Catch, length data and standardized CPUE of swordfish caught by the Taiwanese fisheries in North Pacific Ocean

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Abstract

In this working paper, catch data and length composition of swordfish exploited by Taiwanese fisheries in the western central North Pacific Ocean (WCNPO) from 1959 – 2021 and 2004 – 2021 were summarized, respectively. In addition, catch rates of swordfish collected by Taiwanese distant-water tuna fishery data were standardized using a Vector-Autoregressive Spatio-Temporal model with year, quarter, spatial, spatio-temporal, vessel, and HPB effects as explanatory variables. Results showed that the total catch was stable at around 1,800 mt after 2016, however, the catch of 2021 reached the lowest level over the recent 10 years. Size compositions of swordfish harvested by the Taiwanese distant-water longline fishery showed that the mean length was relatively stable around 165 cm LJFL during 2004 – 2021. Additionally, the standardized catch rate of the distant-water tuna longliner for the WCNPO swordfish has fluctuated overtime and recently increased from 2015 to 2021, except for 2019.

Introduction

Swordfish (*Xiphias gladius*) inhabit a wide region of the Pacific between the latitudes of 50˚N and 50˚S (Ward et al., 2000). Several stock structures have been proposed for Pacific swordfish (Alvarado Bremer et al., 2006; Ichinokawa and Brodziak, 2008). According to the latest stock assessment boundary based on new movement information from tagging studies (Sepulveda et al. 2020; BILLWG discussion summarized in ISC/21/ANNEX/08) for swordfish in western central North Pacific Ocean (WCNPO). We presented here the catch and length data of swordfish for the Taiwanese fisheries in the area of WCNPO and provided the standardized catch rate of swordfish caught by the Taiwanese distant-water longline fishery. In preparation for the next swordfish assessment in 2023, the updated available fishery

data and standardized abundance indices of swordfish derived from this study could provide basic, necessary input data for the stock assessment.

Materials and methods

Fishery data

Catch data of swordfish, provided by the Oversea Fisheries Development Council (OFDC) of Taiwan was grouped into the two fishery classifications: distant-water tuna longline (DWLL) and small-scale tuna longline (STLL). Time-series of the catch data were summarized during 1959 – 2021. Vessels equal to or larger than 100 GRT were classified as DWLL fishing vessels, and vessels with GRT smaller than 100 (mostly 50 -70) were classified as STLL fishing vessels. Lower jaw fork length (LJFL) data (in cm) of swordfish collected from the Taiwanese DWLL fishery in the WCNPO was summarized using violin plot during 2004 – 2021.

Operational logbook data of Taiwanese DWLL in WCNPO during 1964 – 2021 was provided by OFDC, including time (year and month) and location (longitude and latitude by 5° by 5° grid), and hook per basket (HPB) information. Quarter was assigned to each data with definition as follows: January – March (quarter 1), April – June (quarter 2), July – September (quarter 3), and October – December (quarter 4). CPUE is expressed as the number of fish caught per 1,000 hooks in this study. This paper only presented standardizations of the DWLL dataset from 2000 – 2021, due to the better quality and quantity of the dataset (WCPFC-SC14-2018/ SA-WP-07).

CPUE standardization model

We adapted the *R* package VAST (https://github.com/James-Thorson-NOAA/VAST) developed by Thorson et al. (2015) for conducting the WCNPO swordfish standardization CPUE analysis. VAST uses Gaussian random fields to model spatial correlation and spatio-temporal autocorrelation with the Matérn covariance function (Thorson, 2019). Knots were defined through *k*-mean analysis and then used to estimate the correlation of spatial and spatio-temporal effects. The appropriate knot number for swordfish in WCNPO was explored and 100 was found to be the most appropriate as a further increase in numbers did not improve the outcome. VAST is a delta-generalized linear mixed model that calculates the probability distribution with two components:

