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STANDARDIZED CATCH RATE INDEX FOR YELLOWFIN TUNA (*THUNNUS ALBACARES*) FROM THE TAIWANESE LONGLINE FISHERY IN THE ATLANTIC OCEAN, 1970-2014

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SUMMARY

Catch and effort data from the logbook of Taiwanese longline fishing vessels operating in the Atlantic Ocean during 1970 to 2014 were used to standardize the resources index of yellowfin tuna. Considering the yellowfin tuna is bycatch to Taiwanese fleet, the generalized linear mixed model (GLMM) with delta-lognormal error assumption was applied. Due to the fishing patterns are significant changed in early 1990s, the data is separated to two periods. The first dataset is Task II from 1970 to 1992 when yellowfin tuna was bycatch to Taiwanese albacore fleet. The second stage is the logbooks from 1993 to 2014 because yellowfin tuna was bycatch to Taiwanese bigeye fleet. Data before 1970 and some yellowfin tuna targeting vessels' logbooks data are excluded from the analysis. The variables used included year, quarter, area, species impact (ratio rank for albacore and bigeye tuna) and interaction of year and quarter. The results showed the yellowfin tuna catch per unit effort (CPUE) was decreasing from 1970 and remained low during mid 1970s to late 1980s. It increased in early 1990s and peaked in 1995. The abundance indices then slightly decreased and varied with high CPUE in 2005 and 2013.

RÉSUMÉ

Les données de prise et d'effort des carnets de pêche des palangriers du Taipei chinois opérant dans l'océan Atlantique entre 1970 et 2014 ont servi à standardiser l'indice d'abondance de l'albacore. Etant donné que l'albacore est capturé accidentellement par la flottille du Taipei chinois, on a appliqué le modèle mixte linéaire généralisé (GLMM) avec un postulat d'erreur delta-lognormal. Etant donné que les modes de pêche ont considérablement changé au début des années 90, les données sont séparées en deux périodes. Le premier jeu de données est la Tâche II de 1970 à 1992 lorsque l'albacore était une prise accessoire de la flottille de germon du Taipei chinois. Le deuxième stade sont les carnets de pêche de 1993 à 2014 étant donné que l'albacore était une prise accessoire de la flottille de thon obèse du Taipei chinois. Les données antérieures à 1970 et les données des carnets de pêche de certains navires ciblant l'albacore sont exclues de l'analyse. Les variables utilisées incluaient année, trimestre, zone, impact de l'espèce (classement du ratio pour le germon et le thon obèse) et interaction d'année et trimestre. Les résultats ont fait apparaître que la capture par unité d'effort (CPUE) de l'albacore était en chute depuis 1970 et est demeurée faible du milieu des années 70 à la fin des années 80. Elle a augmenté au début des années 90 et atteint son apogée en 1995. Les indices d'abondance ont ensuite légèrement diminué et ont varié, avec une forte CPUE en 2005 et 2013.

RESUMEN

Se utilizaron los datos de captura y esfuerzo del cuaderno de pesca de los palangreros de Taipei Chino que operaron en el océano Atlántico durante el periodo de 1970 a 2014 para estandarizar el índice de abundancia de rabil. Considerando que el rabil es capturado de forma fortuita por la flota de Taipei Chino, se aplicó un modelo lineal mixto generalizado (GLMM) con un supuesto de error delta lognormal. Debido a que los patrones de pesca cambiaron en gran medida a comienzos de los noventa, los datos se han desglosado en dos periodos. El primero conjunto de datos es la Tarea II de 1970 a 1992, cuando el rabil era capturado de forma fortuita por la flota de atún blanco de Taipei Chino. La segunda fase son los datos de los cuadernos de pesca de 1993 a 2014, cuando el rabil era capturado de forma fortuita por la flota de patudo de Taipei Chino. Se han excluido del análisis los datos anteriores a 1970 y algunos datos de los cuadernos de pesca de los buques que se dirigen al rabil. Las variables utilizadas incluyen año, trimestre, área, impacto de las especies (rango de ratio para el atún blanco y patudo) e interacción entre año y trimestre. Los resultados mostraban que la captura por unidad de esfuerzo (CPUE) de rabil

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comenzó a descender a partir de 1970 y se mantuvo en un nivel bajo durante mediados de los setenta hasta finales de los ochenta. Se incrementó a comienzos de los noventa y llegó a un punto máximo en 1995. Los índices de abundancia descendieron ligeramente después y variaron con una CPUE elevada en 2005 y 2013.

KEYWORDS

Atlantic Ocean, generalized linear mixed model, yellowfin tuna

1. Introduction

The commercial yellowfin tuna (*Thunnus albacares*) fisheries started in 1955 in the Atlantic Ocean with small baitboats and followed by purse seiners in early 1960s. Longline fisheries from Japan, Korea and Taiwan joined in late 1950s and 1960s. The total catch reached 81,350 mt in 1969 and decreased (Lenarz and Sakagawa 1973). The catch of purse seiners increased rapidly and the total catch was over 100,000 mt in 1975 and remained in the level between 100,000 mt to 120,000 mt in 1980s. The catch reached historical high 160,000 mt in 1990 and decreased to around 120,000 mt thereafter. After 2004, the total catch reduced to around 80,000 mt (ICCAT 2012).

Taiwan tuna longline fisheries extended to operate in the Atlantic Ocean in mid 1960s. The catch of yellowfin tuna was high in late 1960s (12,202 mt in 1969). However, when Taiwanese fleets transferred to target on albacore in 1970s, the catch decreased to low level and fluctuated between 1000 mt to 2000 mt during 1980s. Until 1990, the Taiwanese longline fishery changed its fishing strategy by using deep longline in tropical areas. The bycatch of yellowfin also increased and maintained between 4000 t to 5000t until 2005. In response to the decreasing of fishing vessels after 2005, the catch decreased to low level, which were only around 1200 t after 2005 (**Figure 1**).

The stock status of yellowfin tuna was previous accessed by the ICCAT in 2011. Both age-structured model and a non-equilibrium production model are applying to the available catch data through 2010. The estimate of MSY (~144,600 t) may be below what was achieved in past decades(ICCAT 2012). During the assessment, abundance index of longline fisheries from Japan, United States, Brazil, EU, and Taiwan were used. The GLM was applied for Japan because it was main target species(Satoh, Okamoto et al. 2012). In the other hand, the delta-lognormal models were applied for Brazil, US, and Taiwan because the yellowfin tuna was bycatch to these fisheries (Cass-Calay 2012; Hazin, Hazin et al. 2012; Hsu 2012; Walter 2012).

For Taiwan longline fleets, the abundance indices were first evaluated in 1996. The CPUE was standardized by generalized linear model with log-normal error structure in the Atlantic. The effects of year, area, and season were considered. The results showed the standardized CUPE decreased in the late 1960s and gradually until 1978 and then increased slightly and fluctuated since then (Ma and Hsu 1997). In 2000, the general linear model was used again to update the CPUE. The catch-at-age was used to derive age-specific catch per unit effort. The standardized catch per unit effort for total Atlantic yellowfin tuna tended to decrease from 1968 to 1975, and increased from the lowest level in 1975 to the highest level in 1995, then decreased again until 1998 (Hsu, Yeh et al. 2001).

More recently, the standardized catch per unit effort of yellowfin tuna was estimated by general linear mixed model with log-normal error structure on a yearly and quarterly basis. Factors including year, quarter, and sub-area were used as fixed factors and a two-way interaction, year-subarea, as a random factor. The results indicated the lowest abundance index was during the 1970s, and fluctuation occurred after 1990. The current estimated abundance level in 2008 and 2009 was likely equivalently equal to the levels in the 1980s after reaching its recent highest level in 2005 (Hsu 2012).

In this study, the spatial-temporal catch of yellowfin tuna for Taiwanese longline fisheries is reviewed and considered to standardize the resources abundance index in the Atlantic Ocean during 1970-2014.

