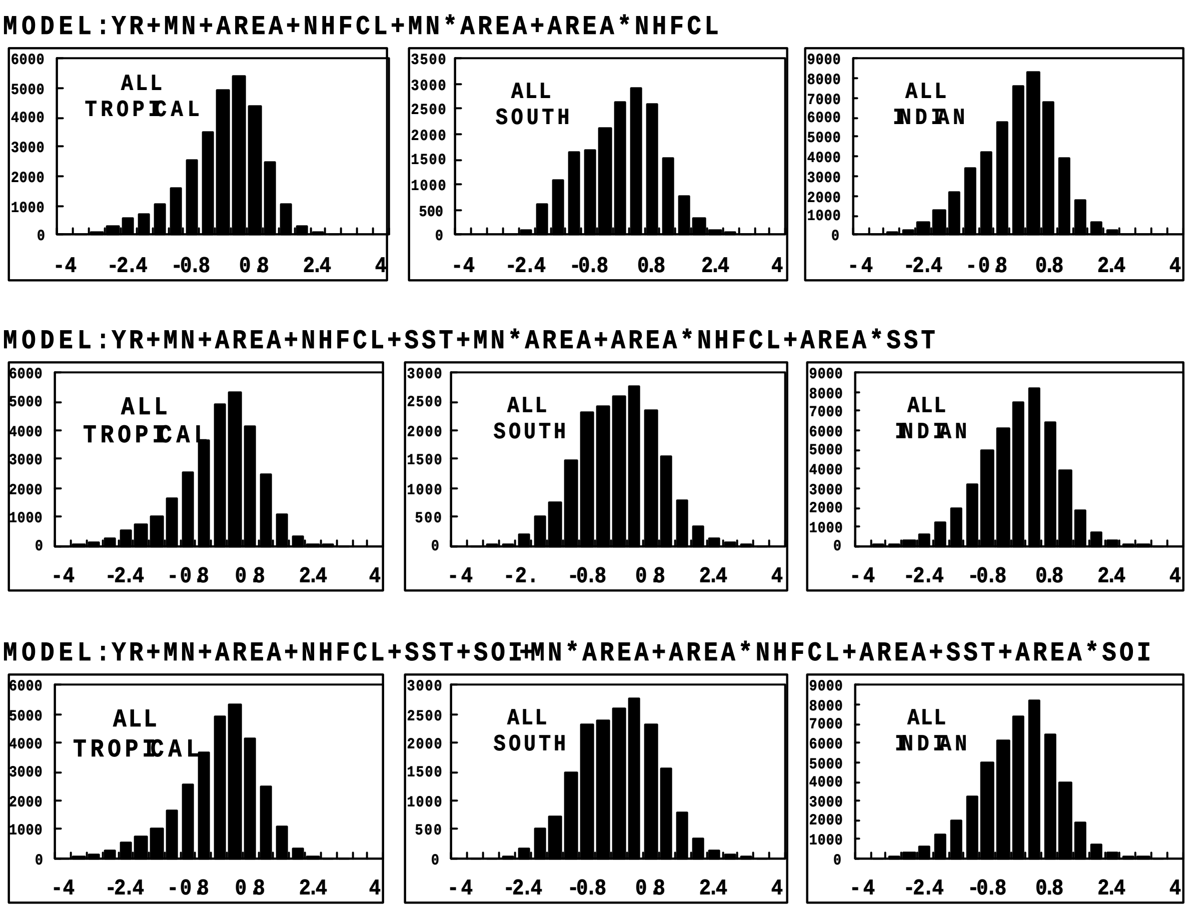
Year	ALL TROPICAL Model1	ALL TROPICAL Model 2	ALL INDIAN Model 1	ALL INDIAN Model2
1955	1.7986	1.7013	1.8253	1.2391
1956	1.8287	1.7407	1.9173	1.1869
1957	1.3954	1.3706	1.4159	0.9479
1958	1.3300	1.2733	1.2016	0.8928
1959	1.1016	1.1414	0.9366	0.8581
1960	1.3626	1.2970	1.2153	1.0544
1961	1.0968	1.0539	0.9709	0.8632
1962	1.2757	1.1954	1.1314	0.9841
1963	1.1929	1.1860	1.0920	0.9425
1964	1.1623	1.1493	1.0748	1.0052
1965	1.0142	1.0042	0.9546	0.9091
1966	1.1088	1.0748	1.0247	0.9419
1967	0.9381	0.9313	0.9919	1.0403
1968	1.1420	1.0610	1.2068	1.2028
1969	0.9556	0.9276	0.9663	1.0161
1970	0.9159	0.8772	1.0984	1.2609
1971	0.8030	0.8028	0.9595	1.0613
1972	0.9245	0.8682	0.9667	1.0108
1973	0.9752	0.9557	1.0130	1.0299
1974	0.9926	0.9886	0.9647	1.0134
1975	0.8069	0.7961	0.7862	0.8336
1976	0.8560	0.8548	0.7921	0.8750
1977	1.3930	1.3210	1.4036	1.3209
1978	1.3595	1.3656	1.4580	1.4100
1979	0.9347	0.8811	1.0351	1.0472
1980	0.9866	0.9494	1.0746	1.1104
1981	0.9444	0.9250	1.0408	1.0400
1982	0.9899	0.9992	0.9977	0.9586
1983	1.0234	0.9820	1.0980	1.0869
1984	0.7930	0.8201	0.8892	0.9076
1985	0.8182	0.8312	0.8431	0.8300
1986	1.0217	1.0333	1.0361	0.9516
1987	1.0940	1.1668	1.1366	1.1401
1988	0.9226	0.9626	0.9795	0.9566
1989	0.9369	0.9404	0.9733	0.8839
1990	0.8595	0.8812	0.8793	0.8767
1991	0.7687	0.8185	1.0230	1.0306
1992	0.7380	0.8042	0.8381	0.8803
1993	0.7136	0.8374	0.9723	1.0875
1994	0.6451	0.7485	1.0476	1.0225
1995	0.7231	0.7674	0.9975	0.9768
1996	0.6831	0.7556	0.9052	0.9475
1997	0.5610	0.6586	0.7005	0.8159
1998	0.5632	0.6523	0.6772	0.7866
1999	0.5497	0.6475	0.6460	0.7623



Appendix figure 2. Overall histograms of standardized residuals from GLM analyses for each areas based on old and new sub-area definitions.



Appendix figure 3. Overall histograms of standardized residuals from GLM using two types of model for number based CPUE in each area.



Appendix figure 4. Overall histograms of standardized residuals from GLM using three types of model for weight based CPUE in each area.