Investigation on Taiwanese longline fishing condition of SBT in the Central Indian Ocean and its relationship with ocean temperature variability

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Abstract

The report describes the present fishing condition of SBT in the Central Indian Ocean (CIO), including catch rates, hook depths and ambient temperatures, through an *in-situ* observation during 2004 fishing season. About 95% of hooks deployed during the investigation were suspended between 50~200m and the average ambient temperature were around 14~19.4℃ or 14~16.5℃ in the high catch rate period/region. The seasonal SBT fishing ground for Taiwanese longliners in the CIO is located north of Sub Antarctic Zone and within the Subtropical Zone with SST around 17~19℃. We also analyze the historical catch rates (1981~2003) of Taiwanese longliners seasonally targeting SBT in the CIO in relation to the ocean temperature and climatic variability. The adjusted catch rates of SBT using Generalized Linear Model were compared with the large-scale SST data in the Indian Ocean during the period. The SST fluctuation almost synchronizes the ENSO signal in the tropical waters (0~20° S), however the SST variations in the higher latitudes (30~50° S) show slower and longer tempo. The catch rate of SBT in the CIO seems to vary out of phase with SST oscillations in the mid latitudes around 30~50° S, i.e. the catch rates rise while the SSTs drop. The fluctuation of SBT catch rates in the latitudes of Taiwanese fishing ground is probably linked to the expansion of cold water mass in the Southern Ocean. The phenomenon observed in the report is still preliminary.

Introduction

In the past, southern bluefin tuna (SBT) was mainly a by-catch of Taiwanese tuna longline fishery and their fishing locations were therefore very extensive in space and time. However, in recent years the fishing operations seasonally targeting SBT become an important component of Taiwanese tuna fishery in the Indian Ocean and the fishing grounds for such fishery are seasonally active in the astral temperate waters (CCSBT, 2004). As a result of such development, two major fishing grounds/seasons, namely the Central Indian Ocean (Jun~Sep) and South East Africa (Oct~Feb), are identified according to the historical records of 1981~2003 (Fig. 1). The catches of SBT have exceeded 1,000 mt since 1989 of which the CIO and SEA fishing grounds consists of more than 70% of the total SBT catch thereafter (Fig. 2).

The CIO fishing ground itself, comprising more than 90% of the total SBT catch since 2002, become increasingly important in present stage (Fig. 2) and even in the future hopefully. However, the characteristic of fishing conditions in the CIO fishing ground where Taiwanese longliners seasonal targeting SBT, such as the hook depths and the ambient temperature of the key water column, has never been investigated or documented before.

On the other hand, the ocean temperature fluctuation caused by climatic change is an important factor that affects tuna fishing condition in other oceans (Kimura et al., 1997; Lehodey et al., 1997, 2003; Lu et al., 1998, 2001). The monsoon circulation is the main climate system of Indian Ocean and the ENSO-forced anomaly is also significant in the tropical and subtropical waters (Schott and McCreary Jr., 2001). As the latitudes of the CIO fishing ground are between Subtropical and Sub Antarctic Zones, both climatic factors from Tropical and Antarctic are the important sources of ocean temperature variability. The response of fishing condition to the oceanic condition change may be different from the tropical cases found in other oceans.

The purpose of the report is to describe the present fishing condition in the CIO through an *in-situ* observation during 2004 fishing season and trying to analyze the historical catch rate of SBT in relation to ocean temperature change as well as to ENSO-forced climatic variability in the India Ocean.

Materials and Method

There are two parts of data acquisitions in this report, one from the observer program and the other from the national fishery archive maintained in Oversea Fishery Development Council of the Republic of China (OFDC).

In the first part, we collect the gear performance data of longline seasonally targeting SBT in the CIO through scientific observer's *in-situ* investigation. Figure 3 shows the two cruises carried out by a scientific observer on two tuna fishing boats operating in the CIO during 2004 fishing season. The first survey started from west to east during SBT fishing season from 14th June ~ 23rd August, 2004 and the second survey started from the end of the season heading from east to west during 4th September ~ 14th November, 2004. In each daily set, the observer attached three Temperature Depth Recorders (TDRs) to collect hook depths and vertical temperature structures data.

In the second part, those catch and effort data (LG data) provided within the CIO region, in this report defined as region within 55~105° E / 20~40° S, were segregated and submitted to following analysis. Since the effort for SBT catch rate is hard to be defined, in this study all daily records from the vessels that have SBT catch in the CIO were included in the calculation of fishing effort. We use Generalized Linear Model, GLM with normal error structure, to adjust the catch rates of SBT. Main effects (year, season, bycatches of albacore, bigeye and yellowfin) and interactions (year, season) were included in the model (Wu and Yeh, 1999).

$$LOG(CPUE+1) = \mu + Year + Season + ALB + BET + YFT + Interaction + \varepsilon$$

Catch rates of the bycatch of albacore (ALB) and bigeye (BET) tunas were calculated and coded by quartile. The catch rate of bycatch of yellowfin (YFT) were only coded by two levels, 0 or not 0. The ε denotes error term with $N(0, \sigma)$.

Factors were removed from the model if not statistically significant at $p<0.05$ levels during the GLM analysis. The reduced model was examined until all factors were significant. With the selected models from GLM, the adjusted catch rates were estimated by least square mean method.

The adjusted catch rates in the CIO were then analyzed with climatic data collected from International Research Institute (IRI), including monthly sea surface temperature data (1 x 1 degree) and Southern Oscillation Index (SOI).

Results and Discussion

Fishing condition in the CIO during 2004 Fishing Season

There were totally 131 fishing days observed in the CIO during the 2004 fishing season with 63 days in ship 1 and 68 days in ship 2. During the observation, the catch of SBT commenced in early July, reached the highest in August, and ended in September (Fig. 4A). The periods before 27July and after 10 September were without SBT catch but with dominant catch of albacore.

According to the depth and temperature data read from the 389 TDR records, there were about 95% of hooks deployed during the fishing operation were suspended between 50~200m and the average ambient temperature were around 14~19.4℃ no matter in type of 11 or 10 HBF (hooks between floats). In the main fishing season/ground of SBT, gear type were mainly 11 HBF, the depth of hooks were slightly deeper than those of 10 HBF, and the temperature (14~16.5℃) were lower than those of 10 HBF as well.

Fig. 4B shows the vertical isotherm along the trackline using daily T-D data collected during the period while observer on board (14 June ~ 18 November, 2004). Obviously, the oceanographic characteristics of SBT fishing season/ground with 17~19℃ at sea surface and 14 ℃ at depth of 200m, are different from those of albacore with warmer water temperature (Fig. 5).