2. Materials and methods

2.1 Data

Taiwanese tuna longline fisheries data is collected, and complied by Overseas Fisheries Development Council of Republic of China (OFDC). The data used in this research include Task II and Logbooks data. Task II catch/effort data are compiled from logbooks collected from individual fishing vessels. The logbook statistics are aggregated by year, month, 5*5 degree. Considering the recovery rates of logbooks were low in some years, the Task I data of major species is used as a reference in producing a version of the Task II data.

Logbooks are composed of general information per set (including set position (by 5*5 degree)), information per set (number of hooks), number and weight of first thirty catch and size data. For catch data, total numbers and weights of catches by species are included. The recovery rates of logbooks were around 60%-80% in early 1980s. However, it decreased in mid 1980s to only 20%. The recovery rate was slowly increased in late 1990s and rapidly increased to over 90% since 2004 due to the implementation of Statistical Documents Scheme.

For the analysis, some data are excluded including (1) considering the yellowfin tuna is bycatch of Taiwanese fleets, some seasonal targeting yellowfin tuna vessels logbooks are excluded in the final analysis; (2) hooks less than 1000 are considered as test sets; (3) During 1992, and 1997-1998, due to low logbook recovery rate, some aggregated bi-weekly or monthly records are included in the logbooks. These data are excluded because of uninformative for daily operation.

2.2 Models

Two previous models, GLM and the generalized linear mixed model (GLMM) were both used for comparison (Hsu, Yeh et al. 2001; Hsu 2012). During 1970 and 1993, Taiwanese fleet was majorly targeted on albacore, and transferred to target on bigeye tuna since 1993. After test, GLMM with delta-lognormal error distribution for the positive catch rates is applied (Lo, Jacobson et al. 1992; Chang, Lee et al. 2007) because there are high proportion of zero catch and skewed distribution of positive catch rates for yellowfin tuna (**Table 1**).

For positive set, which at least one yellowfin tuna caught, the estimated CPUE rate was assumed to follow a lognormal error distribution of fixed factors and random effect interactions.

$$\ln\left(\mu_{\text{year,quarter,area,sp}}\right) = \beta_0 + \beta_{\text{year}} + \beta_{\text{quarter}} + \beta_{\text{area}} + \beta_{\text{sp}} + \beta_{\text{year,area}} + z$$

The estimated proportion is a linear function of fixed effects and interactions, by using logit function as a link between linear factor components and binomial errors. The systematic component is defined as:

$$\ln\left(\frac{\rho_{\text{year,quarter,area,sp}}}{1-\rho_{\text{year,quarter,area,sp}}}\right) = \alpha_0 + \alpha_{\text{year}} + \alpha_{\text{quarter}} + \alpha_{\text{area}} + \alpha_{\text{sp}} + \alpha_{\text{year,area}} + w$$

Where

CPUE (nominal catch per unit effort): is estimated for number (no/1000 hooks).

y: year effect.
q: quarter were 1~4 for January-March, April-June, July-September, October-December.

Area: divided to ten areas showed in **Figure 2** including YF02, 03, 04, 05, 06, 09, 10, 11, 12, 40 (http://www.iccat.int/Data/ICCAT_maps.pdf). The data from north of 50 N and south of 40S and Mediterranean is excluded due to very limited.

Sp_1 (ralbrank) albacore ratio is calculated as (number of albacore)/(number of albacore+ number of bigeye+ number of yellowfin tuna+ number of swordfish). The ratio of albacore is further to category to four levels, 1: *ralb*<0.03; 2: 0.03< *ralb* <0.6; 3:0.6< *ralb* <0.95; 4: 0.95< *ralb* <=1. The values are decided by the Quartile of ratio of albacore.

Sp_2 (*rbetrank*) bigeye tuna ratio is calculated as (number of bigeye)/(number of albacore + number of bigeye + number of yellowfin tuna + number of swordfish). The ratio of bigeye is further separated to four levels, 1: *rbet* <0.01; 2: 0.01<= *rbet* <0.3; 3:0.3<= *rbet* <=0.6; 4: 0.6< *rbet* <=1. The values are decided by the Quartile of ratio of bigeye.

A step-wise regression procedure was used to determine the set of systematic factors and interactions that significantly explained the observed variability. Deviance analysis tables are obtained from the model runs and each table includes the deviance for the proportion of positive observations, i.e. (positive sets) / (total sets), and the deviance for the positive catch rates.

Relative indices for the delta model formulation were calculated as the product of the *year* effect least square means (LSMeans) from the binomial and the lognormal model components. All models using the stepwise approach were fitted with the SAS GENMOD procedure, whereas the final model was run with the SAS GLIMMIX and MIXED procedures (SAS Inst. Inc.). The detail of delta-model statistical algorithm of standardization for CPUE was described in(Lo, Jacobson et al. 1992). The variance is estimated based on (Walter and Ortiz 2012).

Considering the fleets characteristics changed during early 1990s and data types, two models are applied for different data sets for specific periods, including,

Model 1: Task 2 for the period between 1970-1992. The major fleets are albacore. The Sp1 and Sp2 are applied for.

Model 2 Logbook for the period between 1993-2014 for number. The albacore fleets operating in northern and southern areas and bigeye fleets operating in tropical areas. The Sp1 and Sp2 are included.

3. Results and Discussion

3.1 Spatial-temporal variation of Taiwanese fleets

The overall, decade distribution of catch number of yellowfin tuna from Task 2 data are showed in **Figure 3 and 4**. The higher catch was in the tropical areas (15° N to 10° S) especially during late 1960s. The catch decreased in mid-1970s and 1980s. It was increased in tropical areas until 1990 and has some high catch in Caribbean Sea for specific periods because of some seasonal targeting vessels. After 2005, the catch number were decreased dramatically and remained low. There were very few catch in north of 50° N, south of 40° S and Mediterranean Sea. Under the situation, the catch in north of 50° N, south of 40° S and Mediterranean were excluded from the analysis.

The percentage of albacore, bigeye, and yellowfin tuna by area by year are showed in **Figure 5**. In the north and south areas, the albacore percentage is stable and significant higher than bigeye tuna (YF11, 12, 6, 9, and 40). In the tropical areas, the catch of bigeye was increased since late 1980s (YF10, 03, 04, and 05). During specific years, such as 1999 and 2005, there were some seasonal yellowfin targeting vessels, mostly were smaller vessels operated in Caribbean Sea (YF40).

3.2 Standardization CPUE from GLMM

The deviance analysis of explanatory variables for Task 2 data (1970-1992) are showed in **Table 2**. The year, area, ration of albacore and bigeye, and quarter are all significant (p<0.001). However, for the interaction, only the year*area was more important factor for the proportion of positive sets models, others are less significant. For the positive catch proportions, the quarter is less significant. The interaction, year*area are most important. The residual distributions and QQ plots for task 2 (1970-1992) for positive catches were showed in **Figure 6**. It is a better model since it has followed the lognormal error. As results, the fixed factor estimates for proportion positive sub-model is showed in **Table 3** and the nominal and standardized catch rate was showed in **Table 4**.

The deviance analysis of explanatory variables for Logbook data (1993-2014) are showed in **Table 5**. The year, area, ration of bigeye are most significant, followed by albacore ration and quarter. For the interaction, all was less important (% deviance <5). For the positive catch proportions, not only the bigeye ration, but the albacore ratio is also important. The interaction, year*area are most important (%deviance >5%). The residual distribution and QQ plot for positive catch were showed in **Figure 7**. It is a better model since it has also followed the lognormal error.

In summary, the nominal and standardized CPUE from GLMM models are showed in **Figure 8** (1970-1992) and **Figure 9** (1993-2014). In general, the standardized CPUE were continued decreased since 1970 and stable in 1980s. It increased slowly in late 1980s and early 1990s when Taiwanese fleets started to target bigeye and decreased after 1995. In mid 2000s, it increased in 2005, and then decreased again.

