SCRS/2016/102 Collect. Vol. Sci. Pap. ICCAT, 73(5): 1824-1839 (2017)

CPUE STANDARDIZATION OF SAILFISH (*ISTIOPHORUS PLATYPTERUS*) FOR THE CHINESE TAIPEI DISTANT-WATER LONGLINE FISHERY IN THE ATLANTIC OCEAN

Nan-Jay Su[1] and Chi-Lu Sun[2]

SUMMARY

*Catch and effort data of sailfish (*Istiophorus platypterus*) were collected and analyzed for the Taiwanese distant-water tuna longline fishery in the Atlantic Ocean. Nominal CPUE based on catch records in logbooks or that estimated using catch ratio of sailfish over the two species (sailfish and spearfish* Tetrapturus pfluegeri*) were standardized using generalized linear models (GLMs). Two separate eastern and western stocks of sailfish were considered in the analysis, with information on operation type (i.e. hooks per basket) being included as a potential effect. Relative abundance indices showed similar and consistent trends for the two assumed scenarios on catch data. The standardized CPUE of eastern Atlantic sailfish increased from 2009 to a higher level but then dropped in recent two years (2014-2015), while for the western stock the CPUE showed a decreasing trend during 2010 and 2014, with a slightly increase in 2015.*

RÉSUMÉ

*Les données de prise et d'effort du voilier (*Istiophorus platypterus*) ont été recueillies et analysées pour la pêcherie thonière palangrière du Taipei chinois opérant en eaux lointaines dans l'océan Atlantique. Les CPUE nominales fondées sur les registres de capture des carnets de pêche, ou celle estimée au moyen du ratio de capture des deux espèces (voilier et* Tetrapturus pfluegeri), *ont été standardisées au moyen de modèles linéaires généralisés (GLM). Deux stocks de voiliers distincts, Est et Ouest, ont été pris en compte dans l'analyse, l'information sur le type d'opération (p. ex. hameçons par panier) ayant été incluse comme un effet potentiel. Les indices d'abondance relative ont montré des tendances similaires et constantes pour les deux scénarios postulés sur les données de capture. La CPUE standardisée des voiliers de l'Atlantique Est a augmenté à partir de 2009, atteignant un niveau supérieur pour ensuite chuter au cours de ces deux dernières années (2014-2015), tandis que pour le stock de l'Ouest, la CPUE a dégagé une tendance à la baisse entre 2010 et 2014, avec une légère augmentation en 2015.*

RESUMEN

Datos de captura y esfuerzo de pez vela (Istiophorus platypterus) fueron recogidos y analizados para la pesquería de palangre de atún de aguas distantes de Taipei Chino en el océano Atlántico. La CPUE nominal basada en los registros de captura de los cuadernos de pesca o estimada usando la proporción de captura de pez vela para las dos especies (pez vela y Tetrapturus pfluegeri) se estandarizó utilizando modelos lineales generalizados (GLM). En el análisis se consideraron dos stocks separados de pez vela, oriental y occidental, y se incluyó la información sobre el tipo de operación (es decir, anzuelos por cesta) como un efecto potencial. Los índices de abundancia relativa mostraban tendencias similares y coherentes para los dos escenarios sobre datos de captura. La CPUE estandarizada del pez vela del Atlántico oriental aumentaba desde 2009 hasta un mayor nivel y posteriormente caía en los dos años recientes (2014-2015), mientras que para el stock occidental, la CPUE mostraba una tendencia descendente entre 2010 y 2014 con un ligero aumento en 2015.

KEYWORDS

CPUE standardization, abundance index, sailfish, longline, GLM

---

[1] Department of Environmental Biology and Fisheries Science, National Taiwan Ocean University, Keelung, 20224, Taiwan
[2] Center of Excellence for the Oceans, National Taiwan Ocean University, Keelung, 20224 Taiwan. Email: nanjay@ntou.edu.tw

1. Introduction

Sailfish (*Istiophorus platypterus* Shaw and Nodder 1792) are apex predators widely distributed in tropical and temperate waters of the three oceans (Kitchell *et al*. 2006). They are opportunistic foragers in pelagic marine ecosystems, and abundance, density and spatial distribution of their prey items change in different foraging habitats (Rosas-Alayola *et al*. 2002). This species is critically important in a number of tropical and subtropical fisheries (Chiang *et al*. 2004), and is primarily targeted by offshore and coastal set net, gill net, longline and harpoon fleets, and also retained in pelagic distant-water longline fisheries (Tsai *et al*. 2015).

Based on data from longline catches, the spatial distribution in latitude is approximately 40°N to 50°N in the North Atlantic, and from 32°S to 40°S in the South Atlantic (Nakamura 1985). Compared to other billfishes, sailfish typically occur near continental shelves, insular coasts, and reefs (Brinson *et al*. 2006). Studies have indicated that sailfish spend most of their time in the upper layers of warm water above the thermocline where temperatures range between 21°C and 28°C, although they are also capable of descending to rather deep water (Hoolihan *et al*. 2011). This species is considered the least oceanic of the Atlantic billfishes, and is currently managed as separate eastern and western stocks in the Atlantic Ocean (ICCAT 2009).