Historical catch rates of SBT in the CIO

There are totally 38,963 fishing days selected for the analysis of historical fishing condition in the CIO. The ANOVA of the monthly SBT catch rate during 1981~2003 indicates that all main effects and selected interactions were significant at $p<0.001$ levels in the model (Table 3). As the mean squares for season were high, suggest that seasonal variations play important roles in SBT's catch rate in the CIO. About 98% of the catches were concentrated in the second (AMJ) and third (JAS) quarters, and 87% of them were within 30~35° S (Table 4). Therefore, the catch rates of the rest seasons in the CIO are not included in the following analysis.

Figures 6A and 6B show the nominal and adjusted SBT catch rates of quarters AMJ and JAS, respectively. The trends of the nominal and adjusted serials are similar. The high adjusted amplitude for the serial of JAS after 1996 are due to the effect from fishing strategy in the CIO, the effects from bycatches of BET, YFT and ALB.

Catch rates and large-scale SST in Indian Ocean

Both adjusted catch rate serials (n=23) of AMJ and JAS during 1981~2003 were correlated to the SST serials of every 1 by 1 grids in the Indian Ocean. The contours in Figures 7A and 7B are processed by Grigging interpolation method using the correlation coefficient values of each grid. The correlation coefficient values between the catch rates and SST are mostly negative in the CIO. During both AMJ and JAS exists significant negative correlation regions ($r<-0.3$, $df=22$, $p<0.05$) in the CIO fishing ground. As the fishing ground during AMJ were located in the western CIO and spread to the whole CIO during JAS, the contours of significantly negative correlation coefficients during AMJ and JAS were just at the regions where fishing activities took place. This may suggest that the expansion of the cold waters south of SCTZ in the CIO would benefit the catch rate of SBT.

Catch rates, ENSO and SST anomaly

It is obvious that the SST fluctuation in the Indian Ocean tracked the ENSO signal. According to the SST anomalies (AMJ and JAS average) in the four latitudinal bands in the CIO, within 55° E ~ 105° E, the phases of SST anomaly variation in relation to El Niño and La Niña occurrences are different among the latitudinal bands (Fig. 8). The frequency of the phases in lower latitudes were short while the higher latitudes showed prolonged duration of SST anomaly phases.

More detailed descriptions of the SST anomalies in space and time were given in Figures 9 and 10. The contours of SST anomalies (AMJ and JAS average) shown in the Figures are along 60 ° E and 80° E meridianal cross-section during 1982~2003. The baseline SST levels of each month are 22-year monthly SST average during the period. According to the Figures, the SST fluctuation almost synchronizes the ENSO signal in the tropical waters (0~20° S), however the SST variations in the higher latitude (30~50° S) show slower and longer tempo.

The catch rate of SBT in the CIO seems to vary out of phase with SST oscillations in the middle latitudes around 30~50° S. In other words, the catch rates rise while the SSTs drop. During the negative anomalies prevailing period in the latitudes of 30~50° S, a rising trend or positive variation of catch rates were observed (Fig. 9 and 10). This also supports that the enhancement of cold water mass from the Southern Ocean would increase the SBT catch rate of Taiwanese longliners.

The seasonal SBT fishing ground for Taiwanese longliners in the CIO was located north of Sub Antarctic Zone and within the Subtropical Zone with SST around 17~19℃

(Fig. 4). As the region is at the northern edges of juvenile SBT's feeding ground and almost concentrated in latitudes of 30~35° S (Table 4), the fluctuation of SBT catch rates found in the CIO by Taiwanese data is probably linked to the expansion of cold water mass in the south and results alteration in catchability.

Similar phenomenon can also be found in Japan's data, the CPUE figures in Zone 8/CCSBT. The magnitudes of the variability of CPUE are much higher than that observed from Taiwan's data. In the latitudes of Zone 8 are much closer to the Sub Antarctic Zone, the Antarctic Circumpolar Wave (ACW) becomes an important climatic factors from the Southern Ocean that affect Indian Ocean. These should be taken into consideration in further study.

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Acknowledges

The authors would like to express their appreciation to the Council of Agriculture, Taiwan, R.O.C. for the financial support. We also like to thank Mr. Chien-Ho Liu, the scientific observers, for his hard work at sea to collect TDRs data from fishing boats in the CIO.

Table 1 Hook depths distribution of Taiwanese tuna longline fishing SBT

HBF	Proportion of hook by depth (meters) zone								
(%)	0-25	25-50	50-75	75-100	100-125	125-150	150-175	175-200	200-225
10	0	0	16.67	17.16	13.73	25.98	19.61	6.86	0
11	0	0	15.46	21.13	19.07	15.46	11.34	13.40	4.12

Table 2 Depth and Temperature read from the TDRs attached at different hook positions

HBF	Samples	Position	Depth(m)			Temperature(℃)		
			Max	Min	Avg	Max	Min	Avg
10	68	1	141.27	60.54	76.11	21.89	15.12	19.42
	61	3	166.95	76.90	127.09	21.10	13.88	17.81
	4	5	185.16	142.98	161.92	17.45	13.41	16.24
	63	6	194.89	70.53	158.05	20.81	12.83	16.68
	6	8	171.46	106.94	139.08	17.59	15.00	16.14
11	24	1	158.06	55.21	84.02	18.63	14.55	16.52
	2	2	126.28	84.56	105.42	17.94	15.37	16.66
	9	3	166.97	94.59	135.68	17.32	14.40	14.94
	4	4	136.64	108.47	122.56	16.42	14.70	15.56
	63	6	220.95	66.98	168.50	19.23	12.44	14.03
	49	9	192.05	71.49	121.28	17.83	13.20	15.07
	34	11	190.39	51.83	78.19	17.83	13.61	16.50

Table 3 Analysis of variance of standardized CPUEs using GLM procedure of SBT from Taiwanese longline fishery

Source	DF	Sum of Squares	Mean Square	F- Value	Pr>F
Model	93	2213.02	23.79	101.55	<0.0001
Error	38870	9108.25	0.234		
Corrected Total	38963	11321.27			
	R^2: 0.195	C.V.: 176.79			

Source	DF	Type Ⅲ SS	Mean Square	F- Value	Pr>F
Year	22	166.10	7.55	32.22	<.0001
season	3	109.25	36.41	155.42	<.0001
Year*season	60	348.30	5.80	24.77	<.0001
BET	3	19.00	6.33	27.03	<.0001
ALB	3	29.71	9.90	42.27	<.0001
YFT	2	176.23	88.11	376.04	<.0001

Table 4 The percentage of total SBT catch (in number) by month and by latitude caught by Taiwanese longliners in the CIO during 1981~2003.