The QQ-plot of standard residual were shown in normal for GLMM. During the period analyzed, the target is albacore for period 1 and bigeye in period two. It is showed the ration of albacore is a more important variables then bigeye tuna ratio in period 1 then period 2.

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Table 1. Yellowfin tuna catch of Taiwanese fleets (1962-2015) and Number of sets, positive sets and percentage of yellowfin tuna reported in logbooks in the Atlantic Ocean (1981-2015).

Year	*Catch*	*Sets*	*Positive sets*	*Positive%*	*Hooks/set*	*Nominal CPUE*
1962	278					
1963	399					
1964	396					
1965	183					
1966	1243					
1967	3023					
1968	8884					
1969	12202					
1970	7990					
1971	4938					
1972	5317					
1973	3000					
1974	2630					
1975	2669					
1976	1962					
1977	372					
1978	384					
1979	1038					
1980	687					
1981	867	16881	3720	22.0%	2392	0.296
1982	610	20839	3829	18.4%	2520	0.235
1983	539	12701	2995	23.6%	2625	0.204
1984	646	10929	4066	37.2%	2681	0.462
1985	926	16653	4323	26.0%	2744	0.333
1986	1410	16026	5694	35.5%	2881	0.516
1987	902	8384	2538	30.3%	3000	0.417
1988	1848	3844	1181	30.7%	2917	0.555
1989	858	3139	1066	34.0%	2914	0.553
1990	7465	4328	1591	36.8%	3028	1.038
1991	4172	2860	1172	41.0%	3115	0.948
1992	4528	1951	890	45.6%	3191	1.078
1993	4196	3773	1803	47.8%	3035	0.932
1994	6660	8655	3680	42.5%	3073	1.408
1995	4698	11253	6364	56.6%	2972	1.712
1996	6653	15921	9968	62.6%	2837	1.685
1997	4466	15751	7462	47.4%	2884	1.008
1998	5328	13103	5661	43.2%	2920	0.769
1999	4411	25622	11200	43.7%	2989	0.641
2000	5661	20572	10274	49.9%	3002	0.938
2001	4805	15312	6516	42.6%	3113	0.438
2002	4659	18018	8264	45.9%	3169	0.837
2003	6486	10953	5683	51.9%	3136	1.182
2004	5824	22348	11157	49.9%	3181	1.250
2005	3596	25984	14106	54.3%	3220	1.405
2006	1260	16540	5967	36.1%	3576	0.453
2007	1947	20869	7281	34.9%	3212	0.435
2008	1122	17220	5110	29.7%	3177	0.355
2009	1391	20636	6733	32.6%	3040	0.409
2010	824	22723	5792	25.5%	3020	0.256
2011	1768	27305	9284	34.0%	3035	0.418
2012	1071	21500	5811	27.0%	3001	0.308
2013	1260	17058	7158	42.0%	2994	0.540
2014	1047	16422	4641	28.3%	2847	0.499
2015	1220	18188	4989	27.4%	2899	0.411

Table 2. Deviance analysis table of explanatory variables in the delta lognormal model of the Atlantic yellowfin catch rates of Taiwanese longline fishery from 1970-1992 Task II Data. Percent of total deviance refers to the deviance explained by the full model; p value refers to the Chi-square probability between consecutive models.

Model factors: positive catch rate values

Variables	*DF*	*Deviance*	*Change deviance*	*% total deviance*	*P*
Intercept	6297	19370			
Year	6275	16048	2858	20.7%	<0.001
Year Area	6266	10431	4952	53.8%	<0.001
Year Area Quarter	6263	10335	81	0.9%	<0.001
Year Area Quarter Ralbrank	6260	7969	2260	29.7%	<0.001
Year Area Quarter Ralbrank Rbetrank	6257	7226	576	10.3%	<0.001
Year Area Quarter Ralbrank Rbetrank Year*area	6089	6709	510	7.7%	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Quarter	6191	6892	334	4.8%	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Rbetrank	6195	7039	185	2.7%	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Ralbrank	6194	6945	286	4.0%	<0.001

Model factors: proportion positive

Variables	DF	Deviance	Change deviance	% total deviance	P
Intercept	2049	5282			<0.001
Year	2027	5097	185	**3.6%**	<0.001
Year Area	2018	3905	1192	**30.5%**	<0.001
Year Area Quarter	2015	3838	67	1.7%	<0.001
Year Area Quarter Ralbrank	2012	3591	247	**6.9%**	<0.001
Year Area Quarter Ralbrank Rbetrank	2009	3404	187	**5.5%**	
Year Area Quarter Ralbrank Rbetrank Year*area	1830	2706	698	**25.8%**	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Quarter	1943	3256	148	4.5%	<0.001
Year Area Quarter Ralbrank Rbetrank Year*ralbrank	1946	3150	254	8.1%	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Rbetrank	1946	3049	355	11.6%	<0.001

Table 3. Fixed factor estimates for proportion positive sub-model for Model 1.

Effect	Year	Area	Sp_{alb}	Sp_{bet}	Estimate	Standard error	DF	t	Pr > |t|	Lower	Upper
Intercept					1.8269	1.2815	198	1.43	0.1555	-0.7002	4.354
Year	1967				-1.7124	1.906	198	-0.9	0.37	-5.471	2.0461
Year	1968				-1.108	1.3867	198	-0.8	0.4252	-3.8427	1.6266
Year	1969				-2.3202	1.2889	198	-1.8	0.0734	-4.8619	0.2215
Year	1970				-1.9371	1.2839	198	-1.51	0.1329	-4.4689	0.5947
Year	1971				-2.0945	1.2931	198	-1.62	0.1069	-4.6446	0.4555
Year	1972				-2.8212	1.2923	198	-2.18	0.0302	-5.3696	-0.2728
Year	1973				-1.5279	1.3254	198	-1.15	0.2504	-4.1417	1.0859
Year	1974				-2.7036	1.2922	198	-2.09	0.0377	-5.2518	-0.1555
Year	1975				-1.6585	1.3192	198	-1.26	0.2102	-4.2599	0.943
Year	1976				-2.1551	1.2935	198	-1.67	0.0973	-4.7058	0.3956
Year	1977				-2.9377	1.2784	198	-2.3	0.0226	-5.4588	-0.4166
Year	1978				-2.5462	1.2933	198	-1.97	0.0504	-5.0966	0.0041
Year	1979				-2.0104	1.3128	198	-1.53	0.1273	-4.5992	0.5784
Year	1980				-1.723	1.2925	198	-1.33	0.184	-4.2718	0.8258
Year	1981				-0.8659	1.319	198	-0.66	0.5123	-3.4669	1.7352
Year	1982				-2.1226	1.2914	198	-1.64	0.1018	-4.6692	0.424
Year	1983				-1.2833	1.3137	198	-0.98	0.3298	-3.8739	1.3074
Year	1984				-1.6329	1.2943	198	-1.26	0.2086	-4.1852	0.9194
Year	1985				-1.5099	1.2957	198	-1.17	0.2453	-4.0651	1.0452
Year	1986				-1.3966	1.2992	198	-1.07	0.2837	-3.9587	1.1656
Year	1987				-2.4112	1.3023	198	-1.85	0.0656	-4.9792	0.1569
Year	1988				-2.7455	1.417	198	-1.94	0.0541	-5.5398	0.0488
Year	1989				-3.116	1.3034	198	-2.39	0.0178	-5.6862	-0.5457
Year	1990				-2.0907	1.3581	198	-1.54	0.1253	-4.7688	0.5874
Year	1991				-2.2158	1.3104	198	-1.69	0.0924	-4.7999	0.3682
Year	1992				0	.	.	.	.	.	.
Area		1			0.7678	0.4614	198	1.66	0.0977	-0.1421	1.6777
Area		2			-1.9822	0.3222	198	-6.15	<.0001	-2.6176	-1.3468
Area		3			-1.4712	0.3217	198	-4.57	<.0001	-2.1057	-0.8368
Area		4			-0.3805	0.3538	198	-1.08	0.2835	-1.0783	0.3172
Area		5			-1.9215	0.4223	198	-4.55	<.0001	-2.7543	-1.0886
Area		6			-2.0689	0.2656	198	-7.79	<.0001	-2.5927	-1.545
Area		9			-1.6303	0.268	198	-6.08	<.0001	-2.1589	-1.1018
Area		10			0.2483	0.3548	198	0.7	0.4848	-0.4513	0.9479
Area		11			-0.5957	0.2735	198	-2.18	0.0306	-1.135	-0.0564
Area		12			0	.	.	.	.	.	
Spalb			1		2.4106	0.3011	1965	8.01	<.0001	1.82	3.0011
Spalb			2		2.1065	0.2592	1965	8.13	<.0001	1.5982	2.6149
Spalb			3		0.5972	0.07247	1965	8.24	<.0001	0.4551	0.7393
Spalb			4		0	.	.	.	.	.	.
Spbet				1	2.0416	0.2844	1965	7.18	<.0001	1.4839	2.5994
Spbet				2	2.5599	0.2785	1965	9.19	<.0001	2.0138	3.106
Spbet				3	1.3059	0.2307	1965	5.66	<.0001	0.8535	1.7584
Spbet				4	0	.	.	.	.	.	.