Estimates of catch for sailfish are likely less reliable than those for tunas because a greater fraction of the catch is taken in small scale artificial and recreational fisheries, which tend to be less well reported and sampled than commercial fisheries (ICCAT 2014). Compared to rockfishes, species identification is much less of a problem for billfishes. There are, however, still problems constructing catch series for the Atlantic sailfish and spearfish (*Tetrapturus pfluegeri* Robins and de Sylva 1963) because catch data for these two species are often recorded together and because spearfish are hard to identify from white marlin sometimes (Beerkircher *et al*. 2009). Catch data of sailfish and spearfish are therefore needed to be reviewed before being included in assessment models.

Standardization for catch rates have been carried out for the Chinese Taipei distant-water longline fleets in the Atlantic Ocean in several previous studies. For example, catch and effort data of this fishery were standardized based on generalized linear models (GLMs) assuming a delta lognormal error distribution (Chang *et al*. 2007), and based on both GLMs and GAMs (generalized additive models) with a lognormal error distribution (Sun *et al*. 2010). However, most of these studies focused on tunas, marlins, swordfish, and not sailfish.

The objectives of this study were to assess how the estimates of catch based on different sources might influence the sailfish catch rates for the Chinese Taipei distant-water longline fishery in the Atlantic Ocean by conducting the analysis for two catch series, and to examine how sensitive the factor is to the choice of model construction such as the inclusion of gear configuration and area separation when standardizing catch and effort data of this fishery for sailfish. The relative abundance index of sailfish developed from this study could be used as input data in the assessments, and provide implicative suggestions for management.

2. Materials and methods

2.1 Fishery data

Catch and effort data, expressed as the number of fish caught and the number of hooks employed, respectively, were collected from the Chinese Taipei distant-water tuna longline fishery in the Atlantic Ocean, and compiled by the Overseas Fisheries Development Council (OFDC, Taipei). This data set consists of catch information for tuna species such as albacore (*Thunnus alalunga*), bigeye (*T. obesus*), and yellowfin tuna (*T. albacares*). Billfishes including swordfish (*Xiphias gladius*) and sharks are also captured by this fishery. We focus in current study on the analyses of sailfish and spearfish catch data series.

This data set contains information on time (year and month), fishing location (latitude and longitude in 5º), catch in number of fish caught, and the fishing effort in number of hooks. However, information on gear configuration (*i.e*. number of hooks per basket, HPB) is available from daily logbook data since 1995, and was aggregated into monthly 5°×5° grids and included as a predictor variable in the standardization models. CPUE (catch per unit of effort) of sailfish is expressed as the number of fish caught per 1000 hooks in this study.

2.2 Catch ratio over sailfish and spearfish

Catch in number of sailfish and spearfish have been observed and reported in logbooks for the Chinese Taipei distant-water longline fleets in the Atlantic Ocean since 2009. Observed catch data were used to estimate the catch ratio of sailfish over the two species (sailfish and spearfish) in each region. The regions were divided based on the spatial distribution of sailfish CPUE. The regional catch ratio was then used to separate the sailfish catch from the spearfish, which is defined as follows:

Catch ratio for sailfish = SAI/(SAI+SPF),

where SAI and SPF are catch in number summed over the region for sailfish and spearfish, respectively.

2.3 Statistical models

Generalized linear models (GLMs; Nelder and Wedderburn 1972), assuming a lognormal error distribution, were applied to standardize the catch and effort data of the Chinese Taipei distant-water longline fishery for sailfish. GLMs are the most commonly used approach for standardizing fishery data with the assumption that the expected value of a log-transformed response variable is related to a linear combination of multiple exploratory variables (Maunder and Punt 2004). Time (year and month), operation location (latitude, longitude and the interaction between the two effects), and gear configuration (*i.e.* HPB) were included in the GLMs as main explanatory variables. The full GLM with interactions can be expressed as follows:

CPUE ~ Year + Month + Latitude + Longitude + Latitude:Longitude + HPB,

where CPUE is the nominal CPUE of sailfish based on observed catch in logbooks or estimated catch from the regional catch ratio. To avoid taking the logarithm of zero, records with zero catch of sailfish were removed from the analyses. No interactions with the year effect were considered in the GLM analyses, while the effect of gear operation configuration (HPB) was included in the models because of their likely impacts on sailfish CPUE recognized in previous studies (Sun *et al*. 2014).

Alternative diagnostic analyses, *e.g*. the distributions of residuals and the quantile-quantile (Q-Q) plots, were used to examine the error models (assuming a lognormal distribution) in the GLM analyses. Standard methods, such as changes in residual deviance, the χ^2 tests, and the Akaike Information Criterion (AIC) were also used to compare alternative model structures of the GLMs. Relative abundance indices of sailfish were developed using least-square means (LS means) for the year effect. The LS means are marginal means over a balanced population predicted from a linear model at combinations of specified factors.

3. Results and discussion

There were in total 7,398 catch and effort records (aggregated to 5º spatial grid) for 2009-2015, with information on gear configuration (HPB) included in the analyses. Catches of sailfish from this fishery were high in early period (around 1970), while the catches were around 100 mt during the late 1990s and early 2000s and showed a decreasing trend in recent 5 years (**Figure 1**). The main fishing ground of the Chinese Taipei tuna longline fishery was in the central North Atlantic Ocean before 1990, but shifted to tropical waters of the Atlantic Ocean thereafter (**Figure 2**), due to the targeting changed from albacore to bigeye tuna (Sun *et al*. 2014).

