GENERAL LINEAR MIXED MODEL ANALYSIS FOR STANDARDIZATION OF TAIWANESE LONGLINE CPUE FOR BIGEYE TUNA IN THE ATLANTIC OCEAN

Chien-Chung Hsu[1] and Hui-Hua Lee[1]

SUMMARY

Standardized catch per unit effort of bigeye tuna in the main tropical fishing area of Atlantic Ocean was developed for the Taiwanese longline fishery by using general linear mixed models with year, quarter (month), stratum and target effect as fixed factors, and the interactions as random effects. Due to the change of Taiwanese longline fleets to the targeting bigeye tuna in the Atlantic in 1994, two time frames were separated, i.e. from 1981 to 1993 for by-catch period and from 1994 to 2000 for the targeting period. Data used were daily logbooks of the Taiwanese longline fishery from 1981 when the logbooks were available. The results showed a stable standardized catch per unit effort series with a slightly increasing trend during 1981-1993, then a significantly and continuously decreasing trend was found from 1994 to 2000.

RÉSUMÉ

La capture par unité d'effort standardisée du thon obèse dans la principale zone de pêche tropicale de l'océan Atlantique a été mise au point pour la pêcherie palangrière taiwanaise en utilisant des modèles mixtes linéaires généralisés avec, comme facteurs fixes, année, trimestre (mois), strate et effet du ciblage, et les interactions comme effets aléatoires. En raison des changements introduits en 1994 par les flottilles palangrières taiwanaises dans l'Atlantique en ce qui concerne le ciblage du thon obèse, deux cadres temporels ont été distingués, c'est-à-dire de 1981 à 1993 pour la période de prises accessoires et de 1994 à 2000 pour la période de ciblage. Les données utilisées étaient les carnets de bord journaliers de la pêcheurs palangriers taiwanais à partir de 1981, lorsque ces derniers étaient disponibles. Les résultats ont montré une série de captures par unité d'effort standardisées stables, avec une tendance légèrement à la hausse entre 1981-1993, et ensuite une tendance décroissante considérable et continue de 1994 à 2000.

RESUMEN

Se ha desarrollado la captura por unidad de esfuerzo estandarizada de patudo en las principales zonas de pesca tropicales del océano Atlántico para la pesquería taiwanesa de palangre utilizando el modelos lineales mixtos generalizados con factores fijos como año, trimestre (mes), estrato y efecto de direccionamiento, y las interacciones como efectos aleatorios. Dado el cambio que se produjo en las flotas de palangre taiwanesas en 1994 en lo que se refiere al direccionamiento al patudo en el Atlántico, se separaron dos marcos temporales, es decir, de 1981 a 1993 para el período de captura fortuita; y de 1994 a 2000 para el período de especie objetivo. Los datos utilizados fueron los cuadernos de pesca diarios de la pesquería taiwanesa de palangre desde 1981, fecha a partir de la cual se dispuso de los mismos. Los resultados mostraban una serie de capturas por unidad de esfuerzo estandarizadas estables con una ligera tendencia creciente durante 1981-1993; después se detectó una tendencia decreciente continua e importante desde 1994 a 2000.

KEYWORDS

Bigeye tuna (Thunnus obesus*), Abundance index, GLMM, Longline, General linear mixed model (GLMM), Mean weight*

[1] Institute of Oceanography, National Taiwan University, P. O. Box 23-13, Taipei, Taiwan 106; E-mail: hsucc@ccms.ntu.edu.tw

1 INTRODUCTION

Bigeye tuna, *Thunnus obesus*, is mainly exploited in the tropical region in the Atlantic Ocean. Due to its high economic value, the species has become one of the most concerned species by management organizations for the three Oceans, particularly, for ICCAT in the Atlantic Ocean. For stock assessment and management purpose, only one stock is assumed in the Atlantic. And the stock was exploited by longline gear for adults and surface gears mainly for juveniles and sub-adults.

The history of Taiwanese longline fleets exploited bigeye tuna in the Atlantic Ocean can be divided into two time frames, i.e. bigeye tuna were caught incidentally as by catch before 1991, and targeted afterward. As a result, two fishing types are used to target different tuna species for Taiwanese longline fleets in the Atlantic (Hsu and Liu, 1999; Hsu and Liu, 2001; Yeh et al., 2001), in addition to that catch and effort data compilation has been transferred since 1995 (Hsu and Liu, 1996), and the coverage rate of logbooks was low during 1990-1992. Those may result in more or less data discrepancies (Hsu and Liu, 2001). The former may affect the estimation of abundance index through standardization of catch per unit effort due to not easily separate fishing efforts directed to the target species; and the latter may cause changes of original data compilation, including raising factors, sample sizes, and estimation procedures. Thus, Data being used to abundance index estimation have been verified by Hsu and Liu (2001), and suggested that the 1990-1993 catch and effort data sets of Taiwanese longline fishery for bigeye tuna had better used as by catch series, since those coverage rate was low and the logbooks used to compile the catch and effort were favor to albacore rather than bigeye tuna (evidenced hereinafter).

Therefore, the objectives of this report are to follow the suggestion of ICCAT 2002 work plan to estimate the standardized catch per unit effort by small stratum as suggested.

2 MATERIALS AND METHODS

2.1 Data used and data structure

The catch and effort data for bigeye tuna were compiled from logbooks of Taiwanese longline fishery in the tropical Atlantic Ocean. Those logbooks are submitted by fishermen and are cross-checked and compiled by Oversea Fisheries Development Council, Taipei. Generally, the coverage of logbooks is over 70% (?) from 1993 onward and mandatory the first 30 fish (not all bigeye tuna) was measured on board.

2.2 Data compilation and selection

Area defined (**Figure 1**) used in this study is assigned as in the "Bigeye tuna work plan: year 2002," the Atlantic Ocean was stratified into 12 strata. Catch/effort and size data used were compiled and provided by Oversea Fisheries Development Council (OFDC).

In order to investigate where the bigeye tuna were caught for Taiwanese longline fleets, a pie graph was plotted to show the percentages of albacore, *Thunnus alalunga*, yellowfin tuna, *T. albacares*, and bigeye tuna by each year and by strata, the result (**Figure 2**) indicates that strata 2, 4, 5, 6, 7 and 8 have high percentage of bigeye tuna among the strata; Subsequently, those strata were preliminarily selected to study the abundance index. Further, we investigated the number of observation by each daily sets observed in stratum 2, the result (**Table 1**) shows that observations of daily set with bigeye tuna caught are very low in almost years, except 1987 (low observed sets) and 1999, thus, we decided to abandon stratum 2 in the present study.

Moreover, data available for the bigeye tuna within each stratum, daily deployed sets were counted by years, by months and by the selected strata (strata 4, 5, 6, 7, and 8), then the result is tabulated in

Table 2.

2.3 Factors considered

Factors considered for general linear model were fishing year, month, sub-area and two-way interactions among year, month and area. Since the number of hooks between floats and capacity of fishing vessels are not significant difference among fishing vessels, factors of the number of hooks between floats and material of main lines and branch lines were not considered in the present study. Thus, categories in each main effect used in general linear models are summarized as:

Main effects	Data available
Year	1981-2001 (2001 was used as preliminary), and two time frames were used in according to the target status, i.e. 1981-1990; 1991-2001.
Month	January to December
Sub-area	5 (sub-areas 4, 5, 6, 7, and 8) as defined in **Figure 1**.
Targets	Six levels were assigned: Four quantile levels of catch composition of albacore in total catch of albacore, bigeye tuna and yellowfin tuna, zero catch for three species (na) and catch only for yellowfin tuna (yf).

Although some of hooks between floats were available in the logbooks from 1995 and to partition fishing efforts for different fishing types were possible statistically for missing information of hooks between floats (Yeh et al., 2001), a very high proportions of daily longline sets did not have hooks between floats information, thus the alternative target effect was adopted in the present study to represent fishing types.

2.4 General linear models

A log-normal error assumption was used in the general linear model. Thus, model used to develop the standardized index is:

$$\ell n(CPUE + const) = m + Year + Month + Area + Species + Month * Area + Year * Month + Year * area + Year * species + Month * species + Area * species + Year * Month * Area + Year * month * species + Month * area * species + e$$

where CPUE is nominal catch per unit effort computed by catch divided by 1000 hooks, and $const$ is the constant using 10% of overall nominal catch per unit effort.

The fitting was conducted by GLM procedure of SAS/STAT statistical package (version 8.02). The interactions of $Year * Month$, $Year * Area$, $Year * species$, $Month * Area$, $Month * Species$, $Area * species$ and $Year * Month * Area$, $Year * Area * species$, $Month * Area * Species$ were specified as random variable in mixed procedure as done in the assessment (ICCAT 1999; Miyabe 2001) and e .the error term for each year, month, area and species is assumed as log-normal distribution.

3 RESULTS

3.1 Mean weight

The mean weight was examined by catch in weight divided by catch in number for each monthly 5x5 degree square aggregated catch submitted from all fleets operating in that square, and then those mean weights were illustrated by each stratum (**Figure 1**) in each year, as in **Figure 3**. And annual mean weight was illustrated in **Figure 4**, indicating that a less fluctuation was occurred from 1981 to 1990 for all strata investigated, and a more fluctuated mean weight was found then after. However, the mean weight in strata 5, 6, 7 and 8 ranged from 30 kg to 45 kg (**Figure 4**).

