ISC/22/ALBWG-02/07

Catch, length composition, and standardized CPUE of the North Pacific albacore caught by the Taiwanese distant-water longline fisheries in North Pacific Ocean from 1995 – 2021

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This working paper was submitted to the ISC Albacore Working Group Intercessional Workshop, 6-12 December 2022, held at the Fisheries Resources Institute, Japan Fisheries Research and Education Agency, Kanagawa, Japan.

Abstract

In this working paper, standardized catch rate data and length composition of albacore exploited by Taiwanese distant-water longliners (DWLL) in the North Pacific Ocean (NPO) from 1995 - 2021 were summarized. Catch data of the albacore caught by Taiwanese longliners in the NPO was also summarized. In addition, albacore-targeting fleets were identified using two-step cluster analysis based on their catch composition, and the fishing strategies between albacore-targeting fleets and non-albacore-targeting fleets were compared. Catch rates were standardized using a Vector-Autoregressive Spatio-Temporal model with year, quarter, vessel, targeting group, spatial, and spatio-temporal effects as explanatory variables. Results showed that the standardized catch rate of the albacore caught by Taiwanese DWLL fleets was relatively stable and has been fluctuating since 1999. Additionally, the length frequency distribution of NPO albacore caught by Taiwanese DWLL fleets during 1995 - 2021 indicated that after 2003, the length frequency distribution appeared to be more consistent, with the mean fork length value fluctuating around 85 cm.

Introduction

Taiwanese longline fishery operated in the North Pacific Ocean (NPO) mainly targeted albacore before 2000 that the fishing effort was concentrated in the temperate region of NPO (25°N - 45°N, 150°W - 180°W). However, an increasing trend of efforts in the tropical waters of NPO (0°N - 15°N, 140°E - 140°W), which were contributed by fleets targeting bigeye and yellowfin tuna, was observed after 2000 (Chen and Cheng, 2016; 2019). The shift of targeting species resulted in the decline of the nominal catch rate (CPUE; numbers/1,000 hooks) of NPO albacore since 2000.

In this study, we conducted a cluster analysis to distinguish the albacore targeted and non-albacore targeted fleets of the Taiwanese distant-water longliners (DWLL) based on species catch composition information in the logbook dataset (He et al., 1997). Vector-Autoregressive Spatio-Temporal Model (i.e., VAST; Thorson, 2019) was applied to standardize the catch rate of NPO albacore caught by DWLL, and the cluster results were also incorporated into the standardization process as an effect related to fishing strategy. We also summarized the length composition data of the NPO albacore caught by the DWLL. The standardized indices and length composition of NPO albacore would provide basic input data for future stock assessment.

Materials and methods

2.1 Fishery data

Daily operational logbook of Taiwanese longliners in the North Pacific Ocean (NPO) during 1995 - 2021 obtained from Oversea Fisheries Development Council (OFDC) was used in this study. In this study, CPUE is expressed as the number of fish caught per 1,000 hooks (N/1,000 hooks). Quarter was assigned to each input of the dataset with definitions as follows: January - March (quarter 1), April - June (quarter 2), July - September (quarter 3), and October - December (quarter 4). Fork length (cm) data of albacore caught by DWLL fishery in NPO (first 30 fishes caught each set) from 1995 - 2021 was also obtained from OFDC for summarizing the catch size composition.

2.2 Cluster analysis

Cluster analysis was used to categorize catch records by identifying similar species-composition groups in the DWLL dataset. Five species groups were used in this study, including albacore (ALB), bigeye tuna (BET), yellowfin tuna (YFT), swordfish (SWO), and other species (OTH). We applied the two-step clustering method described by He et al. (1997) to identify albacore-targeting and non-albacore-targeting fleets in NPO. First, a non-hierarchical cluster analysis (*k*-means method) was used to group all data into 10 clusters for taking the mixture of fishing operations into account (C_2^5=10 ways in which 2 species can be chosen from 5 species groups). Second, hierarchical cluster analysis with a complete-linkage agglomerative algorithm was conducted to classify 10 species groups. The 10 species groups were then regrouped into albacore-targeting and non-albacore-targeting cluster using a cluster dendrogram plot. Non-hierarchical and hierarchical cluster analyses were conducted using R functions *kmeans()* and *hclust()* (R, 2021).