For the Chinese Taipei longline fleets, most of the sailfish was caught generally in tropical waters of the central Atlantic Ocean (upper panel in **Figure 3**), suggesting that spatial covariates are likely to be an important factor in determining catchability of the Chinese Taipei longline fishery for this species, while the spearfish seem to inhabit open waters of the Atlantic Ocean (lower panel in **Figure 3**). The catch ratios of sailfish over the two species were summarized in **Table 1** for each region (see the regions in **Figure 4**.), and then the ratios were used to estimate the catch series by grid for sailfish. For comparison, spatial distributions of observed and estimated catch of sailfish were plotted in **Figure 4**, which showed much similar patterns on spatial distribution.

The deviance tables summarized the model selection process of the GLM analyses for the observed (**Table 2**) and the estimated catch of sailfish (**Table 3**) in the Atlantic, and those for the eastern and western stocks. Most of the main effects (explanatory variables and the interaction terms) considered in the standardization models were statistically significant ($P < 0.01$), except for month and longitude in the standardization for the western stock. The distributions of residuals for both observed and estimated catch data of sailfish appeared to be normal in a log-scale for all GLM analyses based on a lognormal error distribution (**Figure 5**). This assumption was further confirmed according to the Q-Q plots (**Figure 6**).

Effects of year, latitude and HPB in the GLM accounted for the largest proportions of the explained deviance of the models for the Atlantic Ocean and the eastern and western stocks, with r^2 ranging from 0.348 to 0.438 (**Table 2**). Similar results were found when the estimated catch of sailfish was used in the CPUE standardization (**Table 3**). The effect of gear configuration was also statistically significant in the GLM analysis, which might imply that the inclusion of this factor could capture much of the potential change in the development of deep longline operations that shifted to target bigeye tuna in tropical areas of the Atlantic Ocean.

The AIC values also indicated that the full models provided best fits to the data. Note that r^2 values increased 9% and 3% with the inclusion of gear configuration in the models for the observed sailfish catch (**Table 2**) and the estimated catch of sailfish, respectively (**Table 3**). We therefore suggest that the relative abundance index for sailfish in the eastern and western Atlantic Ocean should be developed base on the best models that incorporate this covariate (HPB), as well as the spatial factors *i.e*. latitude and longitude and their interaction, in the CPUE standardization for Atlantic sailfish.

In general, the standardized CPUE of sailfish in the eastern Atlantic Ocean showed an increasing trend during 2010 and 2013, but decreased to a lower level in 2014, followed by a slight increase in 2015. However, the trend of standardized sailfish catch rates decreased continuously from 2010 to 2014, with a slightly higher estimate in the recent year of 2015 (**Figure 7** and **Table 4**). As demonstrated in **Figure 8**, the trends of standardized CPUE for sailfish observed catch data from the logbooks and the estimated catch data based regional catch ratios showed similar and consistent patterns between the two catch data sources, suggesting that the catch ratio of sailfish has the potential to be used as a proxy to rebuild the catch series of sailfish in the early period where catch data of sailfish were reported with spearfish together. However, a finer region stratification to separate the sailfish catch from the spearfish might be considered in further analysis.

References

Beerkircher, L., Arocha, F., Barse, A., Prince, E., Restrepo, V., Serafy, J., Shivji, M. 2009. Effects of species misidentification on population assessment of overfished white marlin *Tetrapturus albidus* and roundscale spearfish *T. georgii*. Endang. Species Res. 9: 81-90.

Brinson, A.A., Alcala, A., Die, D.J., Shivlani, M. 2006. Contrasting socioeconomic indicators for two fisheries that target Atlantic billfish: southeast Florida recreational charter boats and Venezuelan artisanal gill-netters. Bull. Mar. Sci. 79: 635-645.

Chiang, W.C., Sun, C.L., Yeh, S.Z., Su, W.C. 2004. Age and growth of the sailfish (*Istiophorus platypterus*) in waters off eastern Taiwan. Fish. Bull. 102: 251-263.

Chang, S.K., Lee, H.H., Liu, H.I. 2007. Standardization of South Atlantic swordfish by-catch rate for Chinese Taipei longline fleet. Col. Vol. Sci. Pap. ICCAT 60: 1974-1985.

Hoolihan, J.P., Luo, J. Goodyear, C.P., Orbesen, E.S., Prince, E.D. 2011. Vertical habitat use of sailfish (*Istiophorus platypterus*) in the Atlantic and eastern Pacific, derived from pop-up satellite archival tag data. Fish. Oceanogr. 20: 192-205.

ICCAT 2009. Report of the 2009 sailfish assessment. SCRS/2009/012 – Sailfish Assessment, SCI-030/2009. 1-5 June 2009, Recife, Brazil. 87 pp.

ICCAT 2014. Billfish Species Group Meeting. Inter-sessional Meeting of the Billfish Species Group, ICCAT. 2-6 June 2014, Veracruz, Mexico. 46 pp.

Kitchell, J.F., Martell, S.J.D., Walters, C.J., Jensen, O.P., Kaplan, I.C., Watters, J.R., Essington, T.E., Boggs, C.H. 2006. Billfishes in an ecosystem context. Bull. Mar. Sci. 79: 669-682.

Nakamura, I. 1985. FAO species catalogue. Billfish of the world. An annotated and illustrated catalogue of marlins, sailfishes, spearfishes, and swordfishes known to date. FAO Fish. Synop. 125(5), 65 pp.