3.2 Annual nominal catch per unit effort distribution in strata

Nominal CPUE (number per 1,000 hooks) by strata 4, 5, 6, 7 and 8 were plotted in **Figure 5**. Each open circle in the **Figure 5** represents a daily and 5x5 block data. Most nominal CPUE points could be found in strata 5, 6, 7 and 8 (tropical regions of Atlantic Ocean) from 1990 to 2000. And **Figure 6** showed the mean nominal catch per unit effort for those 4 strata. The nominal catch per unit effort distribution in stratum 4 was also shown in **Figure 5**; it was although a lack of daily 5x5 square data relatively compared to strata 5, 6, 7 and 8, the average nominal catch per unit effort seems very similar among strata studied (**Figure 6**). The nominal catch per unit effort shows decreasing trend in all strata, except stratum 7, from 1994 onward when the trend can indicate a target one for Taiwanese longline fishery started to target bigeye tuna in the Atlantic.

3.3 Catch per unit effort standardization

The availability of logbook data used to pursue standardization of catch per unit effort was tabulated in **Table 2**. It indicated that several months were found without or a few logbooks in years 1981-1983 and 1987-1989, and most months with few logbooks return in years 1990-1993, and all months with many logbooks from 1994 to 2000. Data for 2001 were still very preliminary. To consider this regard, we treated data files into two time frames, 1981-1993 and 1994-2000 for our standardization purpose. Thus, the available data summary was indicated in **Table 3**. And the statistics to test the hypothesis of models was shown in **Table 4**. The test results of fixed effects are not significant ($P > 0.1$).

Thus, an alternative GLM model was used with year, month, sub-area and target species as main fixed factors and only interactions between year and other 3 fixed factors. The time series catch and effort data were used in fitting this model from 1981-2000 without temporal stratification. The test statistics of type III for fixed effects was shown in **Table 5**, indicating that year is not significant factor ($P > 0.2$). In this regard, the GLM model was built with year, month and sub-area as fixed factors and year*month and year*sub-area as random effects, the 1981-2000 catch and effort series in strata 5, 6, 7 and 8 were used, the test statistics for fixed effect (**Table 6**) are all in significance ($P < 0.001$).

Accordingly, the annual abundance index and area abundance index were estimated.

3.4 Abundance index in each stratum

The standardized catch per unit effort for strata 5, 6, 7 and 8 are illustrated in **Figure 7**. In those figures, missing data are omitted. In stratum 5, the standardized catch per unit effort was low from 1981 to 1986 to show a by catch trend, and a slight decrease from 1989 to 1993 when Taiwanese longline fleets started to target bigyeye tuna during this period, and then, the standardized series decreased more significantly from 1994 to 2000. In stratum 6, the standardized trend was not clear from 1981 to 1984, however, a decreasing trend, but more slightly relative to that in stratum 5, was occurred from 1994 to 1995. In stratum 7, a low and fluctuated catch per unit effort wan shown from

1981 to 1994, but a decreasing trend was shown before from 1994 to 1998, then increasing from 1999 to 2000. In stratum 8, the standardized catch per unit effort showed increasing from 1981 to 1985, then decreased; a dome-shaped trend from 1990 to 1993, then decreased from 1994 to 1996, and kept flat then after to 2000.

3.5 Annual abundance index

Figure 8 depicted the nominal and standardized catch per unit effort for Taiwanese longline fishery. The standardized trend included catch and effort data from 1981 to 2000. The series shows decreasing trend from 1981 to 1988, and increased to 1995, then decreased apparently from 1996 to 2000.

4 DISCUSSION

To standardize Taiwanese longline catch and effort data as abundance index needs to understand the evolution and fishing types first for all species, particularly for bigeye tuna, yellowfin tuna, albacore and swordfish (Lin, 1999; Yeh et al. 2001). A longline is a species-directed gear and fishers used it to target different species by different depths of water column and by different bait. Bigeye tuna is one of the tuna species caught by longline at relatively deep waters.

As known from many ICCAT works, Taiwanese longline fleets usually used two kinds of longlining to fish different species (Hsu and Lin, 1996). The conventional fishing type has been using to target albacore from the early 1960s, and the deep longline fishing type has been using to mainly target tropical tuna species since around 1990. Therefore, to standardized catch per unit effort of bigeye tuna should include factors representing the depth of hooks deployment. Due to lack of hooks between floats, though the fishery authority collected this information in the logbooks, we haven't used this category in the present study to avoid too may missing data, however, a target species effect was used to perform this factor in this analysis.

Consequently, **Figure 2** depicts catch composition of the three major species of Taiwanese longline fishery in the Atlantic Ocean: albacore, bigeye and yellowfin tunas. Catch composition of bigeye tuna among the three species has shown that there is a very strong trend of bigeye tuna catch in strata 5, 6, 7 and 9. In this manner, we pay much attention on standardizing catch per unit effort for these strata and excluded stratum 4 as suggested on the 2002 bigeye tuna work plan. These also implied the necessities to take into account the target species effect in the CPUE standardization (Chang and Hsu, 2002). We have taken into account the target species effect during the original run and the alternative run 1, however, those runs result in insignificance of the model test for one of the fixed factors, year. Then, for the alternative run 2, we omitted the target species effect and only Year*month and Year*stratum random effect were used, the test for fixed effects is significant ($P < 0.001$). This may imply that the original daily set data from logbooks may have reflected the target species enough. Hence, if the area stratification was used, the re-categorize fishing effort from either the conventional or deep longline fishing type seems not necessary at this moment.

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Table 1. The number of observed daily set with bigeye tuna caught at stratum 2 (see Figure 1) for Taiwanese longline fleets to show the data availability

Year	Total daily sets observed (A)	Daily set observed with bigeye tuna caught (B)	Percent (A/B)x100
1981	2	2	100
1982	1	1	100
1983	74	30	40.5
1984	357	121	33.9
1985	491	181	36.9
1986	260	71	27.3
1987	85	61	**71.8**
1988	0	0	0
1989	0	0	0
1990	0	0	0
1991	0	0	0
1992	0	0	0
1993	0	0	0
1994	479	1	0.2
1995	525	28	5.3
1996	615	90	14.6
1997	669	165	24.7
1998	713	214	30.0
1999	378	252	**66.7**
2000	456	134	29.4
2001			

Table 2. The number of observed daily set deployed at the selected strata 4, 5, 6, 7 and 8 (see Figure 1) for Taiwanese longline fleets to show the data availability.

Year	Month							
	1	2	3	4	5	6	7	8
1981	678	310	61	50	3	0	7	8
1982	740	67	43	26	31	48	55	23
1983	320	66	29	20	17	1	9	1
1984	276	118	5	13	27	28	56	77
1985	225	73	16	17	13	115	82	46
1986	339	51	45	35	7	45	107	30
1987	211	10	0	5	22	36	46	32
1988	238	8	0	0	0	4	31	23
1989	119	0	0	0	0	0	0	3
1990	209	73	119	128	114	78	82	106
1991	198	175	62	45	45	58	62	43
1992	171	143	143	71	35	44	39	30
1993	57	64	81	40	6	97	85	136
1994	351	204	221	72	125	178	177	111
1995	339	318	319	189	193	288	402	459
1996	1,352	908	724	556	626	699	868	828
1997	1,347	1,127	966	712	440	541	659	691
1998	1,039	744	583	451	407	457	555	490
1999	959	693	696	539	623	577	561	526
2000	689	489	259	249	201	190	207	231
2001	106	57	33	31	30	28	30	29
Sum	9,863	5,698	4,405	3,249	2,965	3,512	4,120	4,103

Table 2. (Continued)

				Strata				
9	10	11	12	4	5	6	7	8
42	435	1,073	1,151	12	11	121	2,803	871
55	420	770	661	15	61	151	2,054	658
14	23	281	316	78	39	14	738	228
16	119	483	426	14	81	15	1,097	437
35	318	575	451	2	307	0	1,350	307
5	154	369	262	105	187	0	1,038	119
7	95	259	232	3	145	0	649	158
2	5	150	166	0	60	0	456	11
41	0	135	230	0	72	4	436	16
67	96	142	246	0	779	67	486	128
61	74	169	200	125	431	119	352	165
34	48	53	29	0	463	63	268	46
123	97	240	338	7	439	251	275	392
165	210	266	301	20	936	444	557	424
577	851	1,005	1,334	82	957	1,143	1,669	2,423
1,044	1,019	1,197	1,307	225	2,042	3,232	2,526	3,103
610	676	732	768	130	1,664	1,938	1,796	3,741
545	658	700	935	9	764	1,631	1,271	3,889
417	462	459	719	43	4,52	1,983	646	4,107
56	29	75	65	8	304	329	477	1,622
7	0	0	0	0	0	7	67	277
3,882	5,830	9,133	1.0137	878	10,194	11,512	21,011	23,122

Table 3. Summary of data availability and used for catch per unit effort standardization in the present study. Results in the text run for stratum 4 were limited to its monthly 5x5 data available.

(a) Data set I

Class	Levels	Values
Years	13	1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993
Quarters	4	1, 2, 3, 4
Strata	4	5, 6, 7, 8
Targets	6	1, 2, 3, 4, no catch and yellowfin tuna catch only

(b) Data set II

Class	Levels	Values
Years	7	1994, 1995, 1996, 1997, 1998, 1999, 2000
Month	4	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11, 12
Strata	4	1, 2, 3, 4
Targets	6	1, 2, 3, 4, no catch and yellowfin tuna catch only

Table 4. Statistics of the general linear mixed model results on the two data sets run.