Encounter rate component (binominal distribution):

$$\text{logit}(p_i)=\beta_1(t_1)+\omega_1(s_1)+\varepsilon_1(s_i,t_i)+\delta_1(v_i)+\sum_{k_1=1}^{n_{k_1}}\lambda_1(k_1)Q(i,k_1)$$

Positive catch rate component (lognormal distribution):

$$\log(q_i)=\beta_2(t_i)+\omega_2(s_i)+\varepsilon_2(s_i,t_i)+\delta_2(v_i)+\sum_{k_2=1}^{n_{k2}}\lambda_2(k_2)Q(i,k_2)$$

where, for each observation i, $\beta(t_i)$ denotes the fixed effect intercept of year t; $\omega(s_i)$ denotes the time-invariant spatial auto-correlated variation for knot s; $\varepsilon(s_i,t_i)$ denotes the time-varying spatial-temporal auto-correlated variation for knot s in year t; $\delta(v_i)$ denotes the random variation in catchability for vessel v; $Q(i,k)$ denotes the fixed effects for seasonal (i =1) and HPB (i = 2) effects ($n_{k1} = n_{k2}$ =2).

Derived standardized CPUE index

The area-weighted abundance, $d(t,q)$, of the WCNPO swordfish for year t and quarter q except for the vessel and HPB effects are estimated as follows (Grüss et al., 2019):

$$d(t,q)=\sum_{s=1}^{n_s}A(s)\times\text{logit}^{-1}\left(\beta_1(t)+\omega_1(s)+\varepsilon_1(s,t)+\lambda_1(q)\right)\times\exp\left(\beta_2(t)+\omega_2(s)+\varepsilon_2(s,t)+\lambda_2(q)\right)$$

where $\lambda(q)$ is the seasonal effect; $A(s)$ is the surface area (in km²) of knot s.

Annual standardized CPUEs of the WCNPO swordfish, $\hat{CPUE}(t)$, are computed from CPUE estimates for each year t and quarter q as described in Campbell (2015):

$$\hat{CPUE}(t)=\frac{1}{n_q}\sum_{q=1}^{n_q}d(t,q)$$

where n_q is the number of quarters (i.e., n_q = 4)

Model selection and diagnosis

We used Akaike Information Criterion (AIC; Akaike, 1973) to identify which model had greater support given available data. The final model was checked for

convergence, and diagnostics were run to evaluate the model fit. We also checked whether observed encounter frequencies for either low or high probability samples are within the 95% predictive interval for predicted encounter probability and visualize fit to residuals of catch-rates given encounters by using quantile-quantile probability plots (Q-Q plots).

Results and discussion

Catch and length composition data

Time-series catches of swordfish in the WNCPO caught by the fisheries of Taiwan were shown in **Table 1**. The majority of swordfish catch in WCNPO was bycaught by the offshore longline fishery (STLL). The catches fluctuated around 900 mt during 1959-1999, however the catches have increased since 2000 (**Fig. 1**). The catch during 2001-2009 was relatively stable at around 3,500 mt, but declined thereafter. The catch reached a peak of 4,175 mt in 2006 then dramatically decreased to 1,800 mt during 2013 – 2020. The catch of 2021 reached the lowest level over the recent 10 years. Length compositions of swordfish harvested by the Taiwanese distant-water longline fishery were shown in **Fig. 2**. The result indicated the mean lengths of measured fishes seem relatively stable at 165 cm during 2004 – 2021 (**Fig. 2 and Table 2**).

Relative abundance index

Spatial distributions of nominal WCNPO swordfish CPUEs for the Taiwanese distant-water longline (DWLL) fishery during 2000 – 2021 were shown in **Figures 3**. The convergence in optimization was confirmed for each VAST model if the Hessian matrix was positive, and the maximum gradient of each component was less than 0.0001 (**Table 3**). Based on the AIC values, the most parameterized model (i.e., the best model) was used to predict the catch rate index of the WCNPO swordfish (M-6; **Table 3**). The deviance explained value of the best model was 65%. Model diagnostics suggested the best model had good fits to the observed CPUEs between encounter rate (**Fig. 4a**) and positive catch rate models (**Fig. 4b**). Results indicated that the standardized catch rate of the DWLL for the WCNPO swordfish has fluctuated overtime, and recently increased from 2015 to 2021, except for 2019 (**Fig. 5**). Relative scale of standardized CPUEs and CVs were summarized in **Table 4**.