Maunder, M.N., Punt, A.E. 2004. Standardizing catch and effort data: a review of recent approaches. Fish. Res. 70: 141-159.

Nelder, J.A., Wedderburn, R.W.M. 1972. Generalised linear models. J. R. Statist. Soc. A 137: 370-384.

Rosas-Alayola, J., Hernández-Herrera, A., Galván-Magãna, F., Abitia-Cárdenas, L.A., Muhlia-Melo, A.F. 2002. Diet composition of sailfish (*Istiophorus platypterus*) from the southern Gulf of California, Mexico. Fish. Res. 57: 185-195.

Sun, C.L., Su, N.J., Yeh, S.Z. 2010. Standardized catch-rates of swordfish (*Xiphias gladius*) for the Chinese Taipei tuna longline fleet in the North Atlantic Ocean. Col. Vol. Sci. Pap. ICCAT 65: 264-273.

Sun, C.L., Su, N.J., Yeh, S.Z. 2014. Updated standardized CPUE of swordfish (*Xiphias gladius*) for the Chinese Taipei longline fishery in the North Atlantic Ocean, 1968-2011. Col. Vol. Sci. Pap. ICCAT 70: 1711-1720.

Tsai, C.N., Chiang, W.C., Sun, C.L., Shao, K.T., Chen, S.Y., Yeh, S.Z. 2015. Stomach content and stable isotope analysis of sailfish (*Istiophorus platypterus*) diet in eastern Taiwan waters. Fish. Res. 166: 39-46.

Table 1. Catch in number of sailfish and spearfish and the ratio of sailfish over the two species for the Chinese Taipei distant-water longline fishery in the eastern and western Atlantic Ocean (see the regions in the maps of **Figure 4**).

Region	SAI	SPF	Ratio	Region	SAI	SPF	Ratio
West1	333	262	0.560	East1	131	74	0.639
West2	72	46	0.610	East2	3588	241	0.937
West3	2199	2452	0.473	East3	5834	1012	0.852
West4	96	656	0.128	East4	330	1664	0.165

SAI: sailfish; SPF: spearfish; catch ratio = SAI/(SAI+SPF)

Table 2. Deviance tables for the models selected to standardize the catch rate of sailfish (observed catch in the logbooks) for the Chinese Taipei distant-water longline fishery in the Atlantic Ocean.

(a) Atlantic Ocean

	Res.DF	Res.Dev	DF	Dev.Exp	*P*-value	AIC
NULL	1363	2221				4540
+Year	1357	2171	6	49.8	<0.01	4521
+Month	1346	2080	11	91.2	<0.01	4484
+Lat	1332	1928	14	151.6	<0.01	4409
+Lon	1315	1892	17	35.8	0.02	4417
+Lat:Lon	1254	1657	61	235.0	<0.01	4359
+HPB	1243	1448	11	209.7	<0.01	4196

$r^2 = 0.348$

(b) Eastern Atlantic

	Res.DF	Res.Dev	DF	Dev.Exp	P-value	AIC
NULL	1064	1748				3554
+Year	1058	1712	6	35.5	<0.01	3544
+Month	1047	1583	11	129.6	<0.01	3482
+Lat	1033	1473	14	109.1	<0.01	3434
+Lon	1023	1405	10	68.5	<0.01	3403
+Lat:Lon	992	1305	31	100.4	<0.01	3386
+HPB	981	1139	11	165.8	<0.01	3264

$r^2 = 0.348$

(c) Western Atlantic

	Res.DF	Res.Dev	DF	Dev.Exp	P-value	AIC
NULL	298	464				984
+Year	292	425	6	38.9	<0.01	970
+Month	281	407	11	18.0	0.14	979
+Lat	270	358	11	48.3	<0.01	963
+Lon	262	350	8	8.0	0.51	972
+Lat:Lon	245	312	17	38.8	<0.01	971
+HPB	235	260	10	51.1	<0.01	937

$r^2 = 0.438$

Table 3. Deviance tables for the models selected to standardize the catch rate of sailfish (estimated catch based on the ratio of sailfish) for the Chinese Taipei distant-water longline fishery in the Atlantic Ocean.

(a) Atlantic Ocean

	Res.DF	Res.Dev	DF	Dev.Exp	*P*-value	AIC
NULL	1592	2725				5380
+Year	1586	2678	6	46.8	<0.01	5364
+Month	1575	2635	11	42.7	<0.01	5361
+Lat	1560	2180	15	455.9	<0.01	5088
+Lon	1543	2097	17	82.1	<0.01	5061
+Lat:Lon	1450	1827	93	270.3	<0.01	5027
+HPB	1439	1643	11	184.1	<0.01	4880
		$r^2 = 0.397$				

(b) Eastern Atlantic

	Res.DF	Res.Dev	DF	Dev.Exp	P-value	AIC
NULL	1209	2059				4081
+Year	1203	2031	6	28.6	<0.01	4076
+Month	1192	1961	11	69.7	<0.01	4056
+Lat	1178	1617	14	343.6	<0.01	3851
+Lon	1168	1535	10	82.5	<0.01	3808
+Lat:Lon	1125	1398	43	136.5	<0.01	3781
+HPB	1114	1253	11	145.4	<0.01	3670
		$r^2 = 0.392$				

(c) Western Atlantic

	Res.DF	Res.Dev	DF	Dev.Exp	P-value	AIC
NULL	382	663				1301
+Year	376	591	6	72.1	<0.01	1269
+Month	365	570	11	21.3	0.06	1277
+Lat	350	457	15	112.8	<0.01	1223
+Lon	340	446	10	10.6	0.47	1234
+Lat:Lon	308	396	32	50.2	0.07	1252
+HPB	298	326	10	70.1	<0.01	1197
		$r^2 = 0.508$				

Table 4. Standardized CPUE and CV of sailfish caught in the Chinese Taipei distant-water longline fishery in the Atlantic Ocean based on the catch observed in logbooks and estimated using regional ratios of sailfish.