Covariance parameter estimates

(a) Data set I – from 1981 to 1993

Covariance parameter	Estimate
Year*Quarter	0.01025
Year*Stratum	0.08723
Year*Target	0.02520
Quarter*Stratum	0.07519
Quarter*Target	0.00000
Stratum*Target	0.03715
Year*Quarter*Stratum	0.05252
Year*Quarter*Target	2.89E-38
Year*Stratum*Target	0.008637
Quarter*Stratum*Target	0.03517
Year*Quarter*Stratum*Target	0.08781
Residual	0.1538

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Year	12	30	7.21	< 0.0001
Quarter	3	9	4.50	0.0344
Strata	3	9	10.88	0.0024
Targets	5	15	78.15	< 0.0001

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Year	12	30	0.73	0.7137
Quarter	3	9	0.13	0.9379
Strata	3	9	1.46	0.2890
Targets	5	15	78.15	< 0.0001

(b) Data set II – from 1994 to 2000

Covariance parameter	Estimate
Year*Quarter	0.002007
Year*Stratum	0.01090
Year*Target	0.004983
Quarter*Stratum	0.007517
Quarter*Target	0.002560
Stratum*Target	0.008203
Year*Quarter*Stratum	0.02099
Year*Quarter*Target	0.000493
Year*Stratum*Target	0.004460
Quarter*Stratum*Target	0.001382
Year*Quarter*Stratum*Target	0.03838
Residual	0.2763

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Year	6	18	7.93	0.0003
Month	11	33	4.24	0.0006
Strata	3	15	22.81	< 0.0001
Targets	5	15	255.03	< 0.0001

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Year	6	18	7.34	0.0004
Month	11	33	1.94	0.0692
Strata	3	15	0.25	0.8610
Targets	5	15	255.03	< 0.0001

Table 5. Statistics of test fixed effects on the alternative general linear mixed model for the alternative run 1.

Class Level Information

Class	Levels	Values
Year	20	1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000
Month	12	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,12
Strata	4	5, 6, 7, 8
Targets	6	1, 2, 3, 4, na, yf

Covariance Parameter Estimates

Covariance parameters	Estimate
Year*month	0.07196
Year*strata	0.14290
Year*targets	0.07745
Residual	0.28080

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Year	19	50	8.54	< 0.0001
Month	11	192	8.83	< 0.0001
Strata	3	50	17.38	< 0.0001
Targets	5	90	165.62	< 0.0001

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Year	19	50	1.27	0.2444
Month	11	192	2.91	0.0014
Strata	3	50	4.47	0.0074
Targets	5	90	165.62	< 0.0001

Table 6. Statistics of test fixed effects on the alternative general linear mixed model for the alternative run 2.

Class Level Information

Class	Levels	Values
Year	20	1981, 1982, 1983, 1984, 1985, 1986, 1987, 1988, 1989, 1990, 1991, 1992, 1993, 1994, 1995, 1996, 1997, 1998, 1999, 2000
Month	12	1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11,12
Strata	4	5, 6, 7, 8

Covariance Parameter Estimates

Covariance parameters	Estimate
Year*month	0.1601
Year*strata	0.3469
Residual	0.6607

Type 1 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Year	19	50	4.98	< 0.0001
Month	11	192	5.65	< 0.0001
Strata	3	50	10.66	< 0.0001

Type 3 Tests of Fixed Effects

Effect	Num DF	Den DF	F Value	Pr > F
Year	19	50	3.40	0.2444
Month	11	192	4.54	0.0014
Strata	3	50	10.66	0.0074

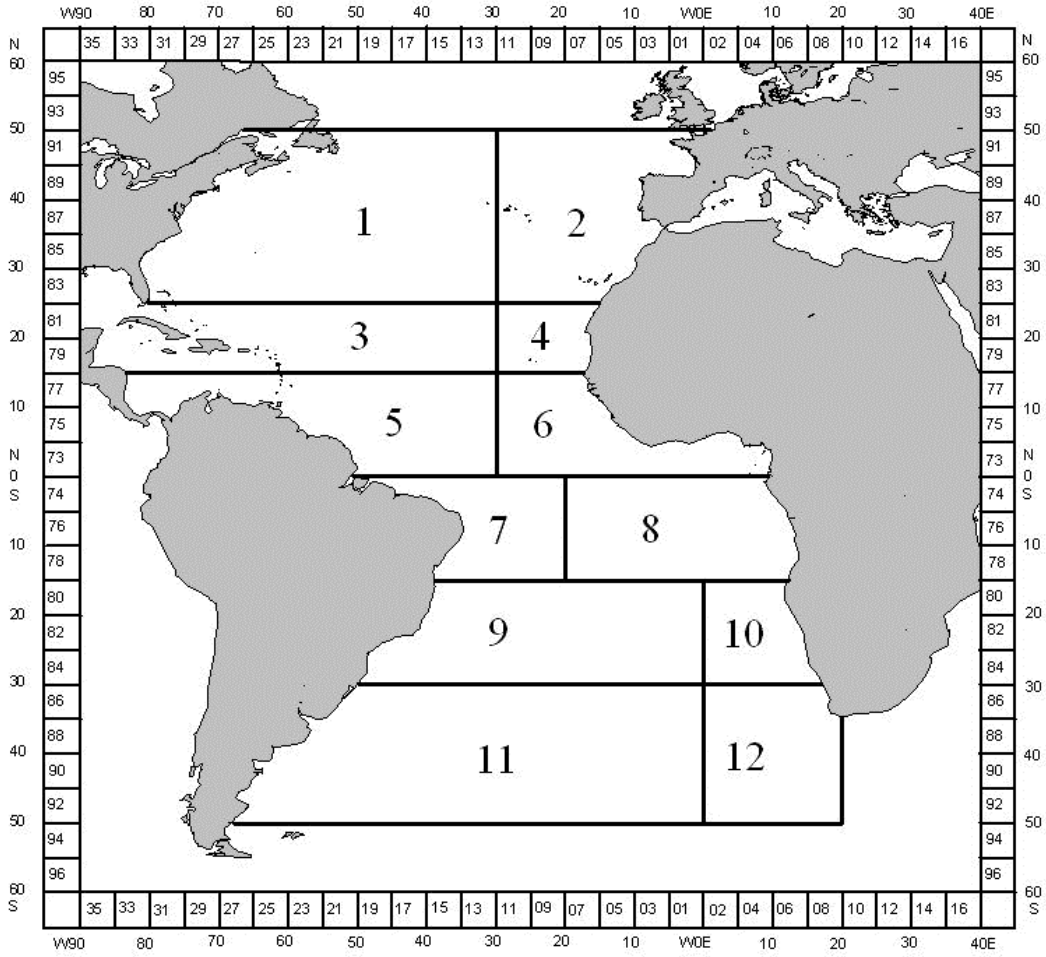
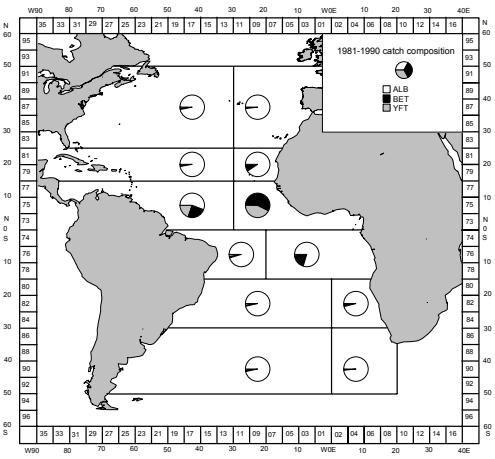
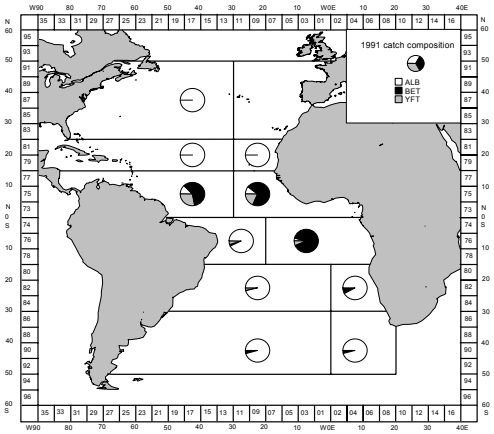
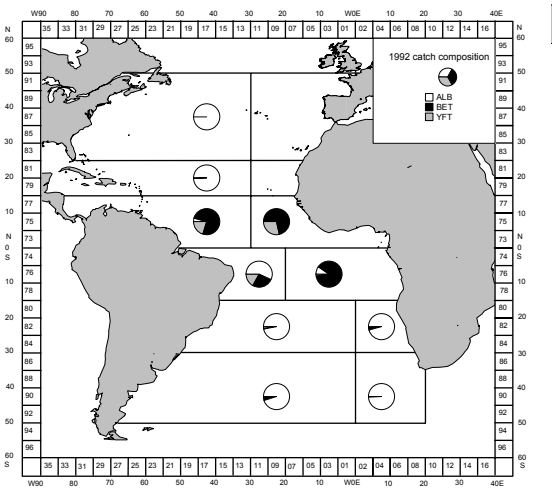
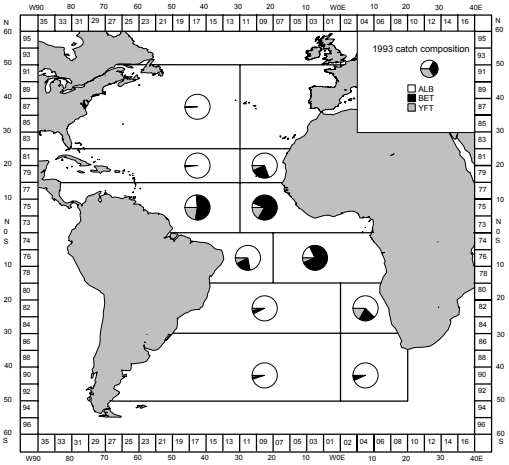