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Table 1. Catch estimates (mt) of swordfish caught by the fisheries of Taiwan in the western and central North Pacific Ocean (WCNPO) during 1959-2021. DWLL= distant-water longline; OSLL= offshore longline. Others = other fisheries.

Year	DWLL	STLL	Others	Year	DWLL	STLL	Others
1959	0	427	91	1991	16	1390	180
1960	0	520	127	1992	14	1473	243
1961	0	318	73	1993	54	1174	310
1962	0	494	62	1994	0	1155	219
1963	0	343	18	1995	46	1135	225
1964	0	358	10	1996	6	701	32
1965	0	331	27	1997	15	1358	61
1966	0	489	31	1998	20	1178	41
1967	0	646	35	1999	59	1385	61
1968	0	763	12	2000	86	3390	86
1969	0	843	7	2001	125	3813	91
1970	0	904	5	2002	209	3766	27
1971	0	992	3	2003	427	3425	11
1972	0	862	11	2004	600	3111	16
1973	0	860	119	2005	270	3431	26
1974	1	880	136	2006	265	3910	61
1975	29	899	153	2007	233	3748	26
1976	23	613	194	2008	234	3397	48
1977	36	542	141	2009	173	3157	121
1978	0	546	12	2010	246	2278	52
1979	6.9	661	33	2011	388	3040	78
1980	10	603	76	2012	292	2852	48
1981	1.4	656	25	2013	241	1499	11
1982	1	855	49	2014	149	2375	8
1983	0	783	166	2015	375	2345	8
1984	0	733	264	2016	514	1245	6
1985	0	566	259	2017	356	1546	0
1986	0	456	211	2018	521	1488	1
1987	2	1328	190	2019	365	1587	2
1988	0	777	263	2020	401	1358	3
1989	15.9	1491	38	2021	277	724	1
1990	79.1	1309	154				

Table 2. Summary of swordfish length data (LJFL, cm) collected by Taiwanese distant-water longline fishery in Western and Central North Pacific Ocean (WCNPO) from 2004-2021.

Year	Median	Mean	Minimum	Maximum	Sample size
2004	162	162.60	73	260	2578
2005	158	158.68	73	314	1554
2006	162	165.55	68	286	836
2007	159	161.42	63	296	1201
2008	157	160.18	60	295	1802
2009	155	156.91	70	265	1256
2010	163	164.27	79	292	2268
2011	165	165.06	60	299	2757
2012	167	165.08	70	272	2279
2013	165	166.69	70	296	1392
2014	165	167.96	102	286	860
2015	165	168.15	110	295	1732
2016	167	171.45	116	293	1926
2017	164	168.80	96	280	1565
2018	161	164.87	62	285	1933
2019	161	166.97	61	286	1871
2020	166	170.64	82	282	1034
2021	165	164.18	78	294	1021

Table 3. Model selection information for the VAST model of swordfish caught by Taiwanese distant-water longline fishery in the Western and Central North Pacific Ocean (WCNPO) during 2000 – 2021.

ID	Model structure	AIC	ΔAIC	Maximum gradient
M1	Year	120159	12268	<0.0001
M2	Year + Spatial	117353	9462	<0.0001
M3	Year + Spatial + Spatio-temporal	114016	6125	<0.0001
M4	Year + Spatial + Spatio-temporal + Vessel	113369	5478	<0.0001
M5	Year + Spatial + Spatio-temporal + Vessel + Quarter	110404	2513	<0.0001
M6	Year + Spatial + Spatio-temporal + Vessel + Quarter + HPB	107891	0	<0.0001

Table 4. Standardized relative CPUE (Std. CPUE) and CV for swordfish in the western central North Pacific Ocean (WCNPO) derived from Taiwanese distant-water longline fisheries (DWLL) from 2000 - 2021.