Table 4. Nominal and standardized catch rate of yellowfin tuna from Model 1.

Year	Nominal CPUE	Std Error	**Std CPUE**	Low CI	Upper CI
1970	3.840	0.143	**2.031**	1.592	2.591
1971	3.996	0.098	**1.261**	0.964	1.649
1972	4.568	0.104	**1.242**	0.932	1.655
1973	2.392	0.112	**1.297**	0.964	1.746
1974	3.096	0.065	**0.769**	0.575	1.028
1975	1.987	0.064	**0.775**	0.584	1.028
1976	0.963	0.080	**0.972**	0.732	1.290
1977	1.091	0.067	**0.797**	0.597	1.065
1978	0.984	0.067	**0.806**	0.605	1.075
1979	0.985	0.083	**0.873**	0.630	1.210
1980	0.785	0.075	**0.908**	0.682	1.208
1981	0.621	0.063	**0.796**	0.607	1.043
1982	0.827	0.061	**0.794**	0.609	1.036
1983	0.409	0.059	**0.742**	0.565	0.975
1984	0.532	0.059	**0.769**	0.589	1.004
1985	0.484	0.053	**0.680**	0.520	0.889
1986	0.582	0.074	**0.944**	0.720	1.238
1987	0.879	0.079	**0.932**	0.695	1.250
1988	0.804	0.104	**0.831**	0.542	1.273
1989	1.257	0.086	**0.739**	0.497	1.100
1990	1.866	0.093	**0.922**	0.652	1.305
1991	1.725	0.120	**1.405**	1.047	1.886
1992	1.584	0.113	**1.208**	0.875	1.669

Table 5. Deviance analysis table of explanatory variables in the delta lognormal model of the Atlantic yellowfin catch rates of Taiwanese longline fishery from 1993-2015 Logbook Data. Percent of total deviance refers to the deviance explained by the full model; p value refers to the Chi-square probability between consecutive models.

Model factors: positive catch rate values

Variables	*DF*	*Deviance*	*Change deviance*	*% total deviance*	*P*
Null	164519	169673			
Year	164497	154115	10.1%	**9.99**	<0.001
Year Area	164488	147870	4.2%	**4.33**	<0.001
Year Area Quarter	164485	147705	0.1%	0.12	<0.001
Year Area Quarter Ralbrank	164482	139718	5.7%	**5.23**	<0.001
Year Area Quarter Ralbrank Rbetrank	164479	106587	31.1%	**31.33**	
Year Area Quarter Ralbrank Rbetrank Year*area	164301	101763	4.7%	4.77	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Quarter	164414	104664	1.8%	1.82	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Ralbrank	164414	103760	2.7%	2.68	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Rbetrank	164414	103600	2.9%	2.62	<0.001

Model factors: proportion positive

Variables	*DF*	*Deviance*	*Change deviance*	*% total deviance*	*P*
Null	4797	137274			<0.001
Year	4775	118023	19251	**16.3%**	<0.001
Year Area	4766	101001	17022	**16.9%**	<0.001
Year Area Quarter	4763	99807	1194	1.2%	<0.001
Year Area Quarter Ralbrank	4760	71300	28507	**40.0%**	<0.001
Year Area Quarter Ralbrank Rbetrank	4757	50381	20919	**41.5%**	<0.001
Year Area Quarter Ralbrank Rbetrank Year*area	4576	42309	8072	19.1%	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Quarter	4691	46614	3767	8.1%	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Ralbrank	4691	46154	4227	9.2%	<0.001
Year Area Quarter Ralbrank Rbetrank Year*Rbetrank	4691	45764	4617	10.1%	<0.001

Table 6. Fixed factor estimates for proportion positive sub-model for Model 2.

Effect	*Year*	*Area*	*Spalb*	*Spbet*	*Estimate*	*Standard error*	*DF*	*t*	*Pr > |t|*	*Lower*	*Upper*
Intercept					-3.338	0.2663	181	-12.53	<.0001	-3.8635	-2.8125
Year	1993				1.2592	0.3376	181	3.73	0.0003	0.593	1.9253
Year	1994				1.4234	0.3271	181	4.35	<.0001	0.778	2.0688
Year	1995				1.7089	0.2946	181	5.8	<.0001	1.1277	2.2902
Year	1996				1.8713	0.3003	181	6.23	<.0001	1.2788	2.4637
Year	1997				1.3753	0.2957	181	4.65	<.0001	0.7918	1.9588
Year	1998				0.9439	0.2967	181	3.18	0.0017	0.3586	1.5292
Year	1999				0.8995	0.2794	181	3.22	0.0015	0.3482	1.4507
Year	2000				0.8318	0.2891	181	2.88	0.0045	0.2614	1.4022
Year	2001				0.6283	0.2991	181	2.1	0.037	0.03821	1.2184
Year	2002				0.7126	0.2981	181	2.39	0.0179	0.1244	1.3009
Year	2003				0.4841	0.3195	181	1.51	0.1315	-0.1464	1.1146
Year	2004				0.8855	0.2846	181	3.11	0.0022	0.3239	1.4471
Year	2005				1.2324	0.2849	181	4.33	<.0001	0.6703	1.7945
Year	2006				1.1233	0.3084	181	3.64	0.0004	0.5148	1.7318
Year	2007				0.3125	0.2901	181	1.08	0.2828	-0.2599	0.8848
Year	2008				-0.2392	0.3133	181	-0.76	0.4461	-0.8574	0.3789
Year	2009				0.08692	0.2959	181	0.29	0.7692	-0.4969	0.6707
Year	2010				0.3599	0.2951	181	1.22	0.2242	-0.2223	0.9422
Year	2011				0.2909	0.291	181	1	0.3187	-0.2832	0.865
Year	2012				0.3017	0.2983	181	1.01	0.3131	-0.2868	0.8902
Year	2013				0.3834	0.3017	181	1.27	0.2054	-0.2119	0.9787
Year	2014				-0.4682	0.3153	181	-1.48	0.1394	-1.0903	0.154
Year	2015				0	.	.	.	.	.	.
Area		YF40			0.6001	0.4085	181	1.47	0.1435	-0.2059	1.406
Area		YF02			-2.6983	0.2867	181	-9.41	<.0001	-3.264	-2.1326
Area		YF03			-0.1241	0.1924	181	-0.65	0.5197	-0.5038	0.2556
Area		YF04			-0.113	0.1763	181	-0.64	0.5226	-0.4609	0.235
Area		YF05			-0.2302	0.1928	181	-1.19	0.2342	-0.6107	0.1503
Area		YF06			-0.6204	0.172	181	-3.61	0.0004	-0.9598	-0.2811
Area		YF09			-0.7701	0.1735	181	-4.44	<.0001	-1.1125	-0.4277
Area		YF10			0.4075	0.1774	181	2.3	0.0228	0.05744	0.7575
Area		YF11			-0.2512	0.1787	181	-1.41	0.1617	-0.6039	0.1015
Area		YF12			0	.	.	.	.	.	.
Spalb			1		2.2479	0.07033	4510	31.96	<.0001	2.11	2.3858
Spalb			2		2.445	0.0775	4510	31.55	<.0001	2.2931	2.5969
Spalb			3		2.233	0.05099	4510	43.8	<.0001	2.133	2.333
Spalb			4		0	.	.	.	.	.	.
Spbet				1	1.5891	0.06287	4510	25.28	<.0001	1.4659	1.7124
Spbet				2	1.7516	0.06355	4510	27.56	<.0001	1.627	1.8762
Spbet				3	1.7959	0.04964	4510	36.18	<.0001	1.6986	1.8932
Spbet				4	0	.	.	.	.	.	.