2.3 CPUE standardization

We adapted the *R* package VAST (https://github.com/James-Thorson-NOAA/VAST) developed by Thorson et al. (2015) for conducting the NPO albacore 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 albacore in NPO 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 $\beta(t_i)$ 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 targeted (i = 2) effects ($n_{k1} = n_{k2}$ =2).

2.4 Derived standardized CPUE index

The area-weighted abundance, $d(t,q)$, of the NPO albacore for year t and quarter q except for the vessel effect is 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 NPO albacore, $C\hat{P}UE(t)$, are computed from CPUE estimates for each year t and quarter q as described in Campbell 2015:

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

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

2.5 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

Time-series catch of albacore harvested by Taiwanese longline fishery in NPO during 1995 - 2021 was summarized in **Fig. 1** and **Table 1**. In general, the albacore catch fluctuated around 8,300 tons during 1996 - 2003. A declined pattern of albacore tuna catch was observed since 2004, and the average catch was approximately 3,000 tons during 2007 - 2015. The catch of albacore gradually increased from 2016 - 2021, except for a slight decrease in 2020. Spatial distribution of the efforts and nominal albacore CPUEs caught by Taiwanese distant-water longliners (DWLL) from 2015 - 2021 is shown in **Fig. 2**. Higher albacore CPUEs were distributed above 25°N, however some high albacore CPUE could be observed below 25°N. Two-stage cluster analysis of the Taiwanese distant-water longline fishery data (DWLL) indicated a possible separation of two clusters (albacore-targeting and non-albacore-targeting) (**Fig. 3 and Fig. 4**). Cluster 1 (albacore-targeting) shows a markedly higher efficiency in harvesting albacore, as the cluster demonstrated noticeably higher catch and CPUE in albacore, with the catch composition dominated by albacore (**Fig. 5 and Table 2**). In contrast, Cluster 2 showed a more diverse composition in the catch. We further examined and compared the albacore catch, fishing area, and fishing strategy between the two clusters. Cluster 1, the albacore-targeting fleet, appears to be responsible for most of the albacore catch. Cluster 2, the non-albacore-targeting fleets, show low albacore catch, though the number has slightly increased for the last 5 years (**Fig. 6a**). In terms of spatial distribution, Cluster 1 mostly operated above 25°N, while cluster 2 operates mainly below 15°N, however the higher effort also distributed above 25°N (**Fig. 6b**). For the configuration of hook per basket (HPB), Cluster 1 tended to apply HPB less than 13, while Cluster 2 applied HPB higher than 13 (**Fig. 6c**). A different pattern in the fishing season was also observed given that Cluster 1 usually starts the fishing season in October and ends in April next year, while the fishing season of cluster 2 appears to be December to June next year, although efforts were observed throughout the year (**Fig. 6d**). Given that the differences in fishing area and fishing strategy, the targeted effect (albacore targeting and non-albacore targeting) should be considered when conducting the CPUE standardization for the NPO albacore.

To understand the abundance of albacore in NPO, we performed standardization of the catch rate of albacore using the DWLL data. Convergence in optimization was confirmed for each model based on their Hessian matrix, and the maximum gradient of each component was checked below 0.0001. Based on AIC values, the best model with the most variables considered was used to calculate the standardized CPUE index of NPO albacore (M6, **Table 3**). Model diagnostics implied good fits to the observed CPUEs between encounter rate (**Fig. 7a**) and positive catch rate models (**Fig. 7b**). The predicted standardized CPUE index revealed that the standardized relative catch rate of DWLL fleets for NPO albacore reached the highest point in 1996 and experienced a decline afterward. Since 1999, the standardized CPUE index was stable overtime (**Fig. 8**). The index of standardized CPUEs and CVs are summarized in **Table 4**.

Length data of albacore collected by Taiwanese DWLL fleets in NPO during 1995 - 2021 were displayed and summarized in **Fig. 8** and **Table 5**. It is noted that the length frequency distribution before 2003 does not exhibit stable patterns and the sample size showed high variation. Since then, the length frequency distribution has a consistent pattern overtime and the mean length value was fluctuated around 85 cm.

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Table 1. Catch summary (in metric ton, mt) of the Taiwanese longline fisheries in the North Pacific Ocean (NPO) during 1995 - 2021.