Year	Std.CPUE	CV
2000	0.59	0.21
2001	1.13	0.17
2002	1.43	0.15
2003	1.01	0.16
2004	1.12	0.14
2005	0.95	0.13
2006	0.69	0.13
2007	0.72	0.15
2008	0.56	0.15
2009	0.71	0.15
2010	0.72	0.15
2011	0.62	0.15
2012	0.84	0.15
2013	0.84	0.15
2014	0.79	0.16
2015	1.09	0.13
2016	1.08	0.14
2017	1.32	0.14
2018	1.68	0.12
2019	1.14	0.13
2020	1.42	0.12
2021	1.55	0.11

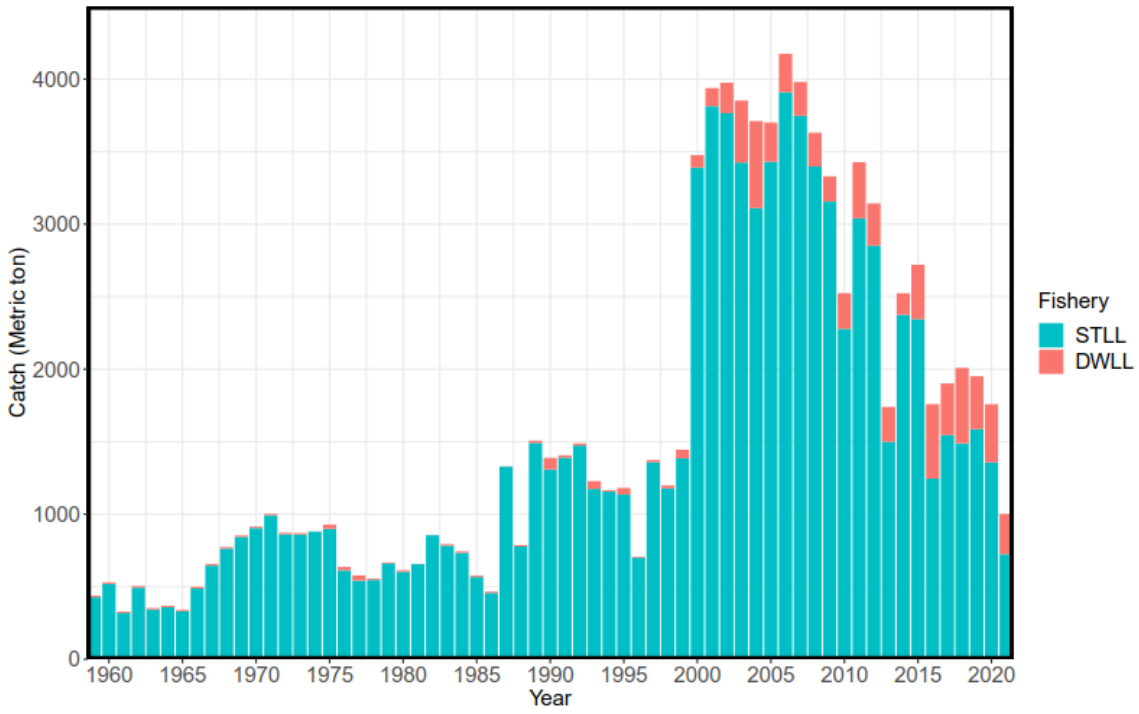

Figure 1. Time-series of swordfish catches caught by Taiwanese longline fisheries in the North Pacific Ocean (NPO) during 1995 - 2021.