Latitudinal band	Months				
	JFM	AMJ	JAS	OND	Sum
20~25° S	0.09%	0.04%	0.52%	0.06%	0.71%
25~30° S	0.01%	0.29%	4.20%	0.06%	4.56%
30~35° S	0.32%	17.96%	68.17%	0.53%	86.98%
35~40° S	1.17%	2.99%	3.55%	0.04%	7.75%
Sum	1.59%	21.27%	76.45%	0.70%	100.00%

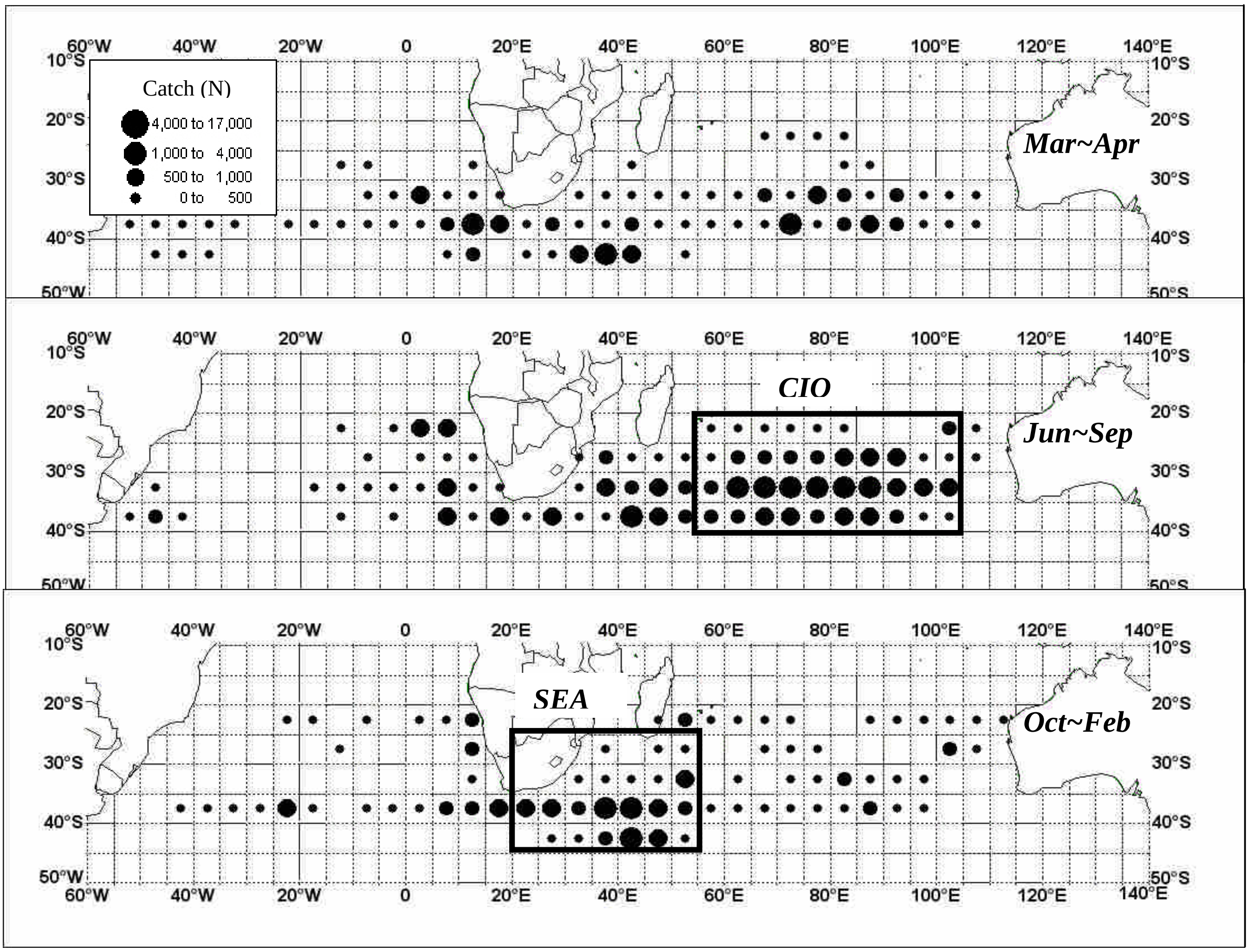


Fig. 1 The accumulative number of SBT caught by Taiwanese longline fishery during 1981~2003.

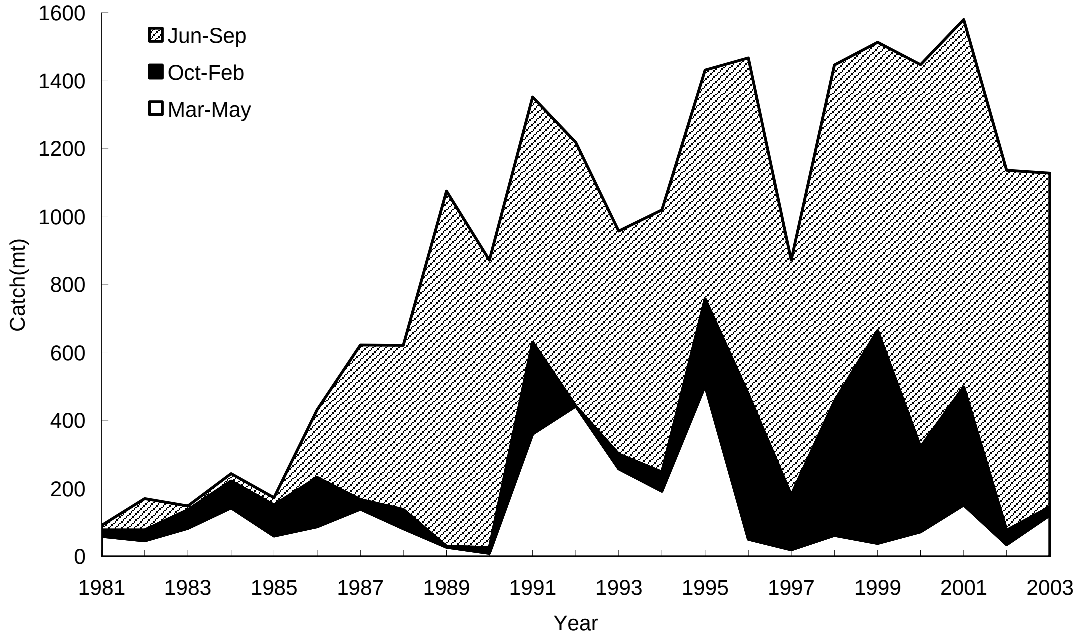


Fig.2 The stacked chart of catches in three major fishing seasons during 1981~2003