Year	Catch
1995	4280
1996	7596
1997	9456
1998	8810
1999	8393
2000	8842
2001	8684
2002	7965
2003	7166
2004	4988
2005	4472
2006	4317
2007	2916
2008	3069
2009	2378
2010	2818
2011	3434
2012	2643
2013	4427
2014	2617
2015	3020
2016	3406
2017	4333
2018	4514
2019	5454
2020	3809
2021	5953

Table 2. Results of clustering analysis based on the catch species composition of Taiwanese distant-water longline fisheries (DWLL) in the North Pacific Ocean (NPO) from 1995 - 2021.

Species	Cluster1		Cluster2	
	CPUE	SE	CPUE	SE
ALB	31.17	0.153	1.17	0.013
BET	1.44	0.016	4.85	0.019
YFT	0.66	0.012	1.97	0.013
SWO	0.36	0.004	1.04	0.009
OTH	2.91	0.021	3.66	0.021
ALB ratio (%)	85.31		9.18	

Table 3. Model selection information of the VAST models for the albacore tuna caught by Taiwanese distant-water longline fisheries (DWLL) in the North Pacific Ocean (NPO) during 1995 - 2021.

ID	Model structure	AIC	ΔAIC	Maximum gradient
M1	Year	401212	53675	<0.0001
M2	Year + Knot	385698	38161	<0.0001
M3	Year + Knot + Year-Knot	369436	21899	<0.0001
M4	Year + Knot + Year-Knot + Vessel	363456	15919	<0.0001
M5	Year + Knot + Year-Knot + Vessel + Quarter	359714	12177	<0.0001
M6	Year + Knot + Year-Knot + Vessel + Quarter + Cluster	347537	0	<0.0001

Table 4. Standardized relative CPUE (Std. CPUE) and CV for albacore tuna in the North Pacific Ocean (NPO) derived from Taiwanese distant-water longline fisheries (DWLL) from 1995 - 2021.

Year	Std.CPUE	CV
1995	1.20	0.15
1996	3.46	0.10
1997	2.70	0.13
1998	1.26	0.15
1999	0.98	0.12
2000	0.94	0.11
2001	0.85	0.11
2002	0.61	0.14
2003	0.59	0.09
2004	0.54	0.10
2005	0.65	0.07
2006	0.68	0.07
2007	0.83	0.07
2008	0.89	0.08
2009	0.74	0.07
2010	1.32	0.08
2011	1.14	0.08
2012	0.82	0.09
2013	1.03	0.08
2014	0.93	0.07
2015	0.73	0.09
2016	0.67	0.08
2017	0.70	0.08
2018	0.78	0.09
2019	0.66	0.06
2020	0.64	0.06
2021	0.70	0.05

Table 5. Summary of length data (fork legth, cm) collected by Taiwanese distant-water longline fisheries (DWLL) in the North Pacific Ocean (NPO) during 1995 - 2021.

Year	Median	Mean	Min	Max	Sample size
1995	81	80.57	69	110	26280
1996	82	78.97	32	131	29786
1997	75	75.05	35	138	18334
1998	75	75.49	42	99	7451
1999	60	59.69	37	93	5816
2000	83	82.67	42	114	10761
2001	100	93.46	70	135	499
2002	73	73.38	43	125	4801
2003	86	85.75	57	131	9483
2004	85	84.31	40	150	44085
2005	88	90.12	30	150	37947
2006	86	85.43	30	146	72930
2007	81	82.11	34	143	42951
2008	85	87.19	37	147	42625
2009	92	91.75	51	144	25360
2010	91	92.23	55	149	26908
2011	92	95.90	54	148	30933
2012	90	92.59	50	148	26839
2013	90	91.51	51	145	24745
2014	89	90.01	60	128	23001
2015	95	93.60	63	129	12308
2016	84	84.76	60	125	14844
2017	92	91.61	70	134	12795
2018	87	87.85	66	140	23585
2019	88	88.37	58	133	25077
2020	79	81.42	54	135	41521
2021	83	83.99	62	131	49985