(a) Eastern Atlantic

	SAI observed		SAI estimated	
Year	CPUE	CV	CPUE	CV
2009	0.054	19.908	0.054	8.555
2010	0.044	20.092	0.050	8.439
2011	0.055	19.356	0.056	8.323
2012	0.097	18.842	0.078	8.742
2013	0.118	20.852	0.090	10.388
2014	0.050	21.082	0.056	9.415
2015	0.052	20.571	0.065	9.239

(b) Western Atlantic

	SAI observed		SAI estimated	
Year	CPUE	CV	CPUE	CV
2009	0.076	25.882	0.054	13.705
2010	0.162	27.598	0.083	17.438
2011	0.121	25.304	0.068	14.653
2012	0.138	25.187	0.086	16.409
2013	0.091	25.866	0.058	14.003
2014	0.013	27.037	0.027	9.069
2015	0.057	24.730	0.061	13.986

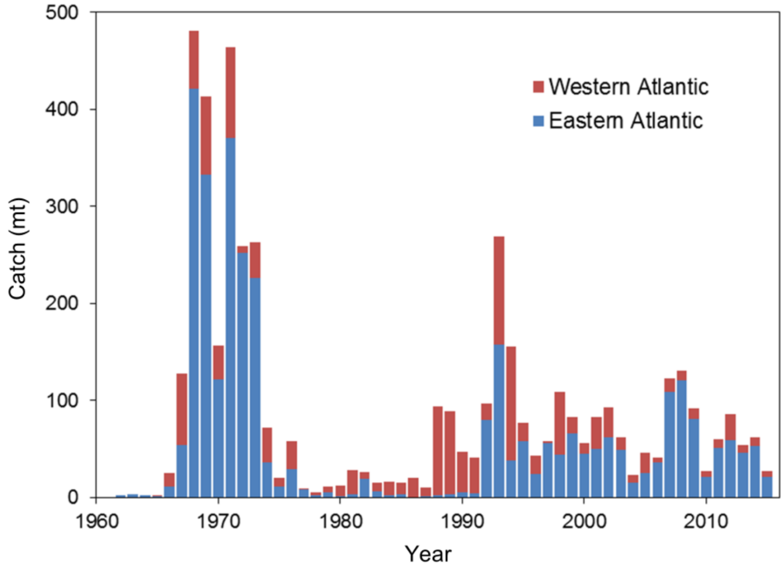

Figure 1. Annual catches of sailfish for the Chinese Taipei distant-water longline fishery in the eastern and western Atlantic Ocean for 1962-2015.

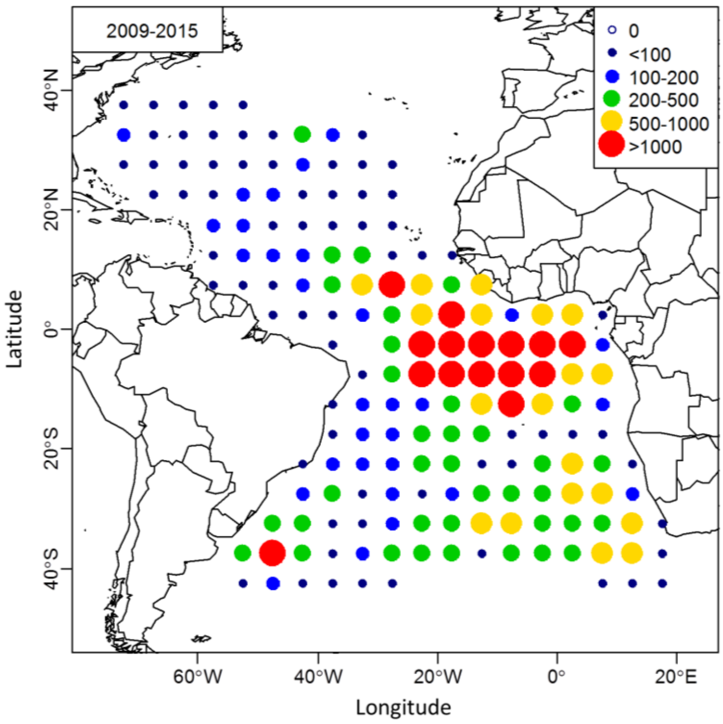

Figure 2. Distribution of fishing effort (in 1000 hooks) for the Chinese Taipei distant-water longline fishery in the Atlantic Ocean averaged over 2009-2015.