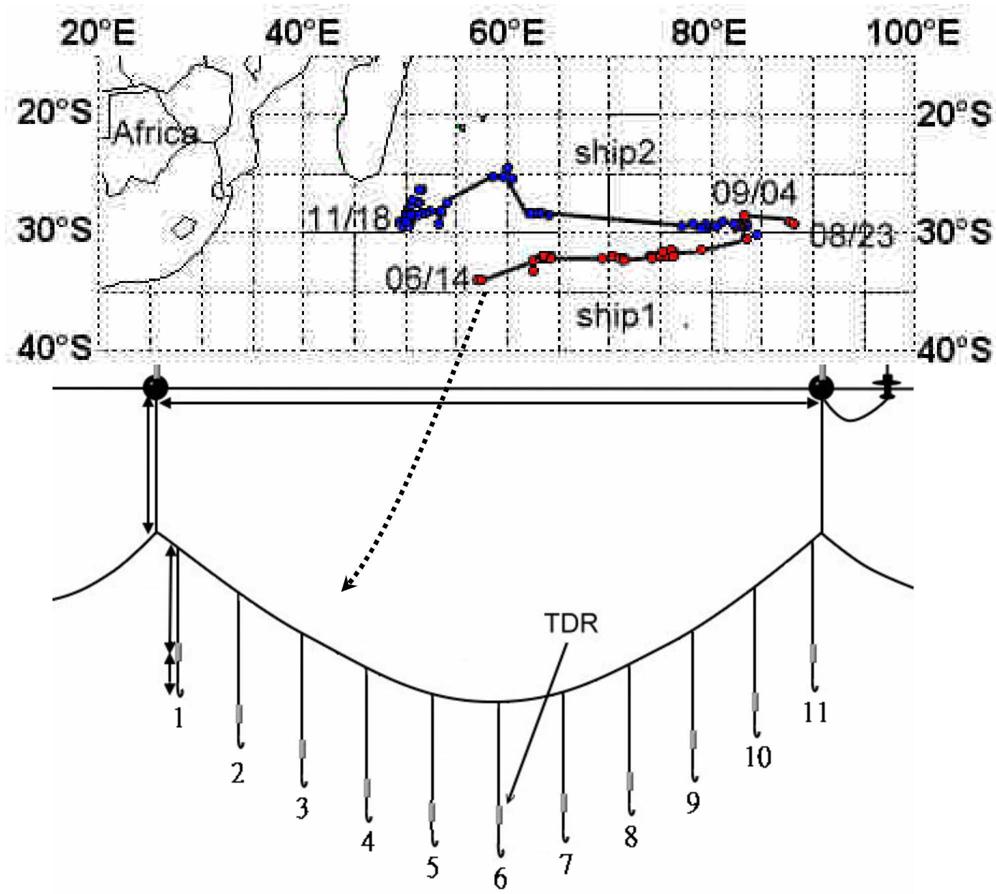


Fig. 3 The tracklines and positions of the two fishing boads where the observer collected TDRs data during daily fishing operations.

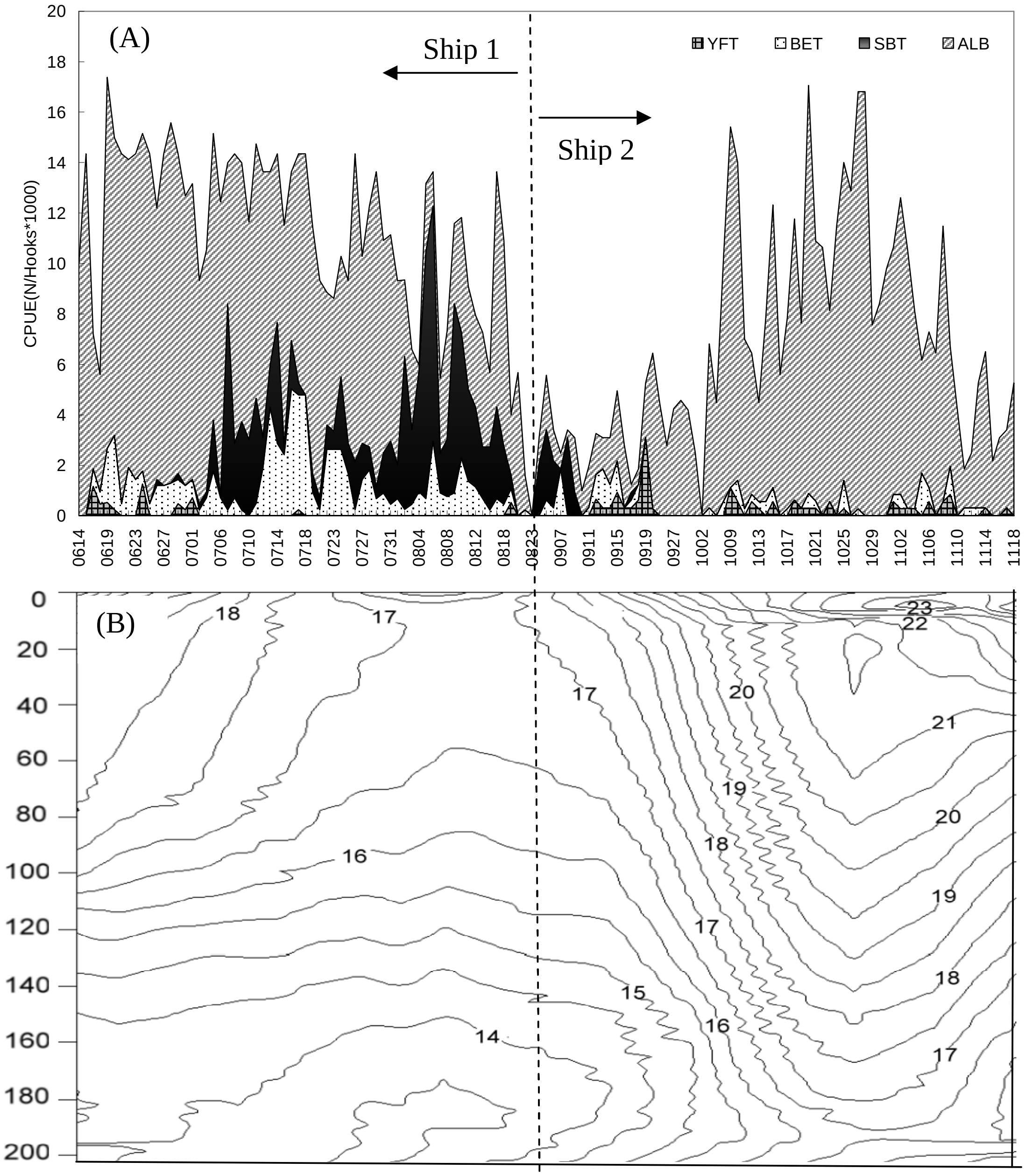
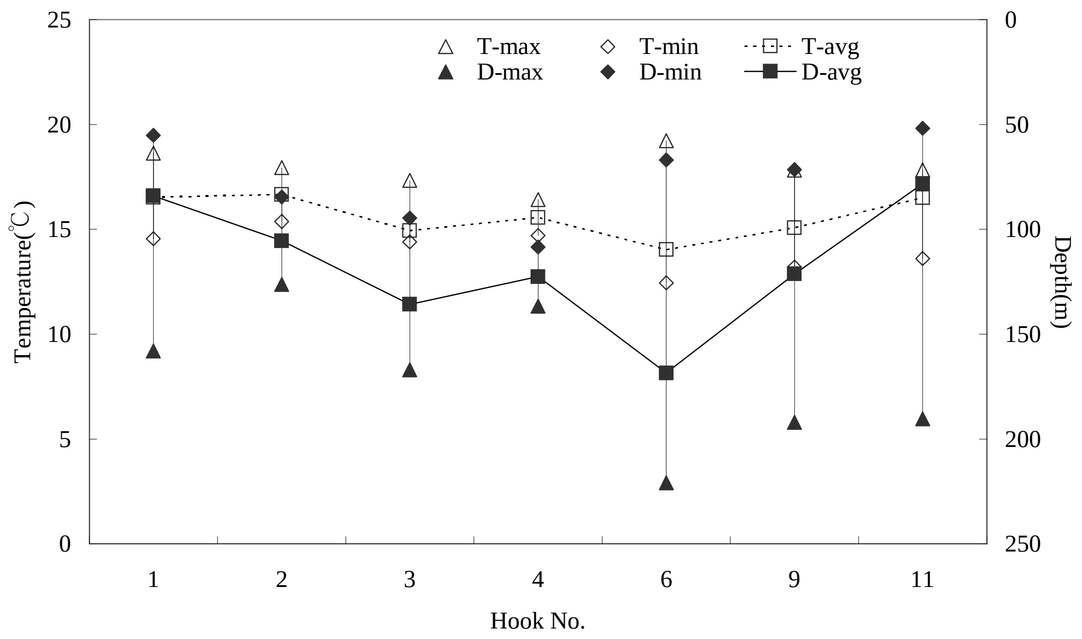