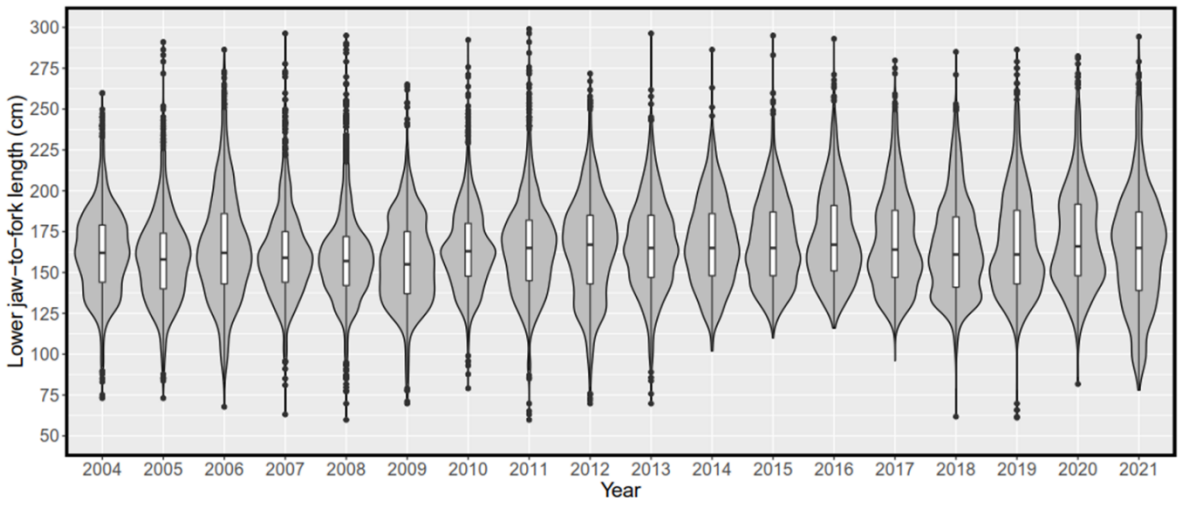

Figure 2. Length frequency distributions of swordfish caught by the Taiwanese distant-water longline fishery in the western central North Pacific Ocean (WCNPO).