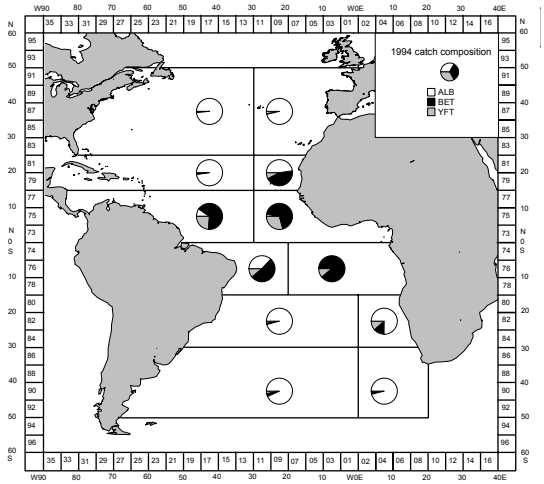
Figure 1. Area stratification of Atlantic for standardizing bigeye tuna catch per unit effort.

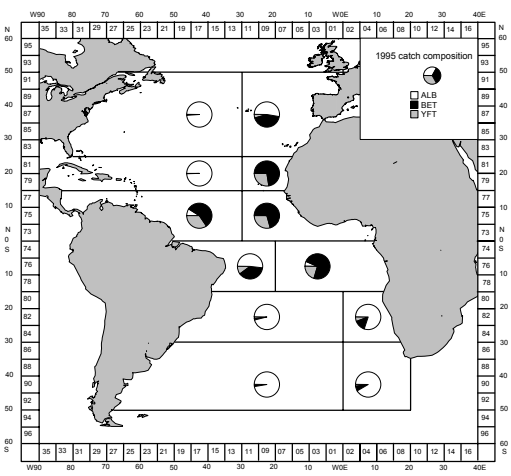

1981-1990 catch composition
ALB
BET
YFT

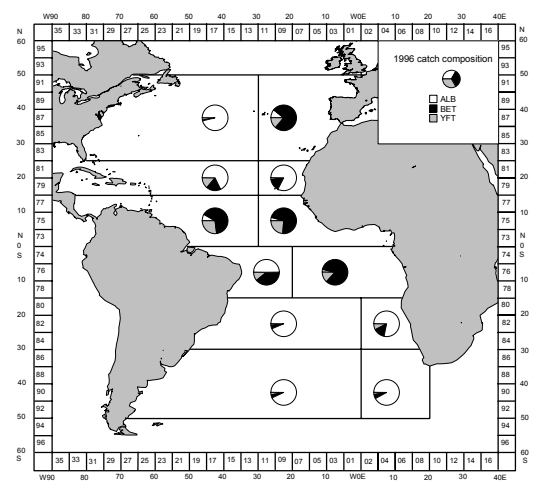

1991 catch composition
ALB
BET
YFT

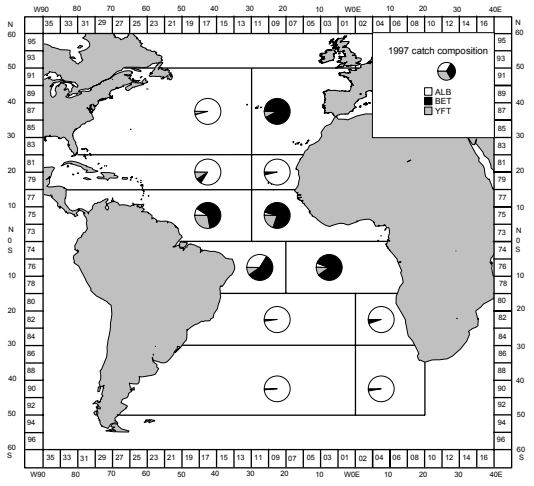

1992 catch composition
ALB
BET
YFT

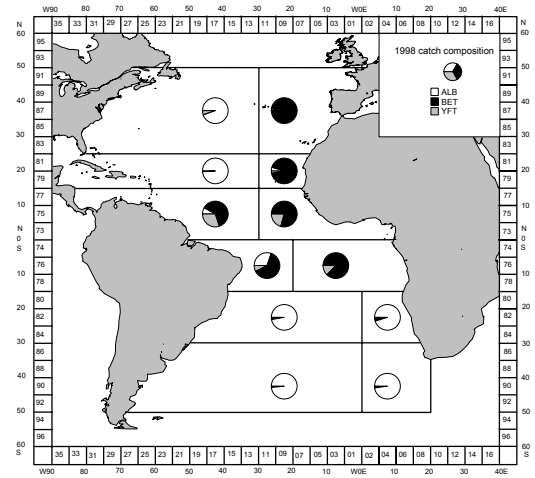

1993 catch composition
ALB
BET
YFT

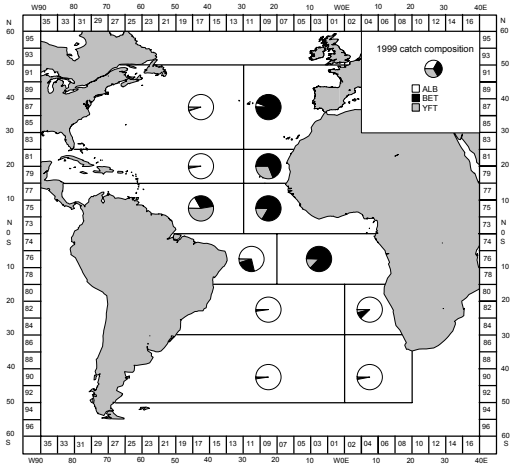

1994 catch composition
ALB
BET
YFT

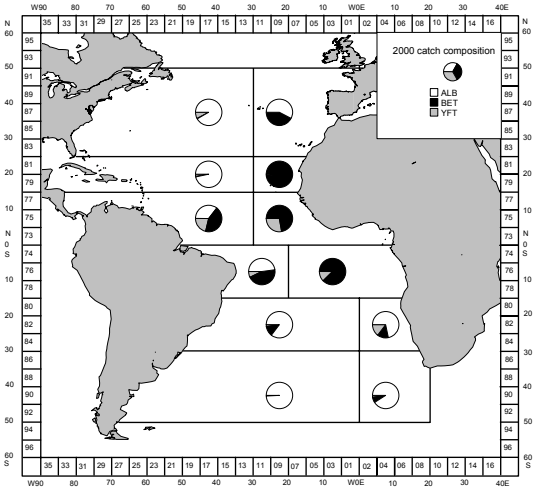

1995 catch composition
ALB
BET
YFT











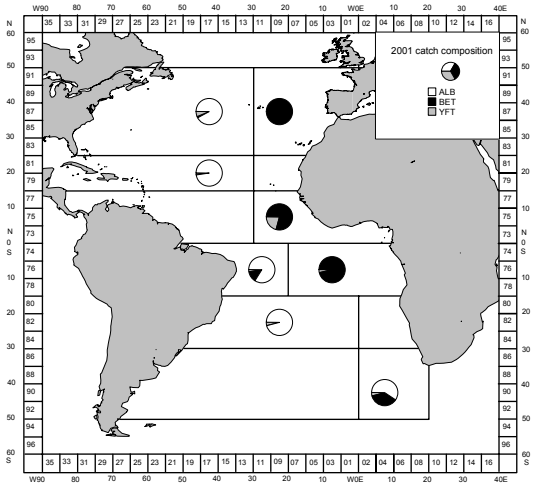
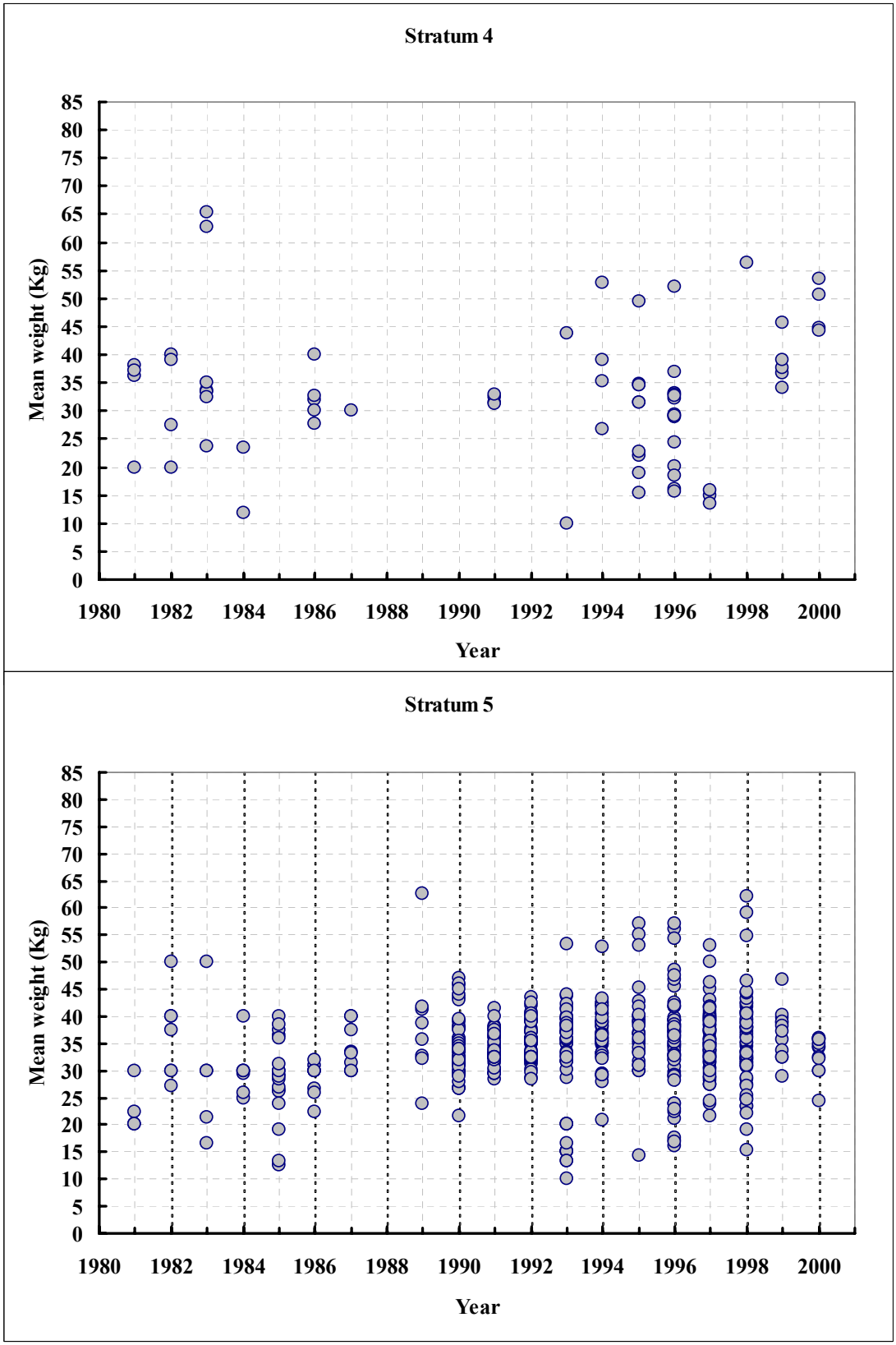