Fig. 4 (A) The daily catch rates of SBT and major tuna species. (B) The vertical structure of temperatures along the two tracklines (Fig. 3) built by the T-D data collected above the daily deepest hooks.

(A) Ship 1 (HBF=11)



(B) Ship 2 (HBF=10)

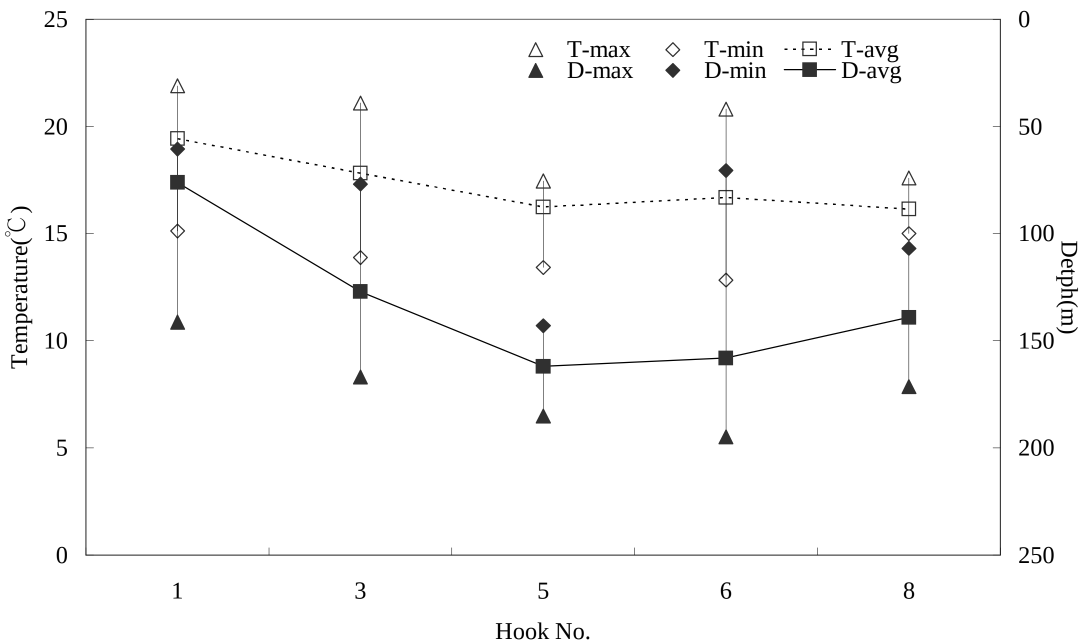
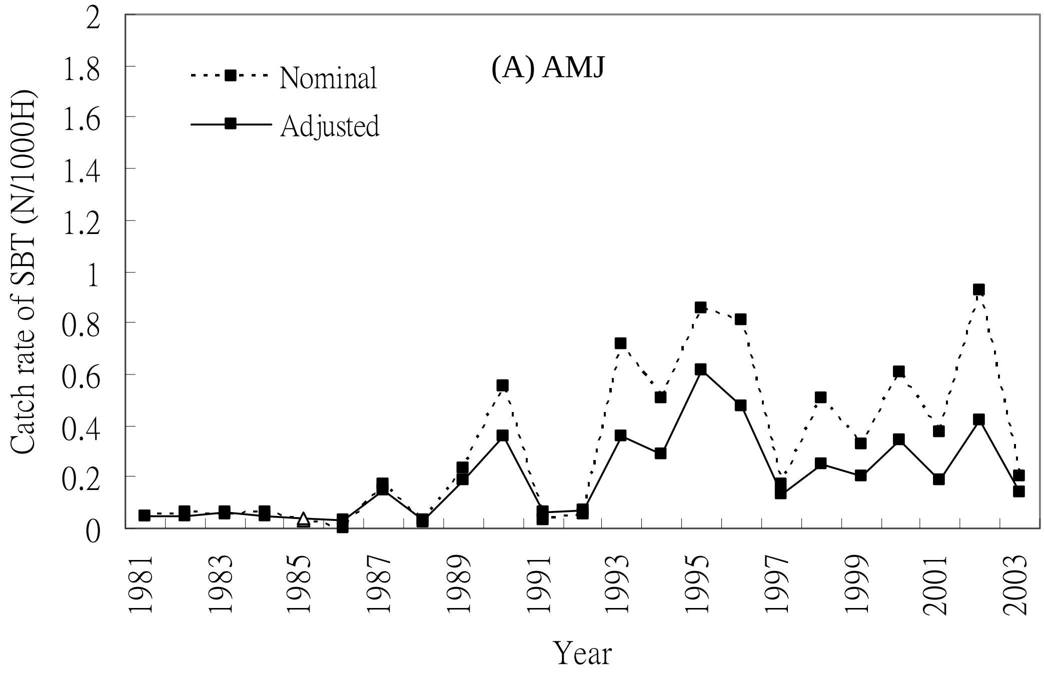