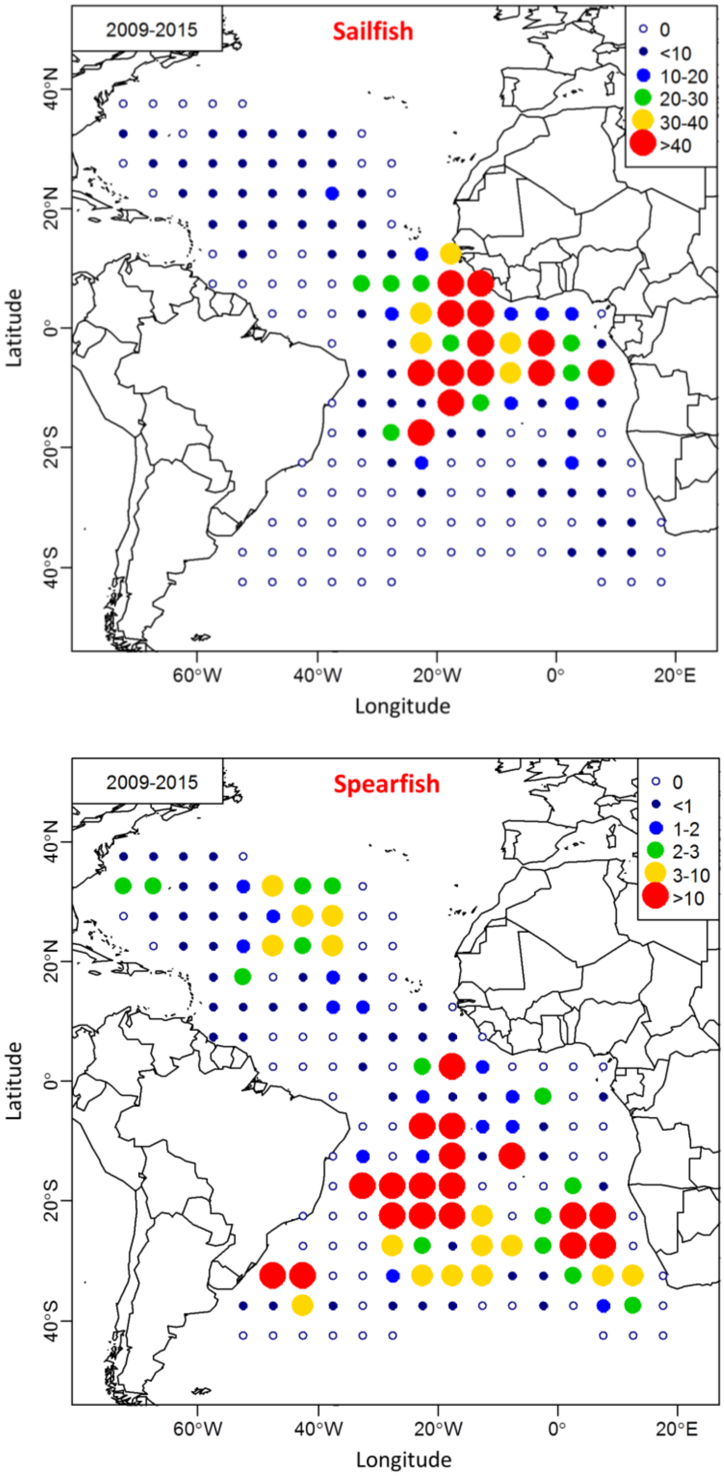

Figure 3. Catch in number of sailfish and spearfish caught in the Chinese Taipei distant-water longline fishery in the Atlantic Ocean averaged over 2009-2015.