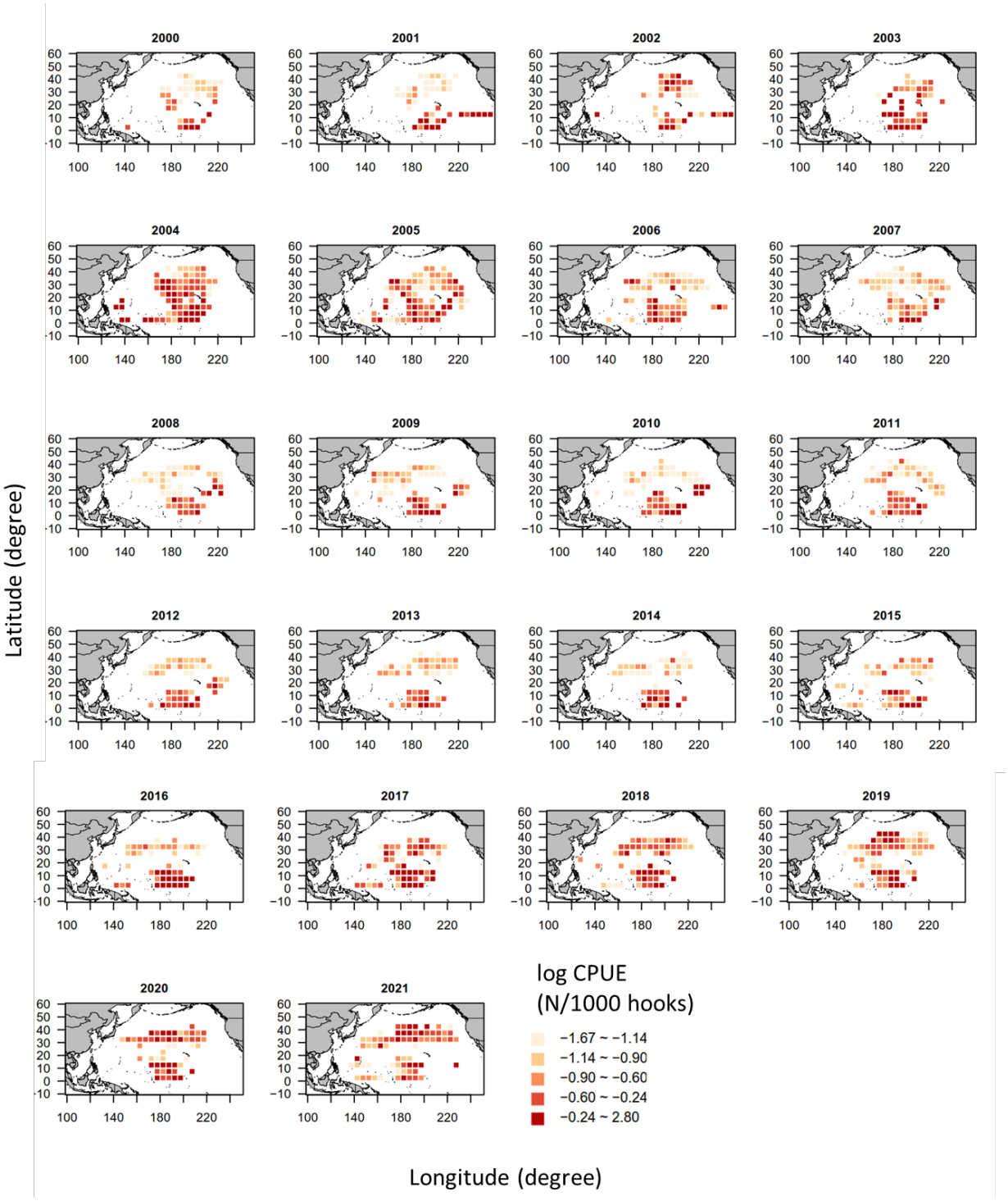

Figure 3. Spatial distribution of fishing effort and nominal swordfish catch-per-unit-effort (CPUE) of Taiwanese distant-water longline fishery (DWLL) in the western central North Pacific Ocean (WCNPO) during 2000 - 2021.