Fig. 5 The average, maximum and minimum depths and associated temperatures read from the TDRs attached in different hook positions during the surveys. (A) HBF=10, (B) HBF=11



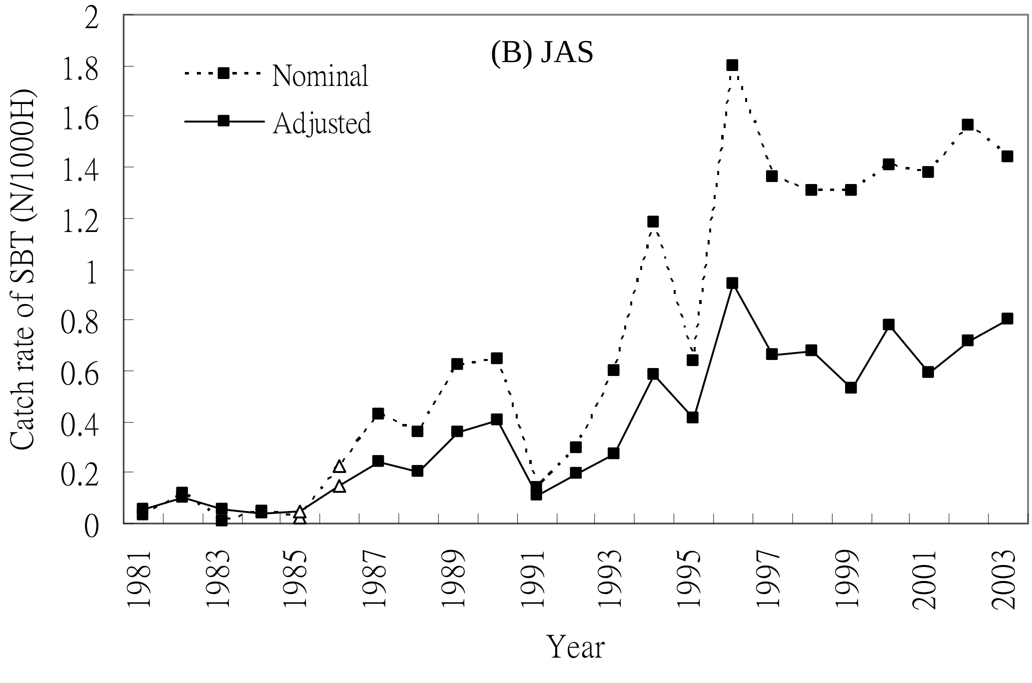
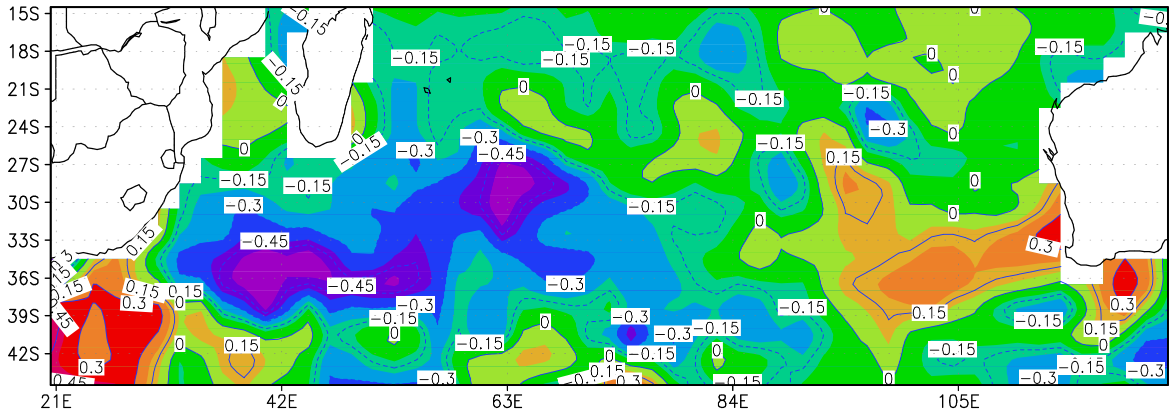


Fig. 6 Nominal and standardized CPUEs series of SBT in the CIO; (A) April~June, (B) July~September. The empty triangles denote missing values interpolated by averaging method.

(A) AMJ



(B) JAS

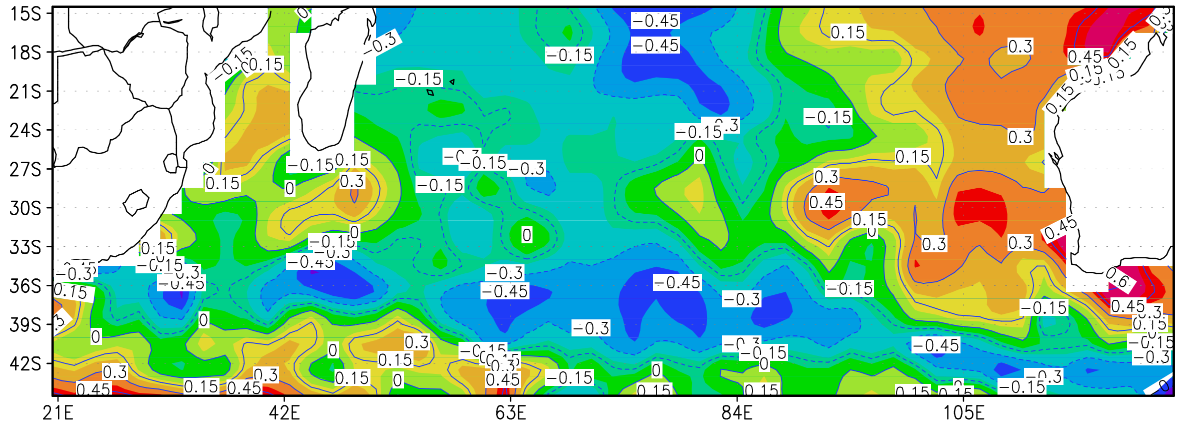


Fig. 7 Contours of correlation coefficients between the adjusted catch rates of SBT in the CIO and the SSTs of each 1° by 1° grid.