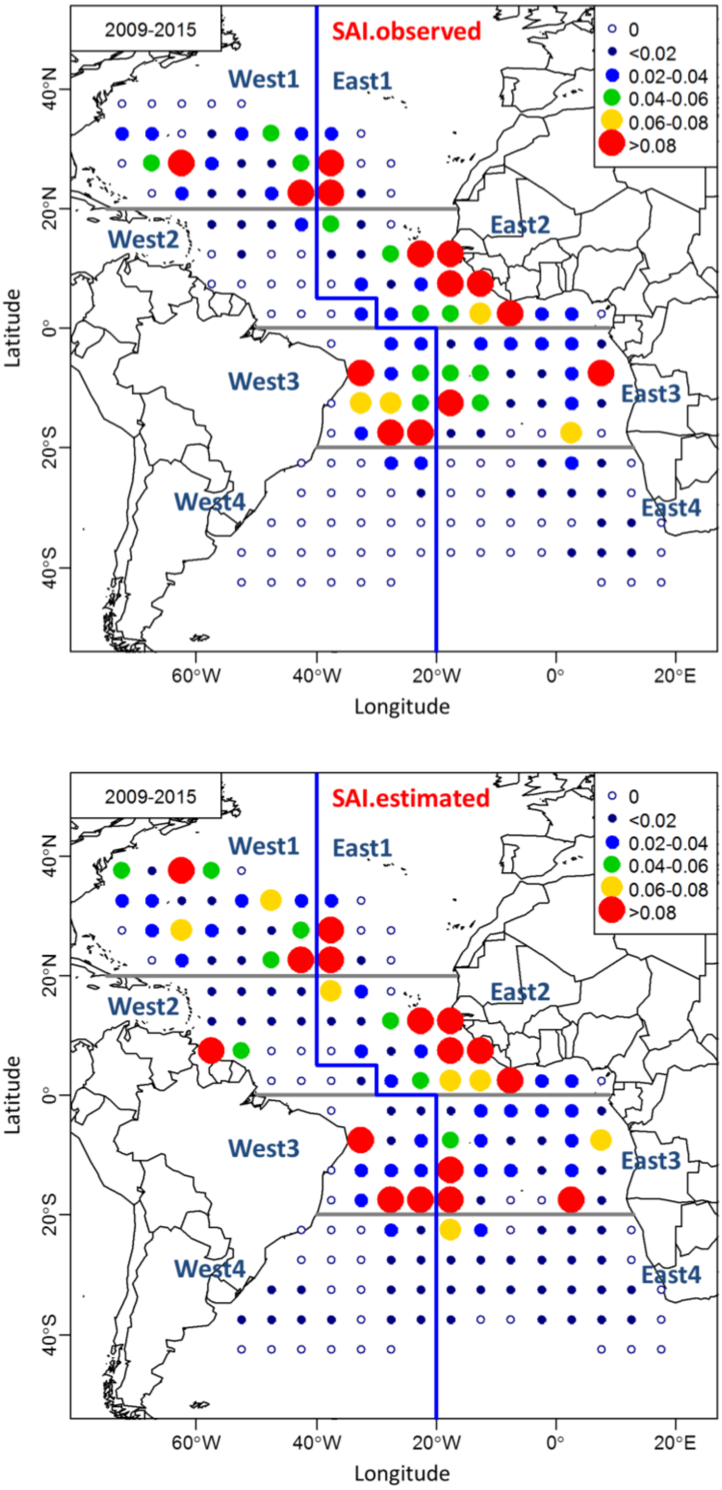

Figure 4. Nominal CPUE (number of fish caught per 1000 hooks) of sailfish based on the observed catch in logbooks (upper panel) and the estimated catch using regional catch ratios of sailfish in **Table 1** (lower panel) for the Chinese Taipei distant-water longline fishery in the Atlantic Ocean over 2009-2015.

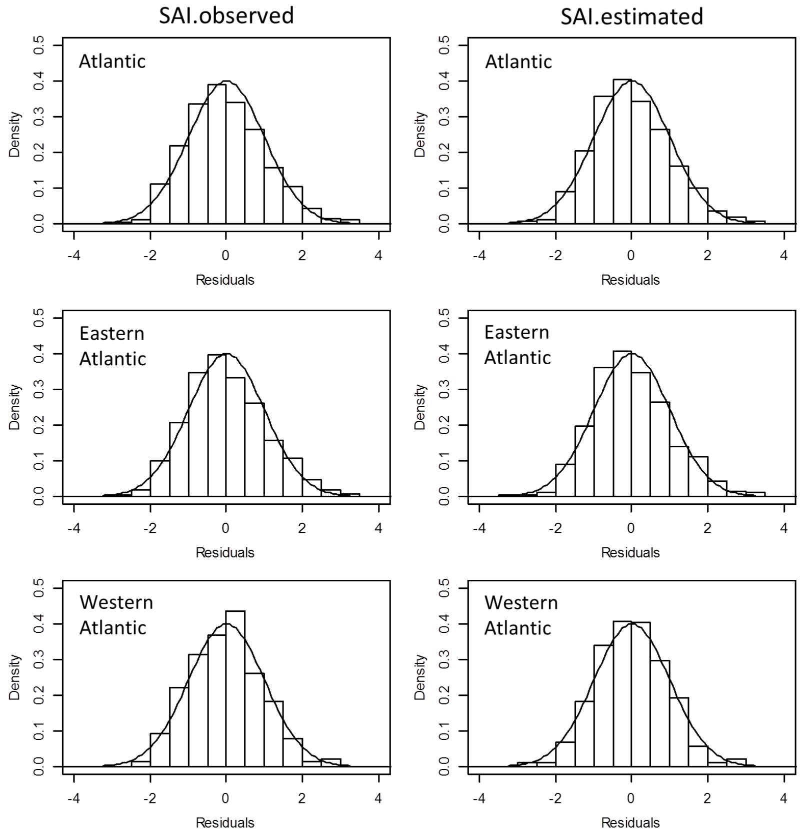

Figure 5. Residual distributions for the models selected to standardize catch rates for the observed catch in logbooks (left panels) and the estimated catch based catch ratio (right panels) of sailfish caught in the Chinese Taipei distant-water longline fishery in the Atlantic Ocean.