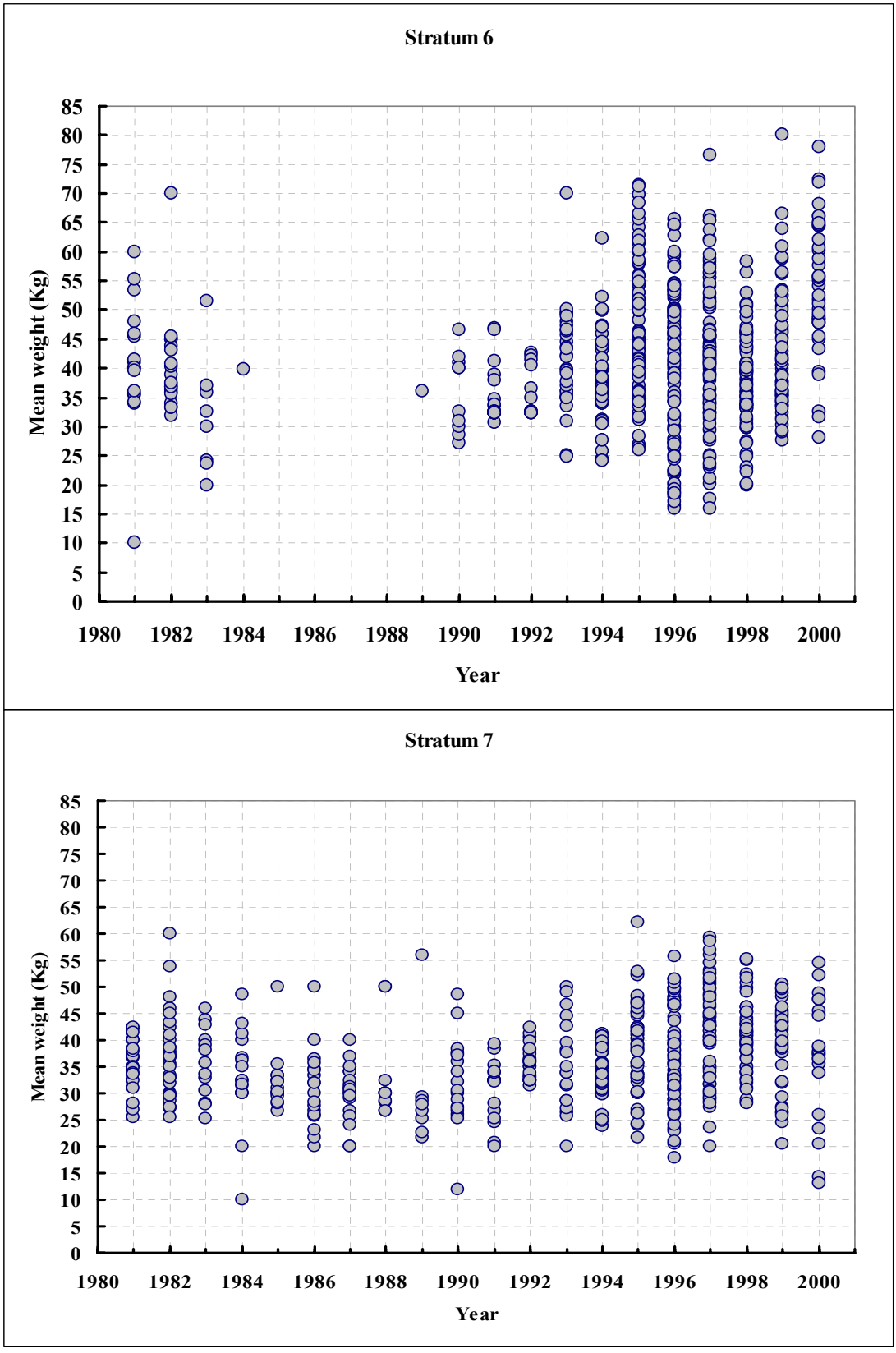


Figure 2. Catch composition for Taiwanese longline fleets in the Atlantic.


Stratum 4
Mean weight (Kg)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
Stratum 5
Mean weight (Kg)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year


Stratum 6
Mean weight (Kg)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year
Stratum 7
Mean weight (Kg)
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year

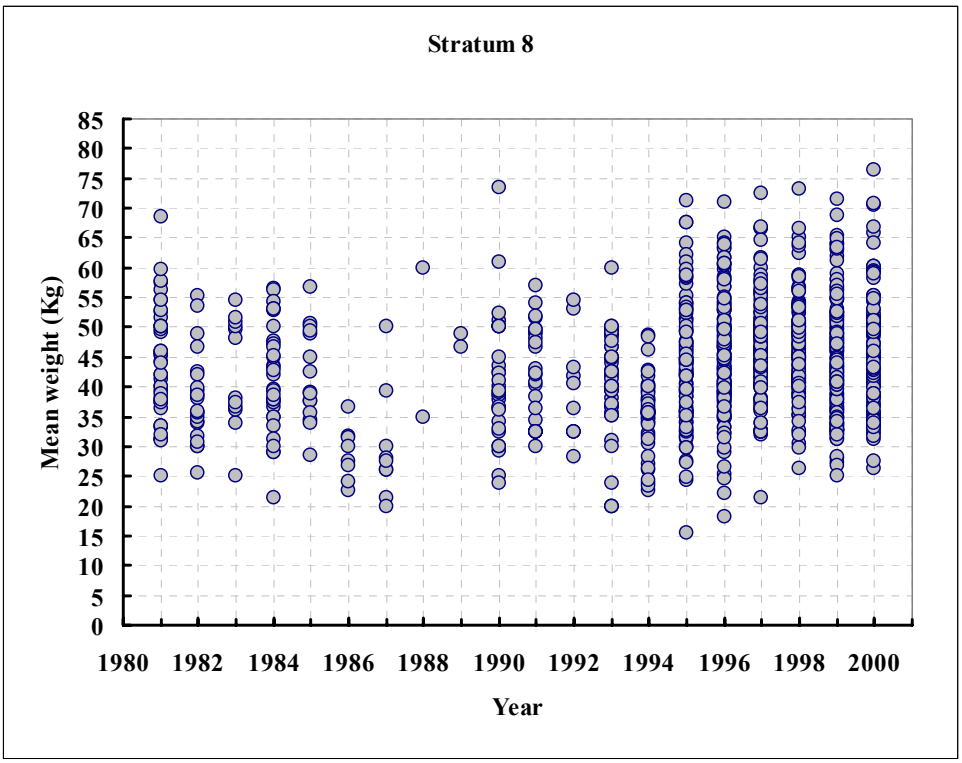


Figure 3. Mean weight of bigeye tuna for each stratum (Figure 1) in each year to indicate the variation of sizes caught by Taiwanese longline fleets in the Atlantic.