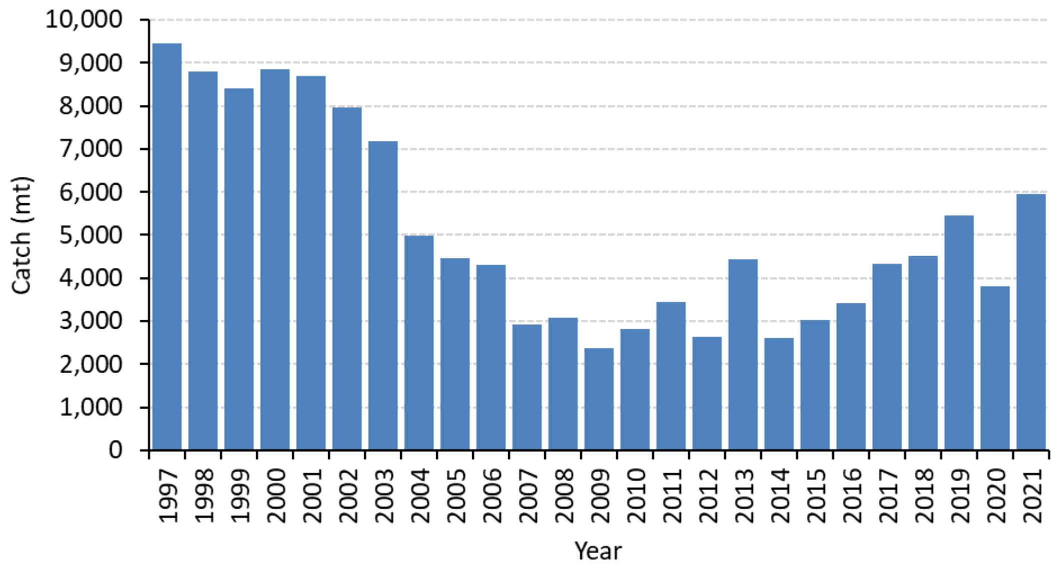

Figure 1. Time-series of albacore catches caught by Taiwanese longline fisheries in the North Pacific Ocean (NPO) during 1995 - 2021.