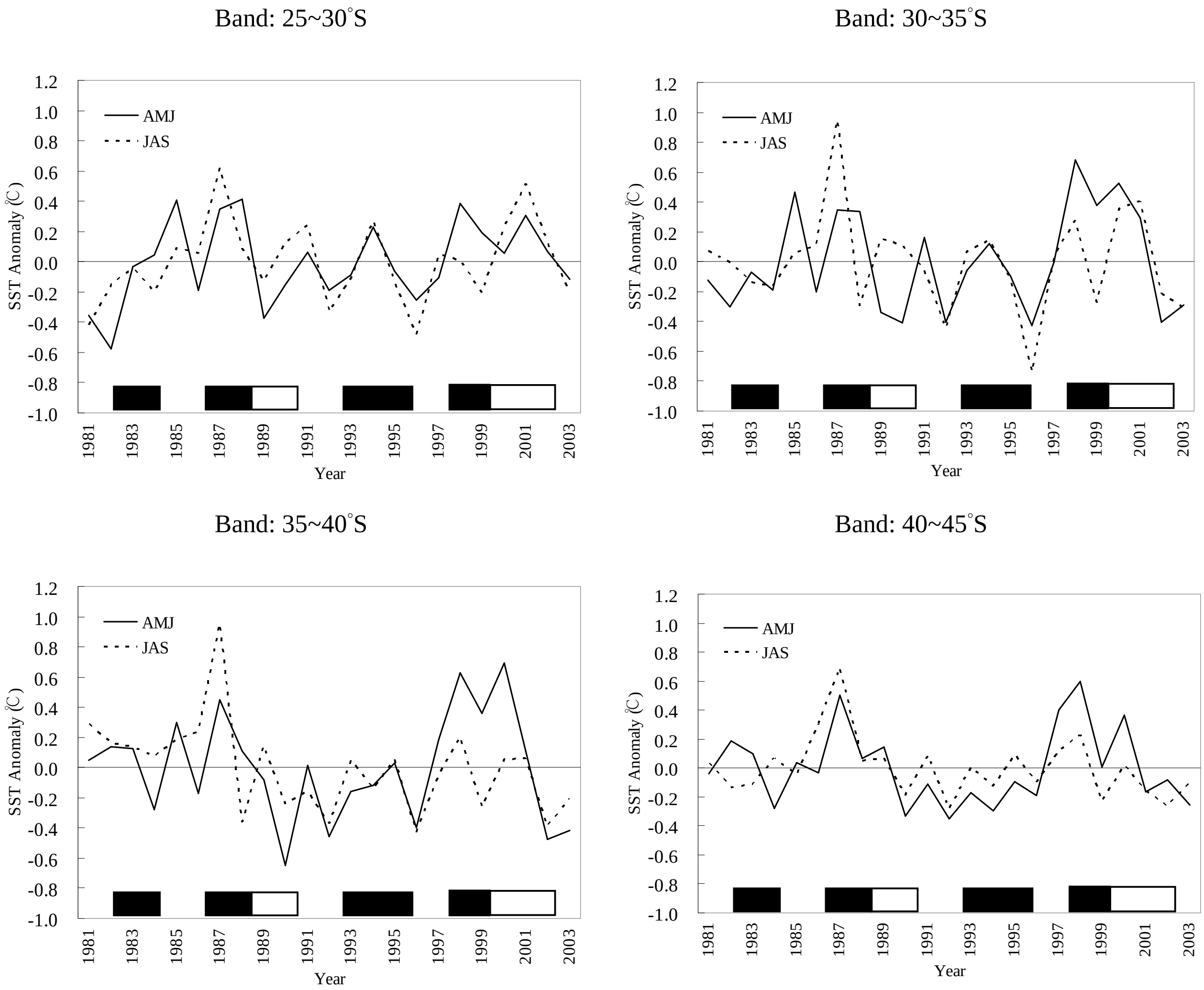


Fig. 8 Variations of average SST anomalies at the four latitudinal bands in the CIO during 1981~2003. (■ : El Niño □ : La Niña)