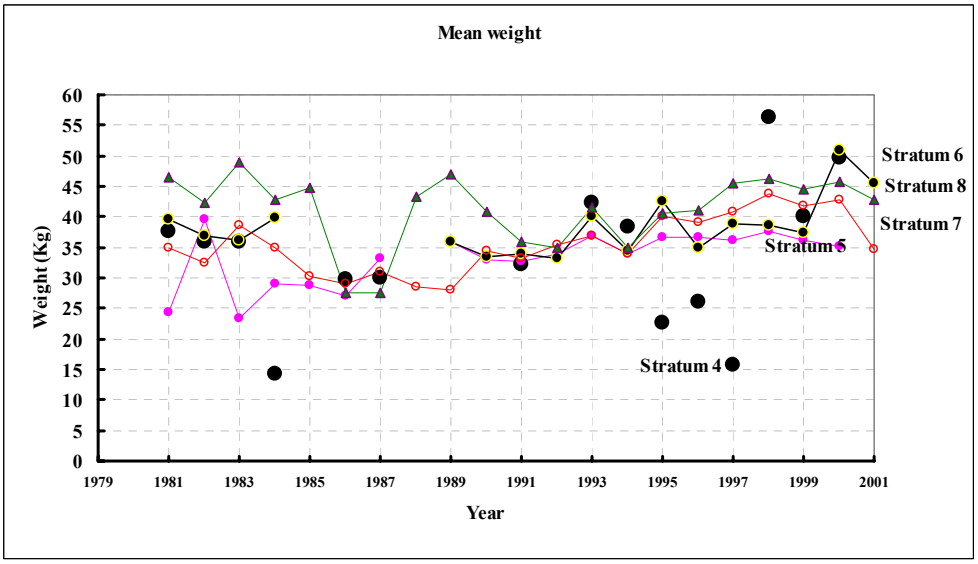
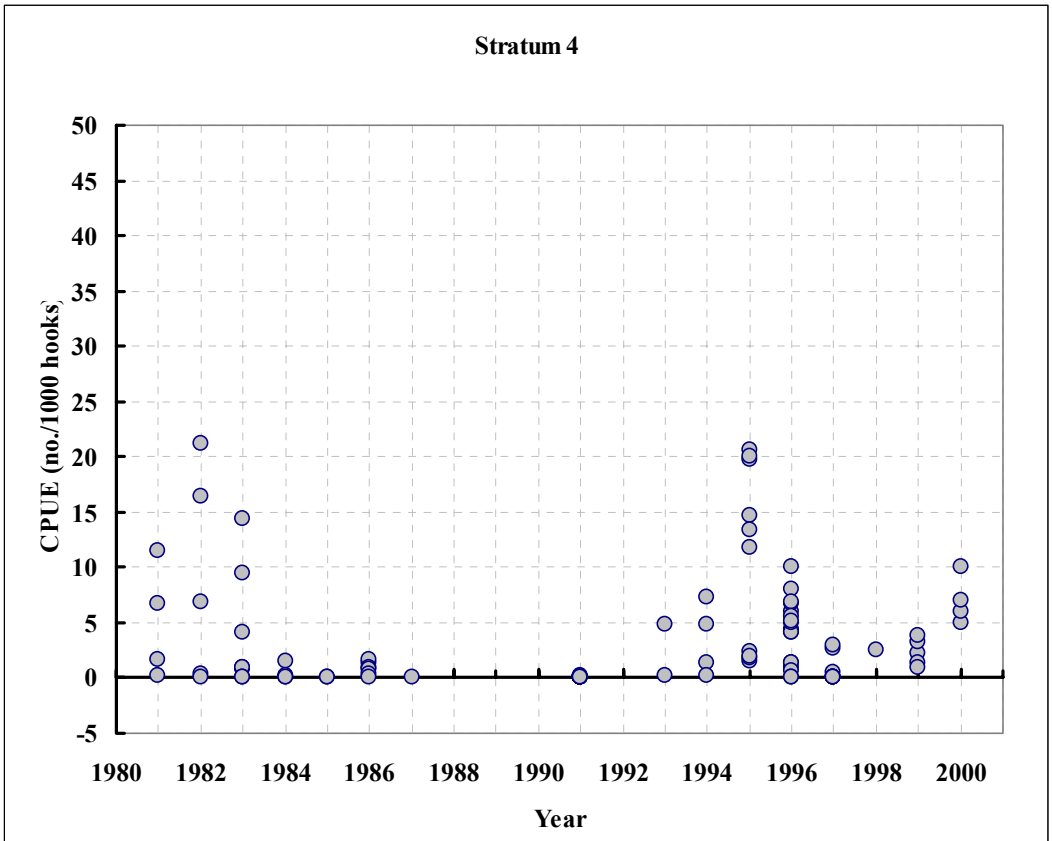
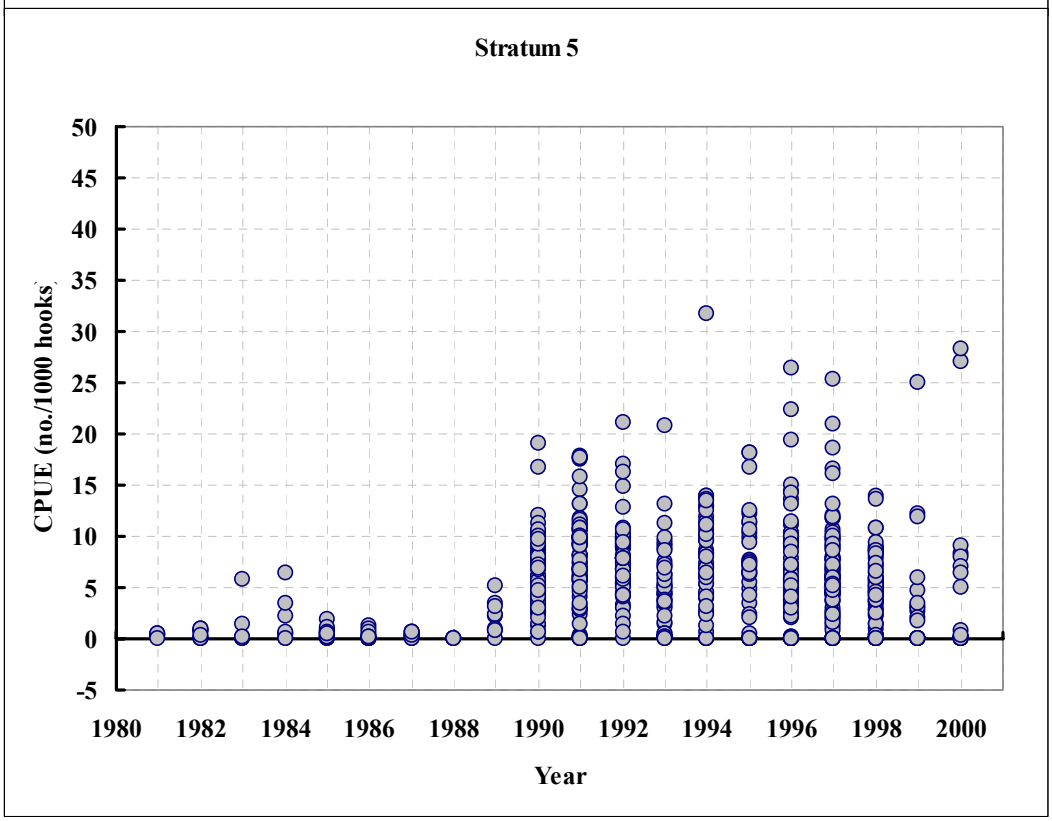


Figure 4. Annual mean weight of bigeye tuna caught by Taiwanese longline fleets by strata in the Atlantic from 1981 to 2001. (Data in 2001 are preliminary)


Stratum 4
CPUE (no./1000 hooks)
50
45
40
35
30
25
20
15
10
5
0
-5
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year


Stratum 5
CPUE (no./1000 hooks)
50
45
40
35
30
25
20
15
10
5
0
-5
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
Year