Table 7. Table Nominal and standardized catch rate of yellowfin tuna from Model 2.

Year	*Nominal CPUE*	*Std Error*	***Std CPUE***	*Low CI*	*Upper CI*
1993	0.932	0.101	**1.025855**	0.788	1.336
1994	1.375	0.131	**1.476962**	1.166	1.871
1995	1.655	0.164	**1.991248**	1.597	2.483
1996	1.642	0.143	**1.76632**	1.424	2.191
1997	0.970	0.128	**1.511645**	1.205	1.896
1998	0.733	0.109	**1.260889**	1.000	1.590
1999	0.612	0.077	**0.920616**	0.737	1.150
2000	0.913	0.086	**1.071347**	0.864	1.329
2001	0.425	0.060	**0.70487**	0.561	0.886
2002	0.776	0.078	**0.94069**	0.753	1.175
2003	1.135	0.094	**1.057808**	0.833	1.343
2004	1.196	0.099	**1.193389**	0.957	1.489
2005	1.357	0.127	**1.604407**	1.297	1.984
2006	0.444	0.085	**0.983744**	0.781	1.240
2007	0.416	0.068	**0.725328**	0.565	0.931
2008	0.334	0.048	**0.45845**	0.346	0.608
2009	0.387	0.057	**0.551032**	0.419	0.725
2010	0.252	0.056	**0.577238**	0.445	0.749
2011	0.434	0.062	**0.668109**	0.521	0.857
2012	0.301	0.051	**0.52321**	0.404	0.677
2013	0.535	0.072	**0.788061**	0.617	1.007
2014	0.484	0.056	**0.507857**	0.379	0.681
2015	0.384	0.065	**0.615768**	0.464	0.818

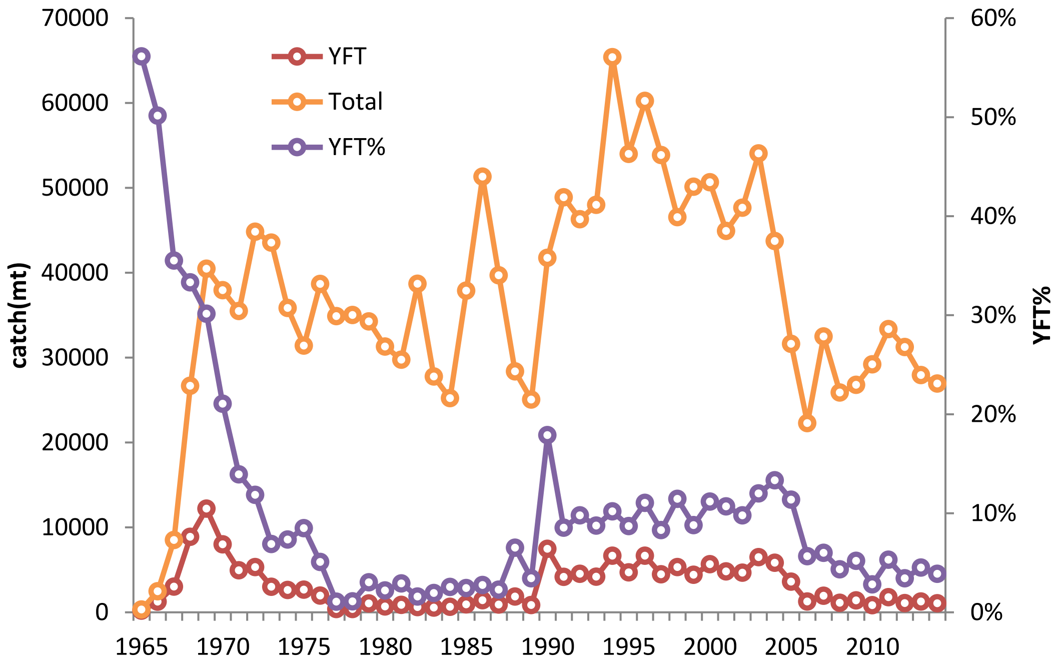


Figure 1. Historical catch of yellowfin tuna, total catch and the percentage of yellowfin tuna of Taiwanese tuna longline fleets in the Atlantic Ocean, 1965-2014. *Sources:* ICCAT (Task 1) and OFDC.

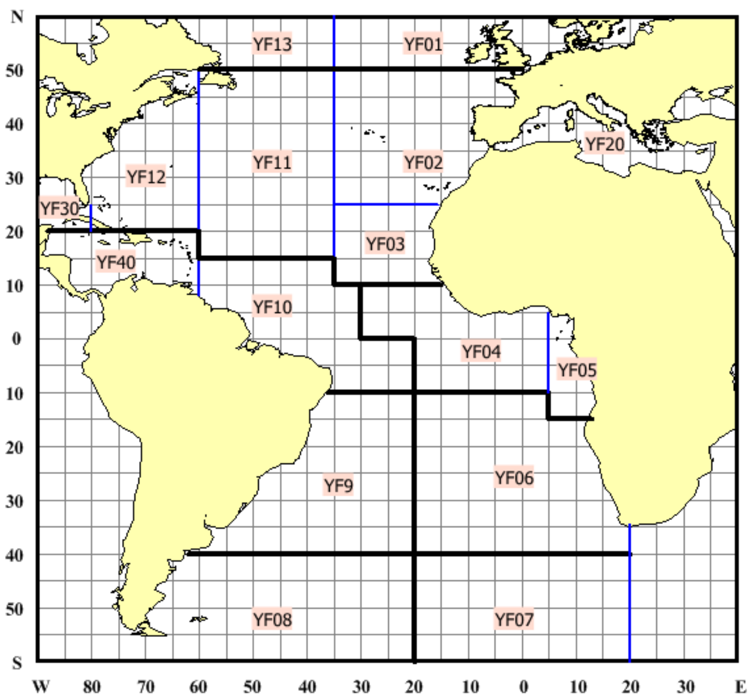


Figure 2. Area stratification of the Atlantic Ocean for standardizing yellowfin tuna catch per unit effort. *Resource:* ICCAT Manual (2016)