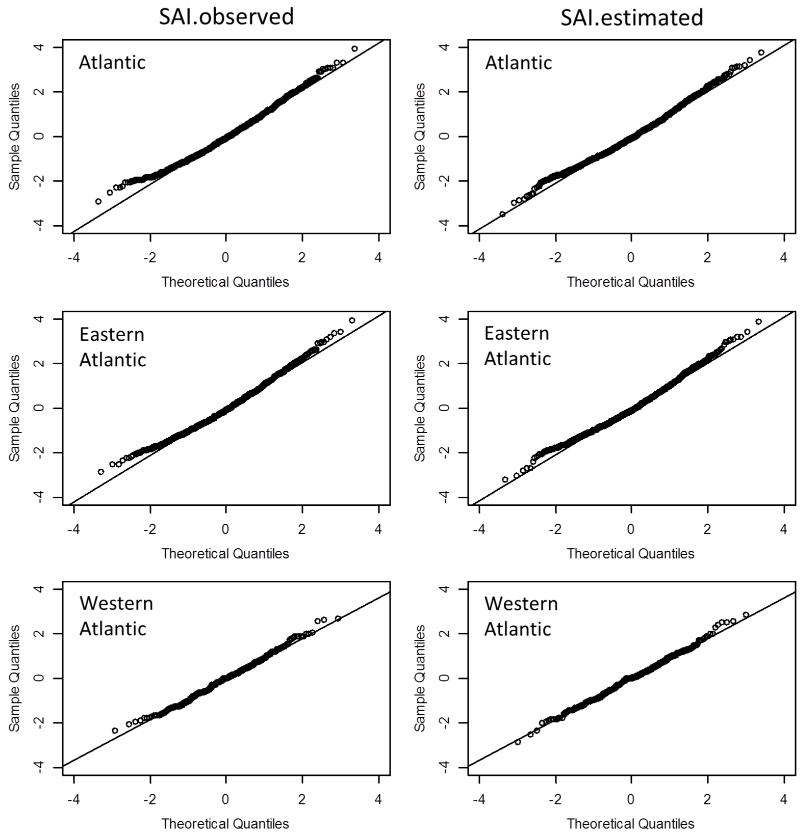

Figure 6. Diagnostic Q-Q plots for the models selected to standardize catch rates for the observed catch in logbooks (left panels) and the estimated catch based on catch ratio (right panels) of sailfish caught in the Chinese Taipei distant-water longline fishery in the Atlantic Ocean.

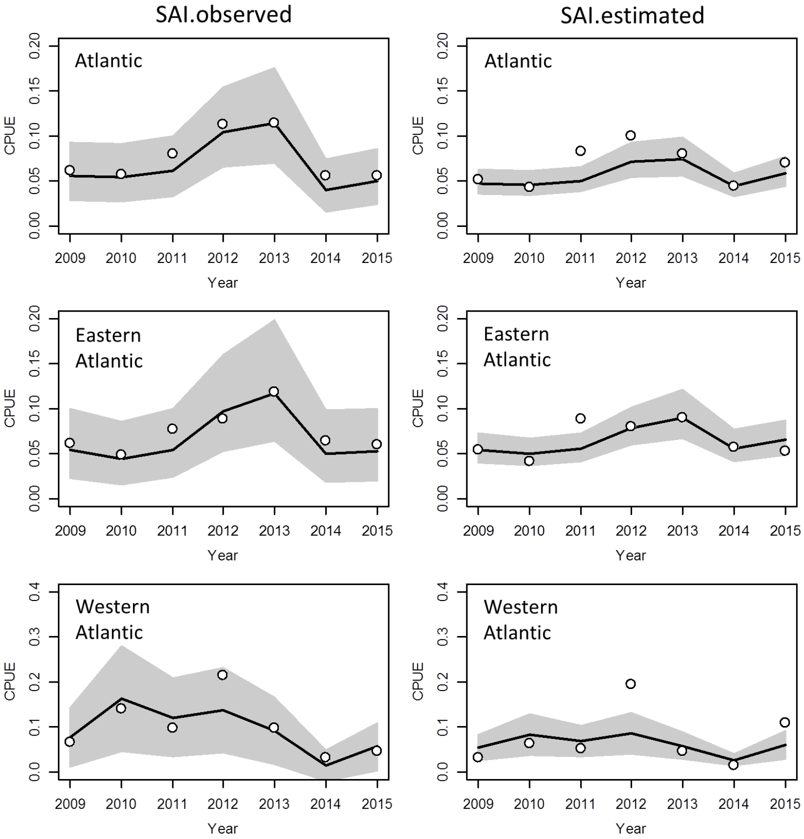

Figure 7. Nominal (open circles) and standardized CPUE (solid lines) of sailfish for the observed catch in logbooks (left panels) and the estimated catch based on regional catch ratio of sailfish (right panels) caught in the Chinese Taipei distant-water longline fishery in the Atlantic Ocean. CPUE is expressed as the number of fish caught per 1000 hooks. Shadows indicate the point-wise standard error for the standardized CPUE of sailfish.

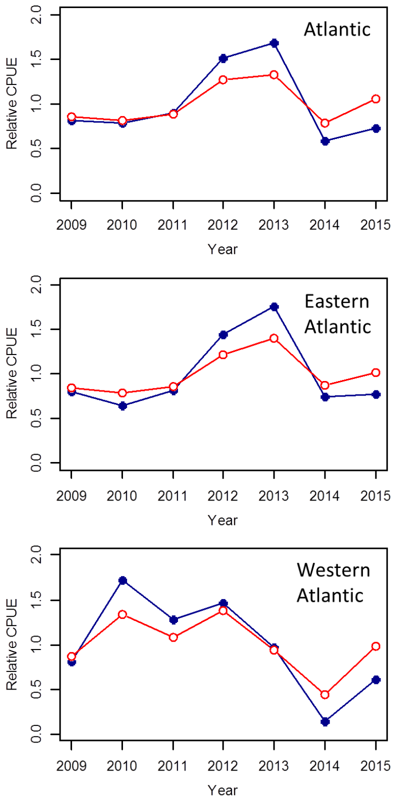

Figure 8. Comparison of standardized CPUE for sailfish based on observed catch in logbooks (solid points) and the estimated catch based on regional catch ratios of sailfish (open circles) for the Chinese Taipei distant-water longline fishery in the Atlantic Ocean.