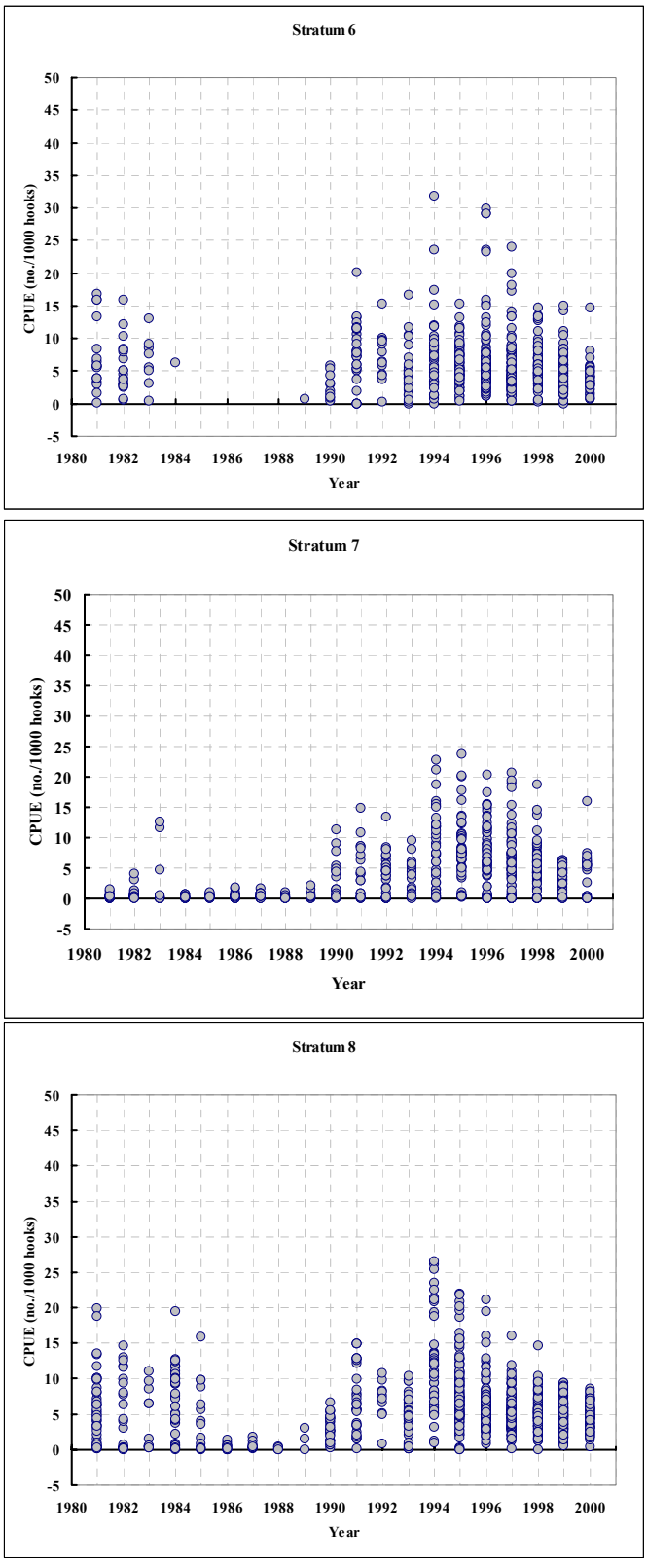
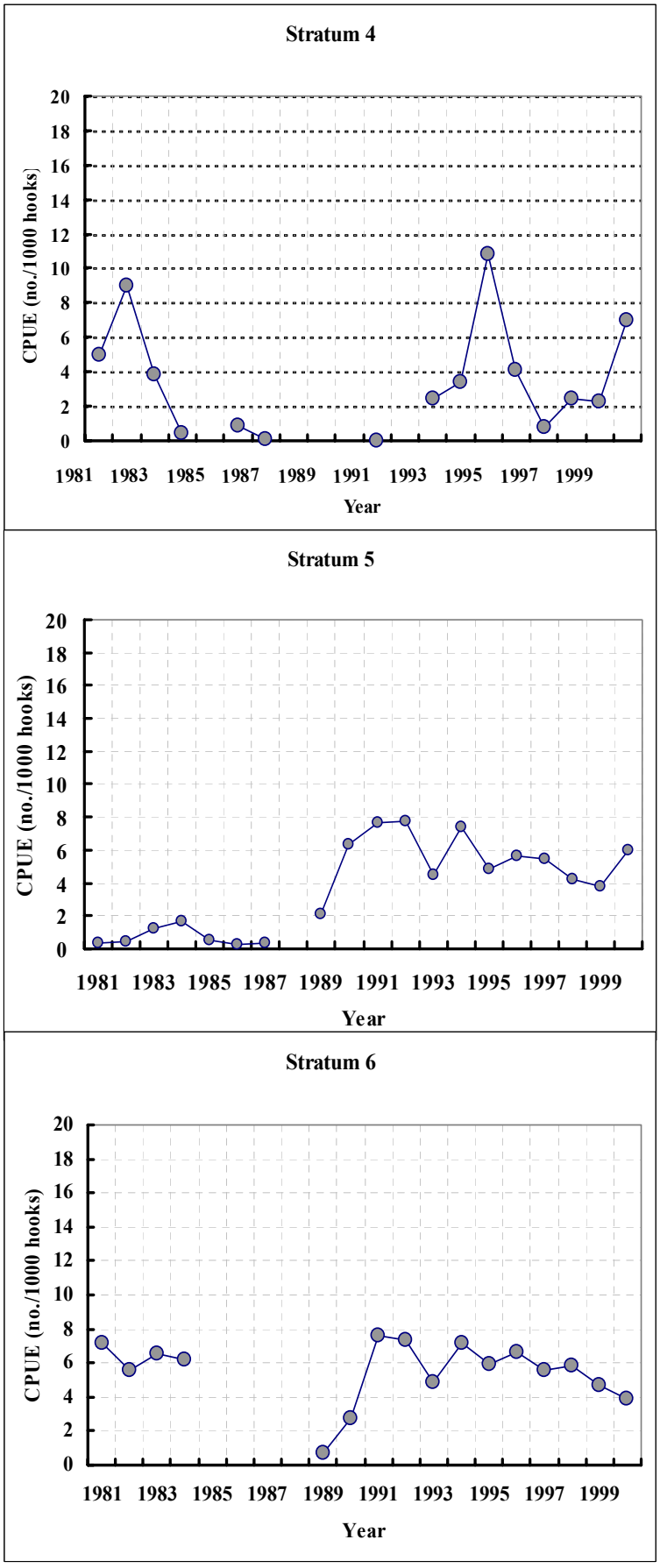


Figure 5. Standardized catch per unit effort of bigeye tuna by each stratum for Taiwanese longline fleets in the Atlantic from 1981 to 2000.


Stratum 4
CPUE (no./1000 hooks)
0
2
4
6
8
10
12
14
16
18
20
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Year
Stratum 5
CPUE (no./1000 hooks)
0
2
4
6
8
10
12
14
16
18
20
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Year
Stratum 6
CPUE (no./1000 hooks)
0
2
4
6
8
10
12
14
16
18
20
1981
1983
1985
1987
1989
1991
1993
1995
1997
1999
Year