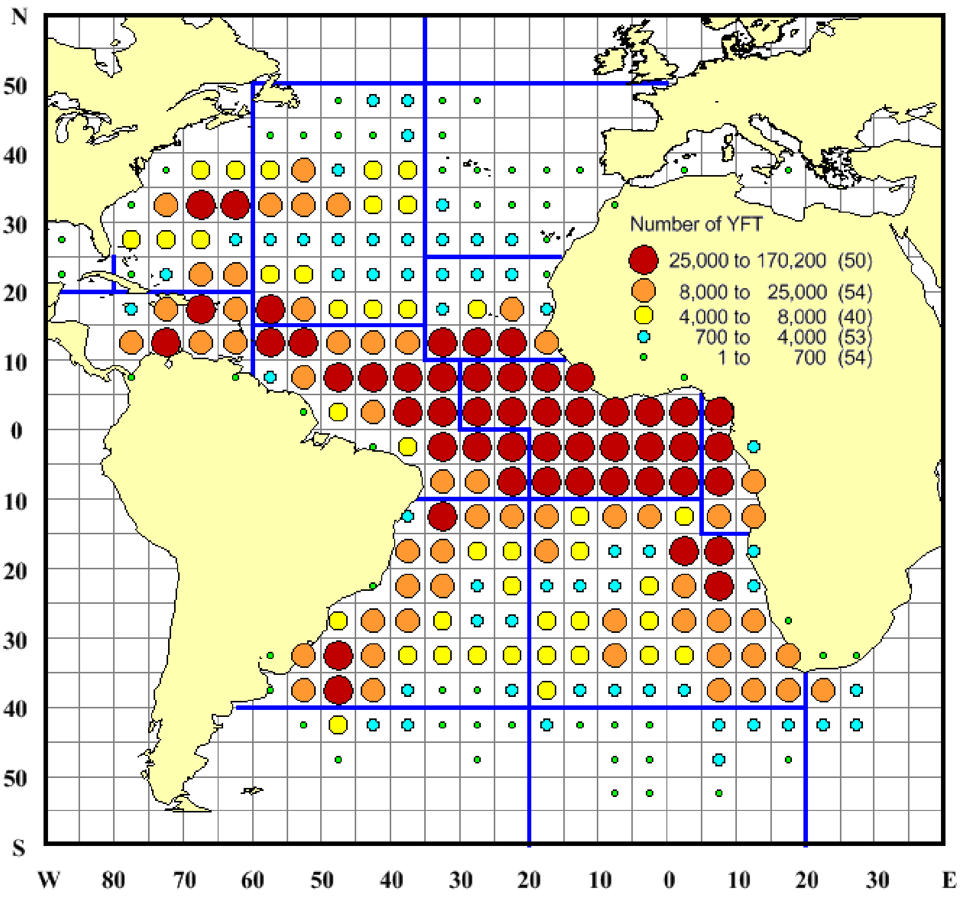


Figure 3. Distribution of catch number of yellowfin tuna of Taiwanese longline fisheries in the Atlantic Ocean from 1967-2014. *Sources:* Task 2 1967-2014

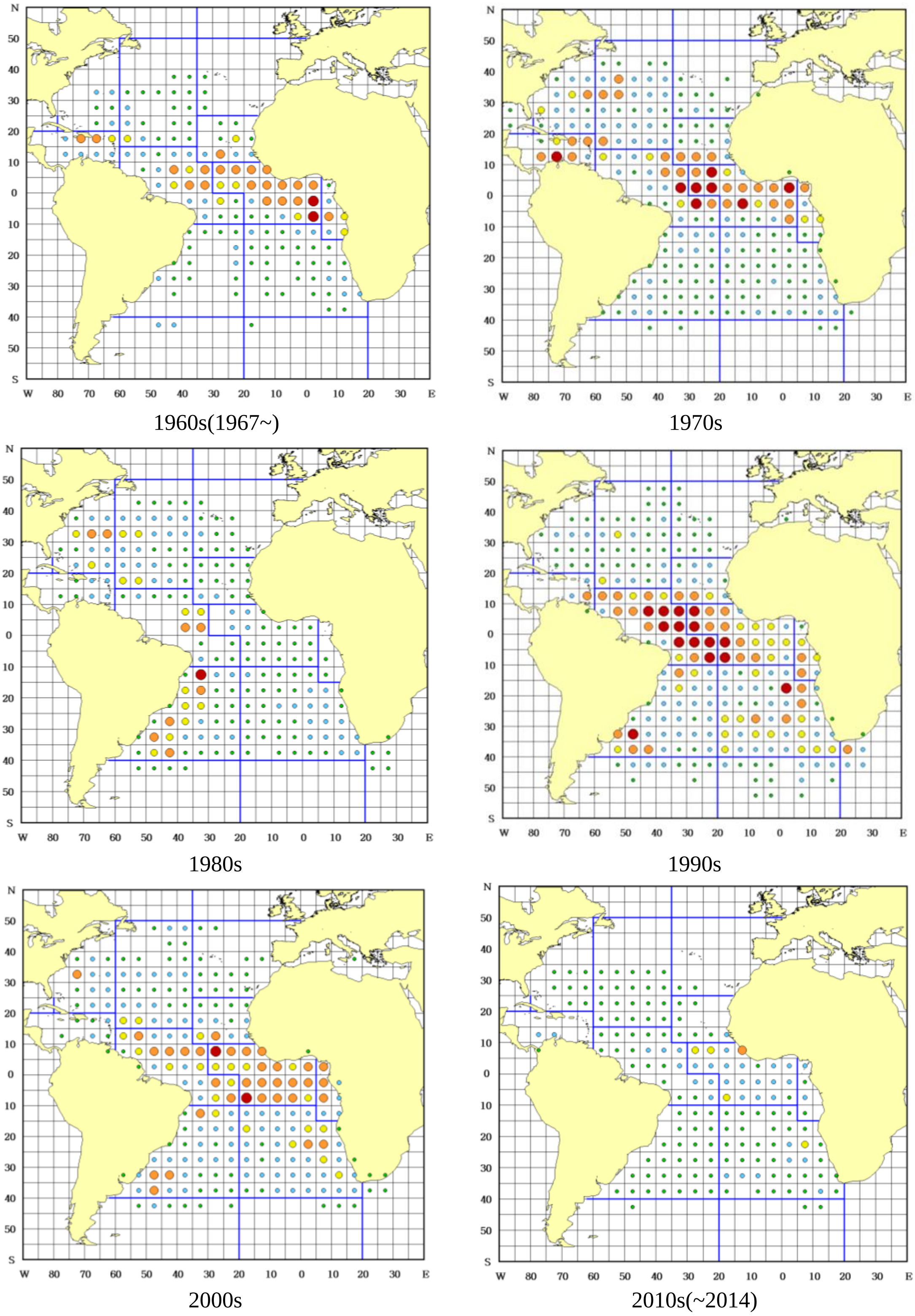
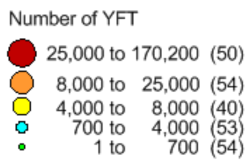


Figure 4. Distribution of catch number of yellowfin tuna of Taiwanese longline fisheries in the Atlantic Ocean from 1967-2014
Sources: Task 2 1967-2014