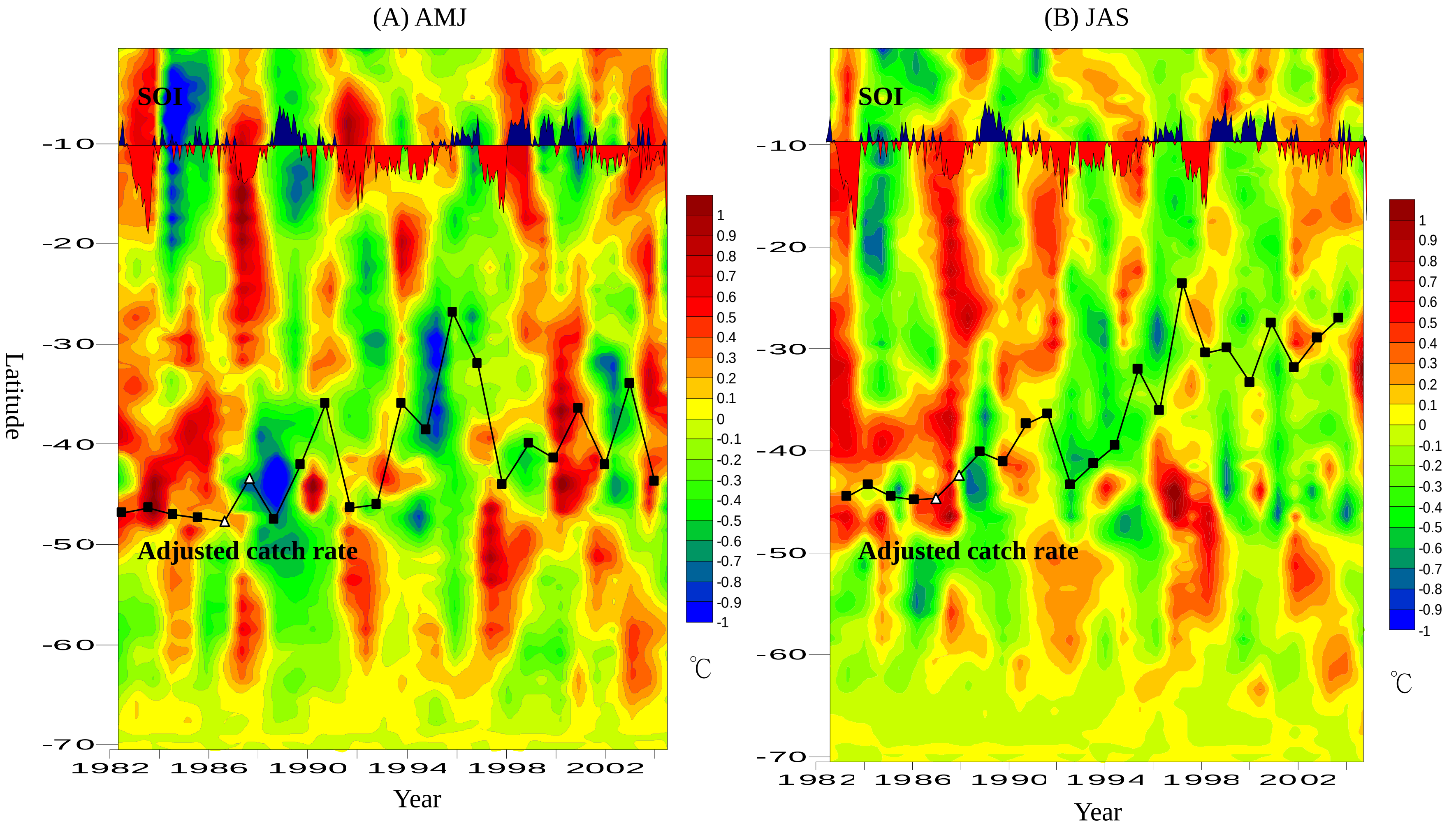


Fig. 9 The SST anomaly contours along 60° E meridional cross-section during 1982~2003. The superimposed time serials are the adjusted catch rates of SBT and the SOI during the same period, respectively.

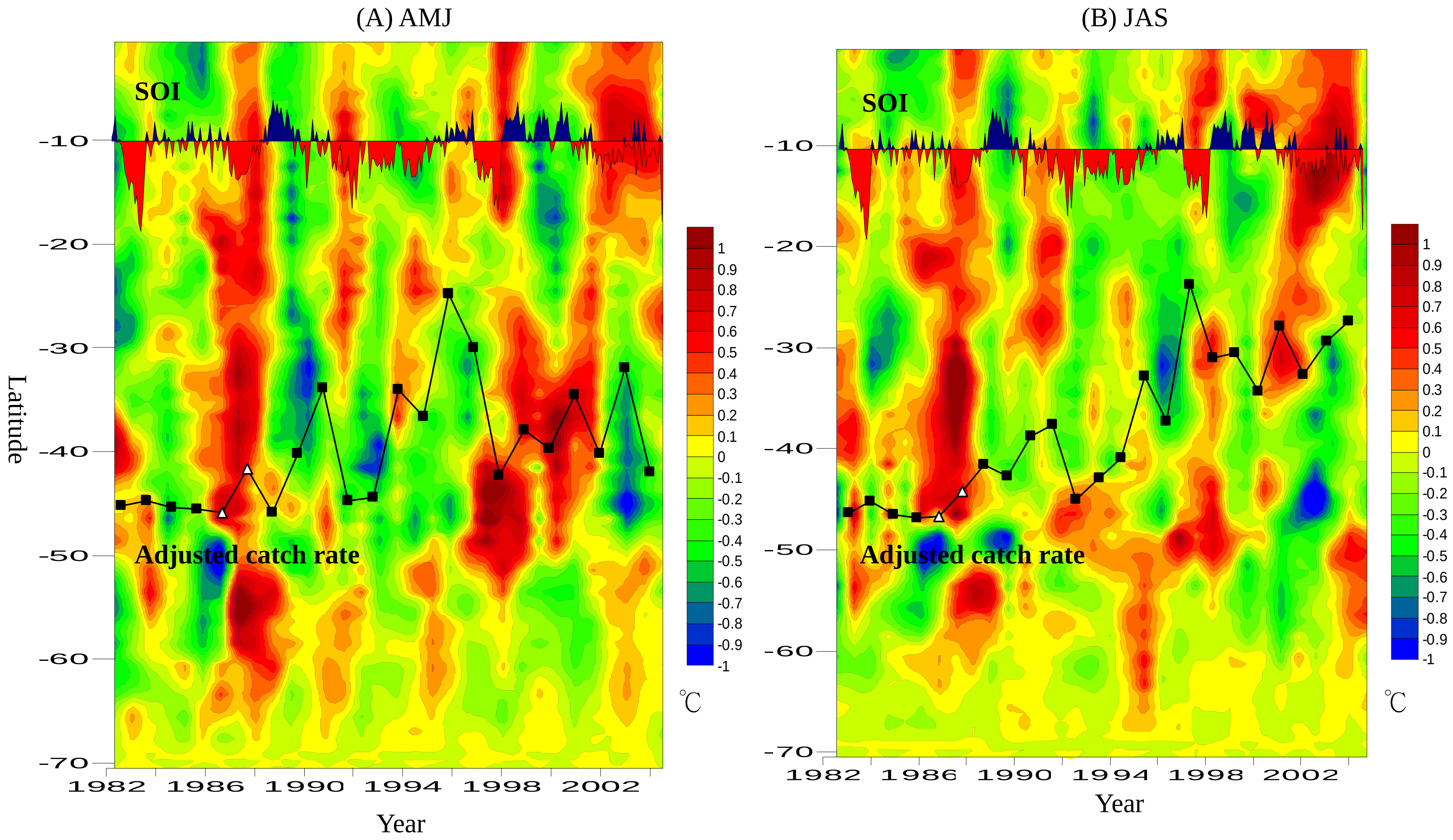


Fig. 10 The SST anomaly contours along 80° E meridional cross-section during 1982~2003. The superimposed time serials are the adjusted catch rates of SBT and SOI during the same period, respectively.