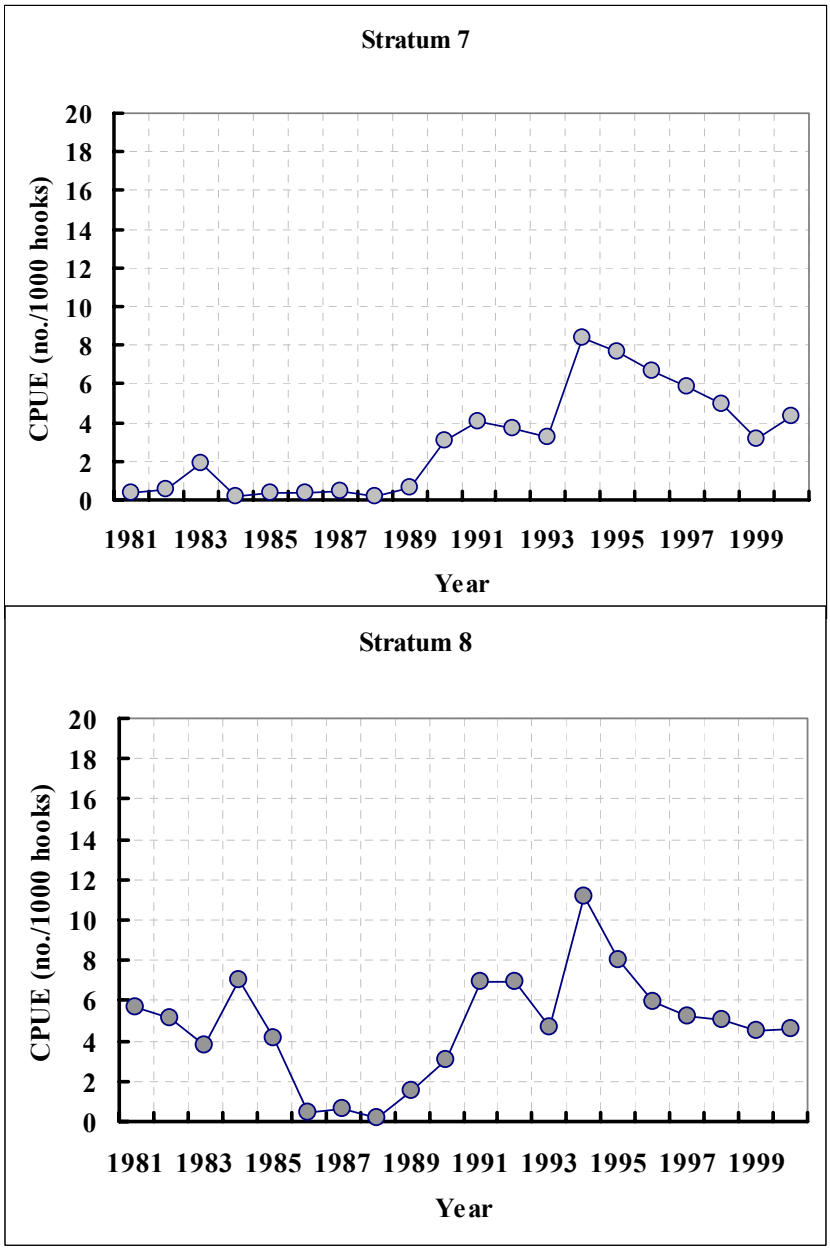
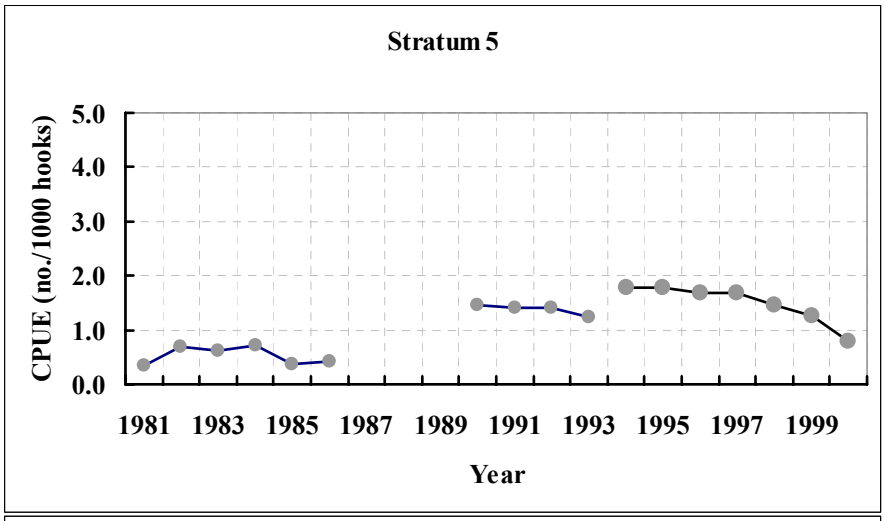
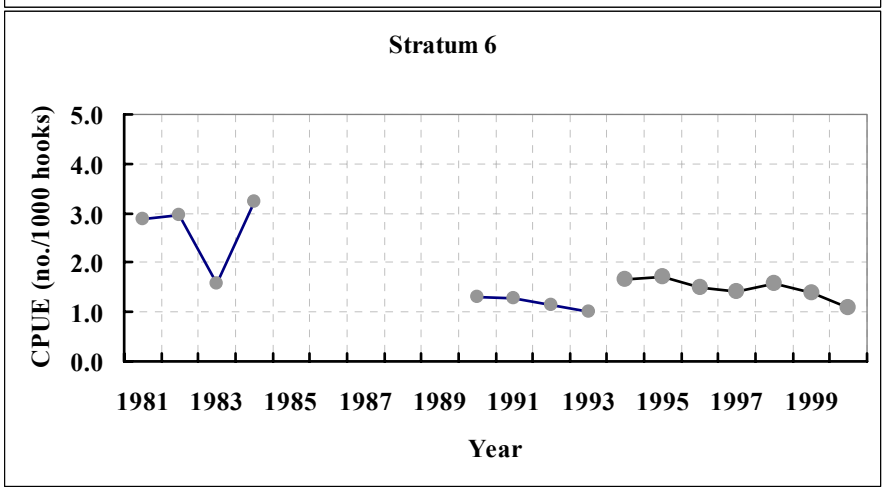
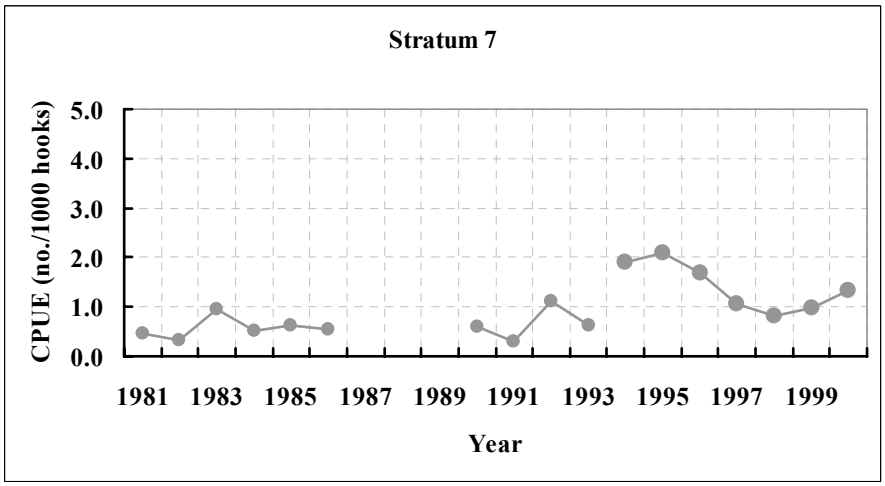


Figure 6. Annual nominal catch per unit effort of bigeye tuna caught by Taiwanese longline fleets in each stratum from 1981 to 2000.


Stratum 5
CPUE (no./1000 hooks)
5.0
4.0
3.0
2.0
1.0
0.0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
Year


Stratum 6
CPUE (no./1000 hooks)
5.0
4.0
3.0
2.0
1.0
0.0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
Year


Stratum 7
CPUE (no./1000 hooks)
5.0
4.0
3.0
2.0
1.0
0.0
1981 1983 1985 1987 1989 1991 1993 1995 1997 1999
Year

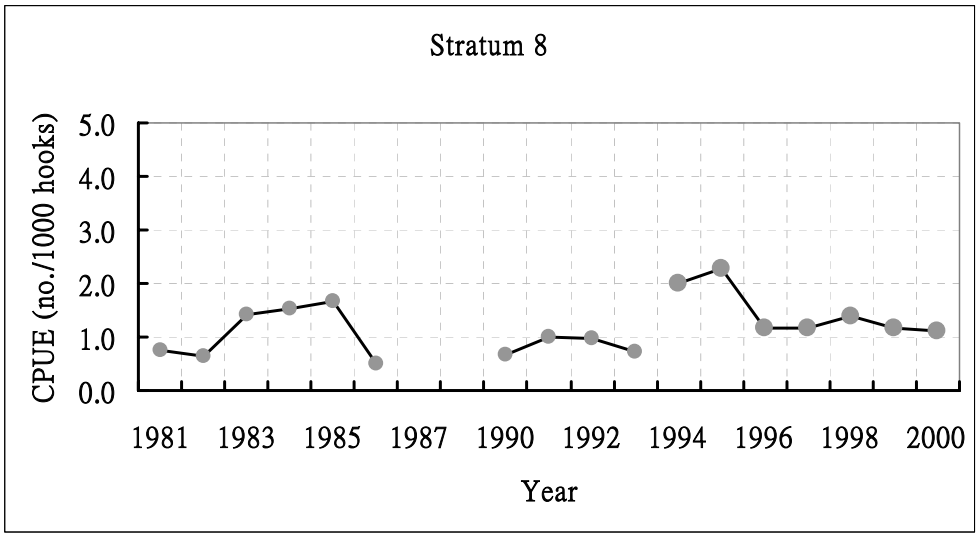


Figure 7. Annual standardized catch per unit effort of bigeye tuna caught by Taiwanese longline fleets in strata 5, 6, 7 and 8 from 1981 to 2000.

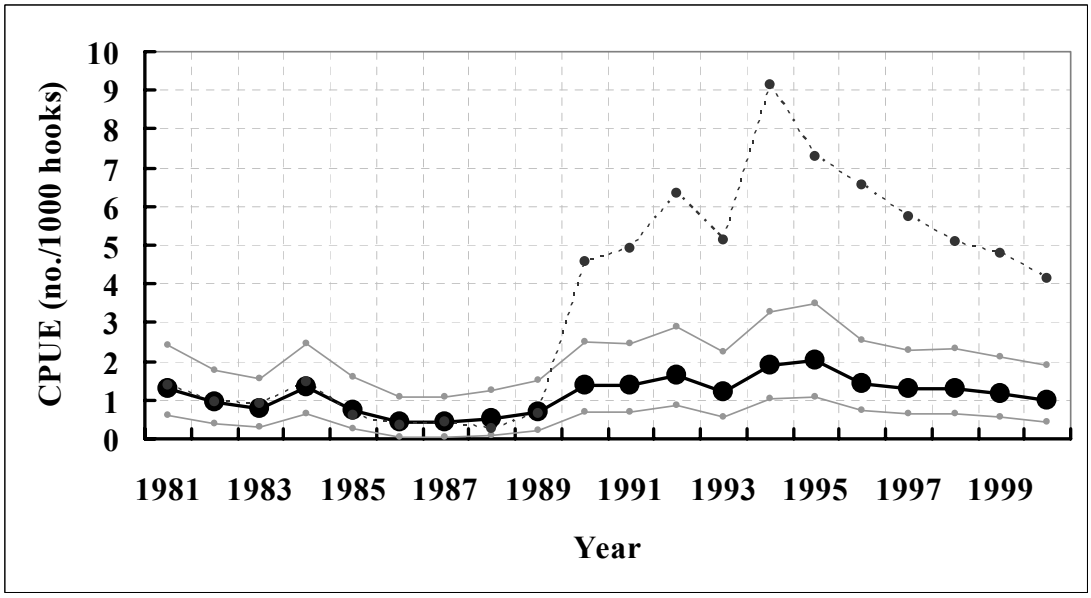


Figure 8. Annual standardized catch per unit effort of bigeye tuna caught by Taiwanese longline fleets in the strata 5, 6, 7 and 8 of the Atlantic.