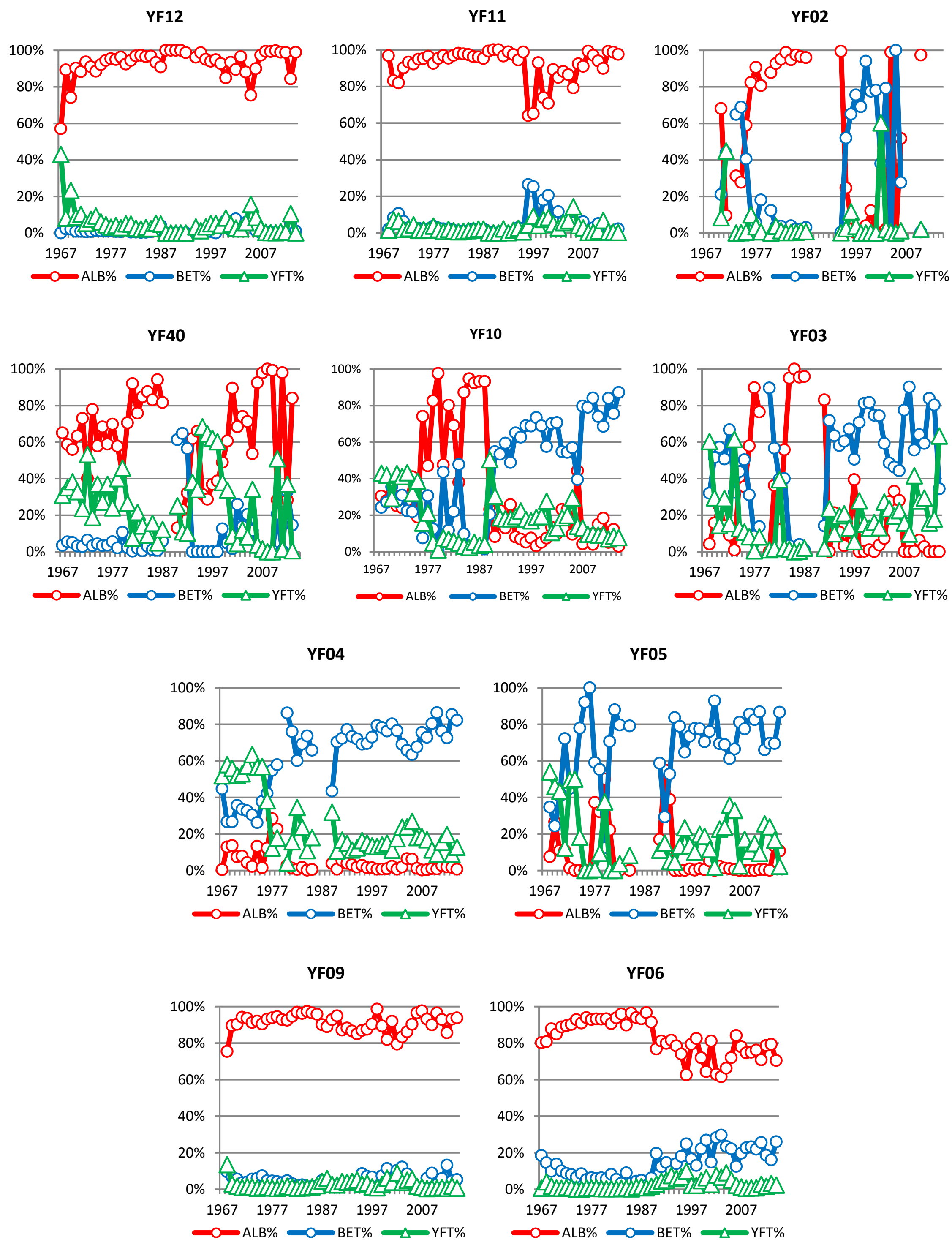


Figure 5. Yellowfin tuna catch compositions of Taiwanese longline fishing vessels from logbook, by year, area, 1981-2014. *Source:* Task2 data of Taiwanese fleets

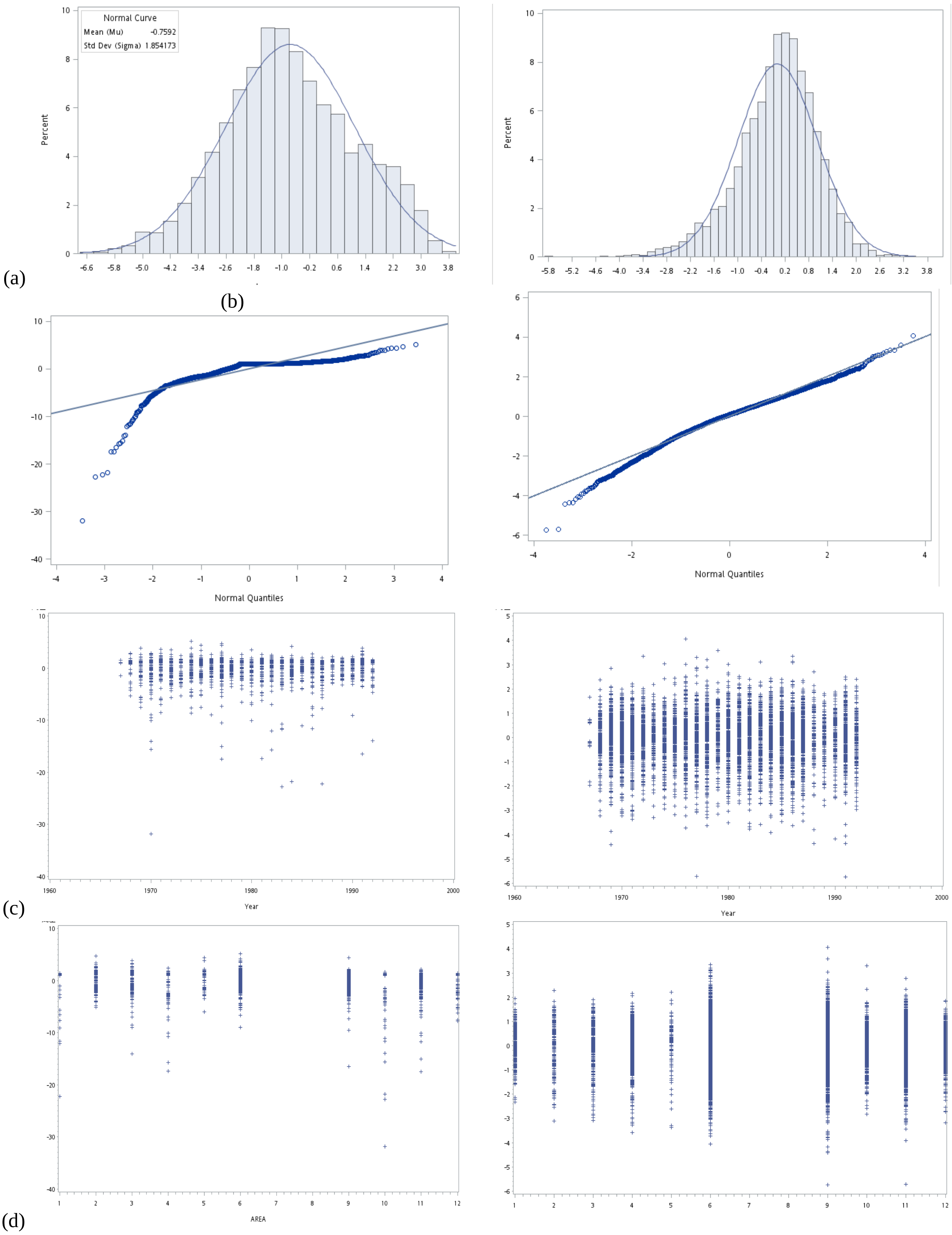


Figure 6. Diagnostic plots for the Model 1. Left for binomial sub-model (Task 2 data during 1970-1992). Right for positive model: (a)overall residuals, (b) QQ-Plot of residual, (c) residuals by year, and (d) residual by area.