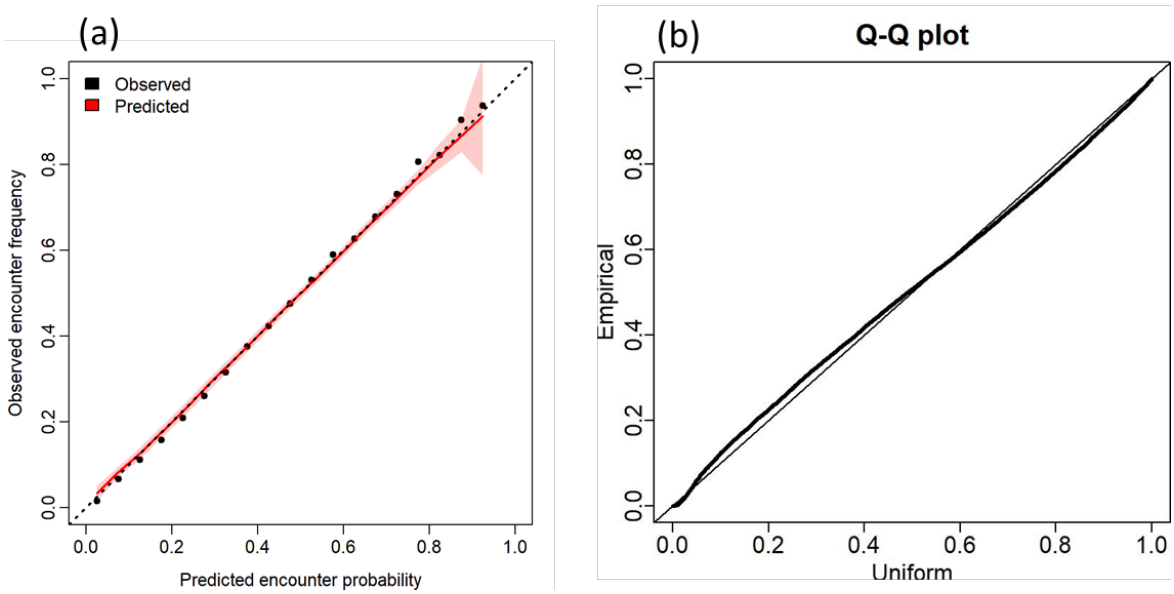

Figure 4. (a) observed (black points) and predicted (red shading) encounter probability and (b) normal Q-Q plot of positive catches component of Western and Central North Pacific Ocean (WCNPO) swordfish for Taiwanese distant-water tuna longliners (DWLL) during 2000 – 2021.

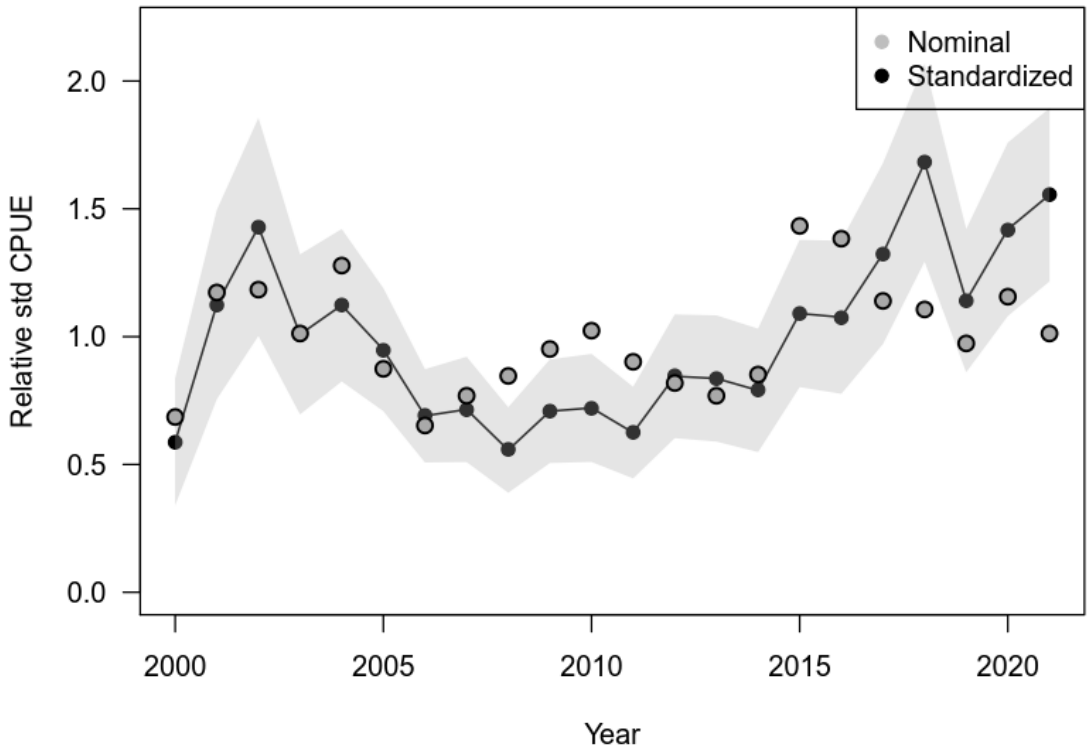

Figure 5. Relative scales (centered to mean) of the nominal and standardized indices for the Western and Central North Pacific Ocean (WCNPO) swordfish for the Taiwanese distant-water longline (DWLL) fishery during 2000 - 2021. Shaded area indicates the 95% confidence intervals.