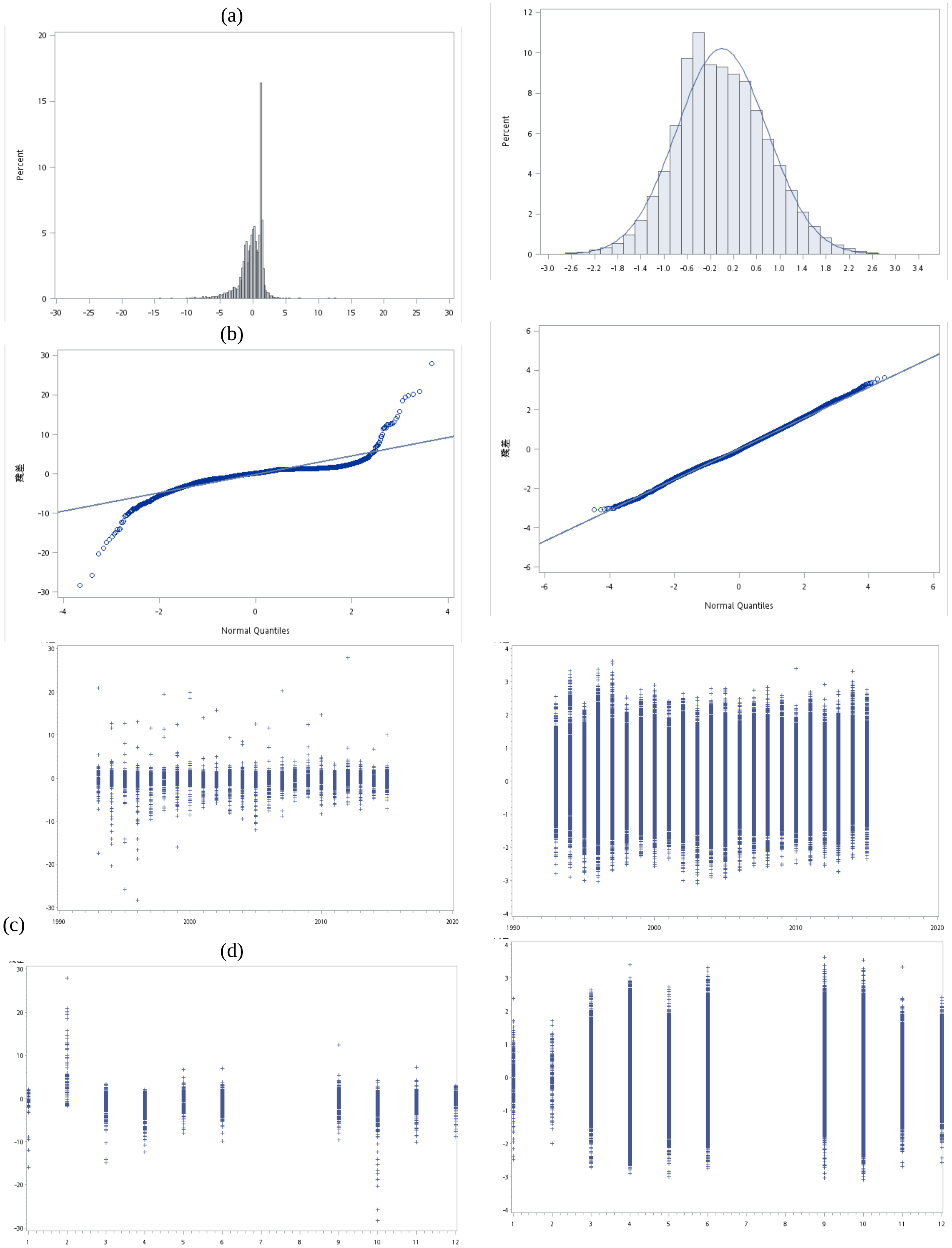


Figure 7. Diagnostic plots for the Model 1. Left for binomial submodel (Logbook data during 1993-2015). Right for positive model: (a)overall residuals, (b) QQ-Plot of residual, (c) residuals by year, and (d) residual by area

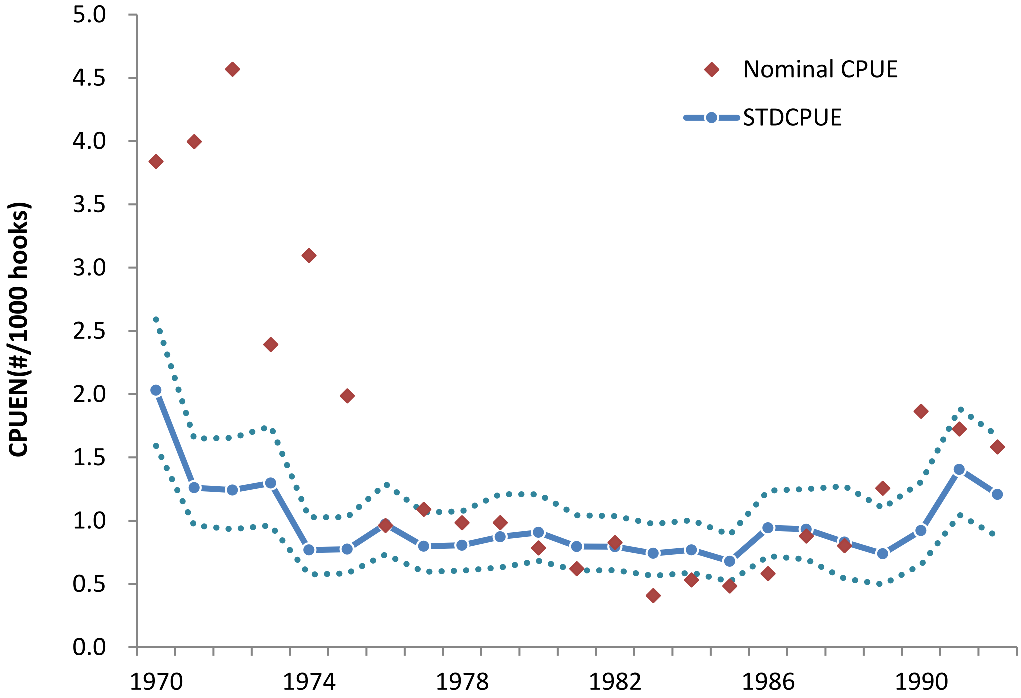


Figure 8. Nominal and standardized CPUE in number and weight from 1970-1992 for Model 1.

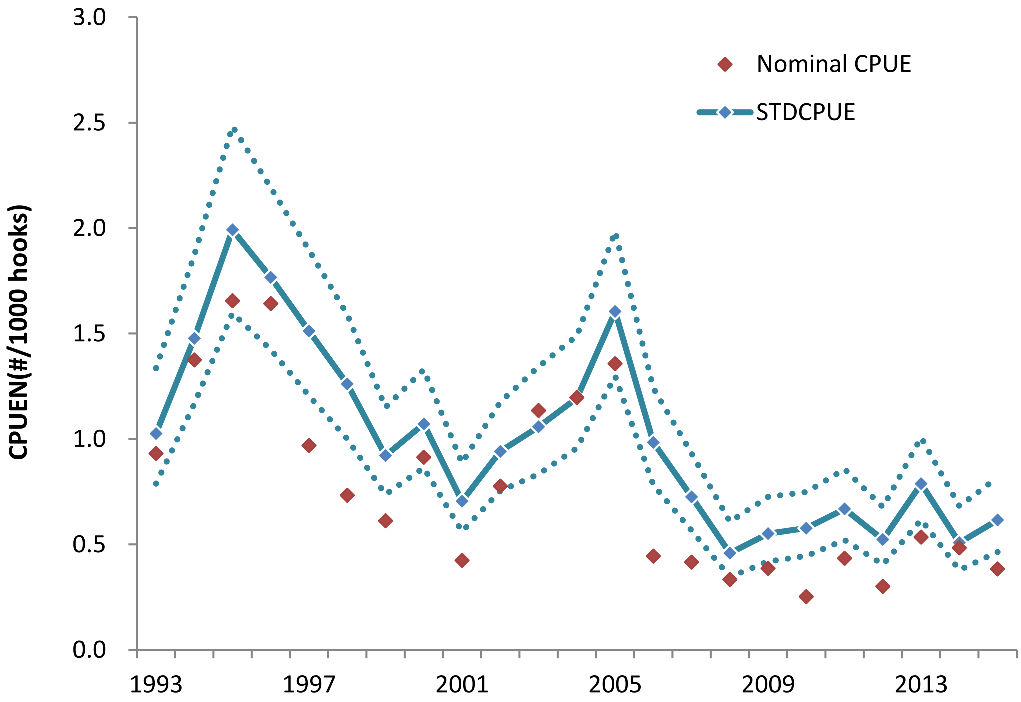


Figure 9. Nominal and standardized CPUE in number and weight from 1993-2015 for Model 2.