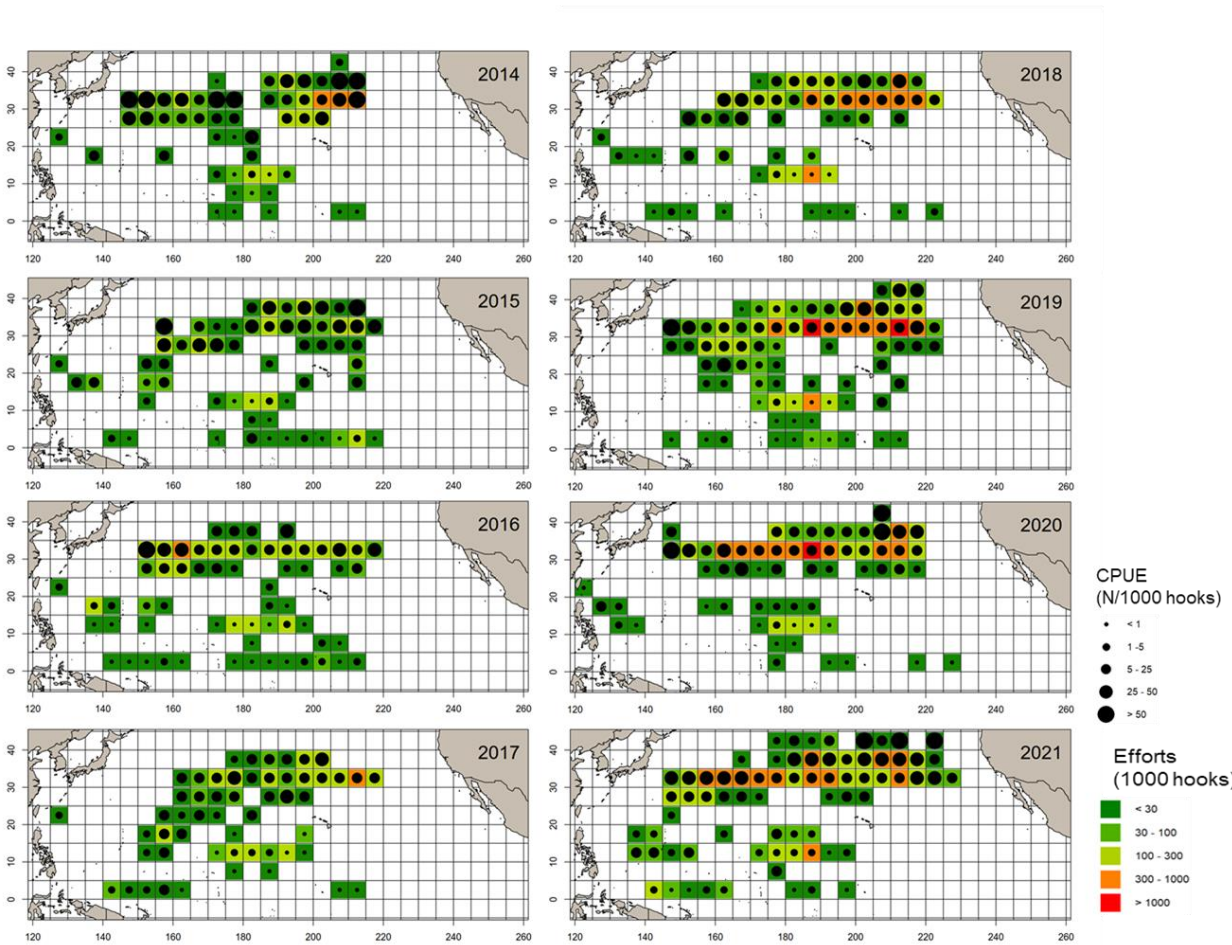

Figure 2. Spatial distribution of fishing effort and nominal albacore catch-per-unit-effort (CPUE) of Taiwanese distant-water longline fishery (DWLL) in the North Pacific Ocean (NPO) during 2014 - 2021.

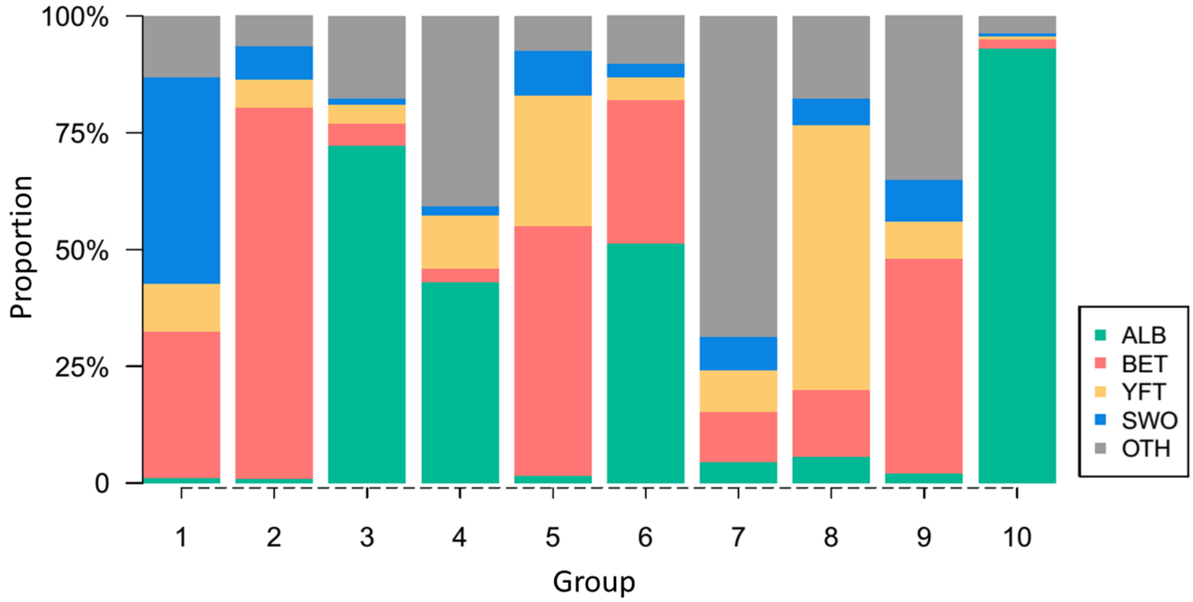

Figure 3. The proportions of catches (number) by species for the 10 non-hierarchical (K-means) clusters based on the Taiwanese distant water longline fishery logbook data from 1995 - 2021.

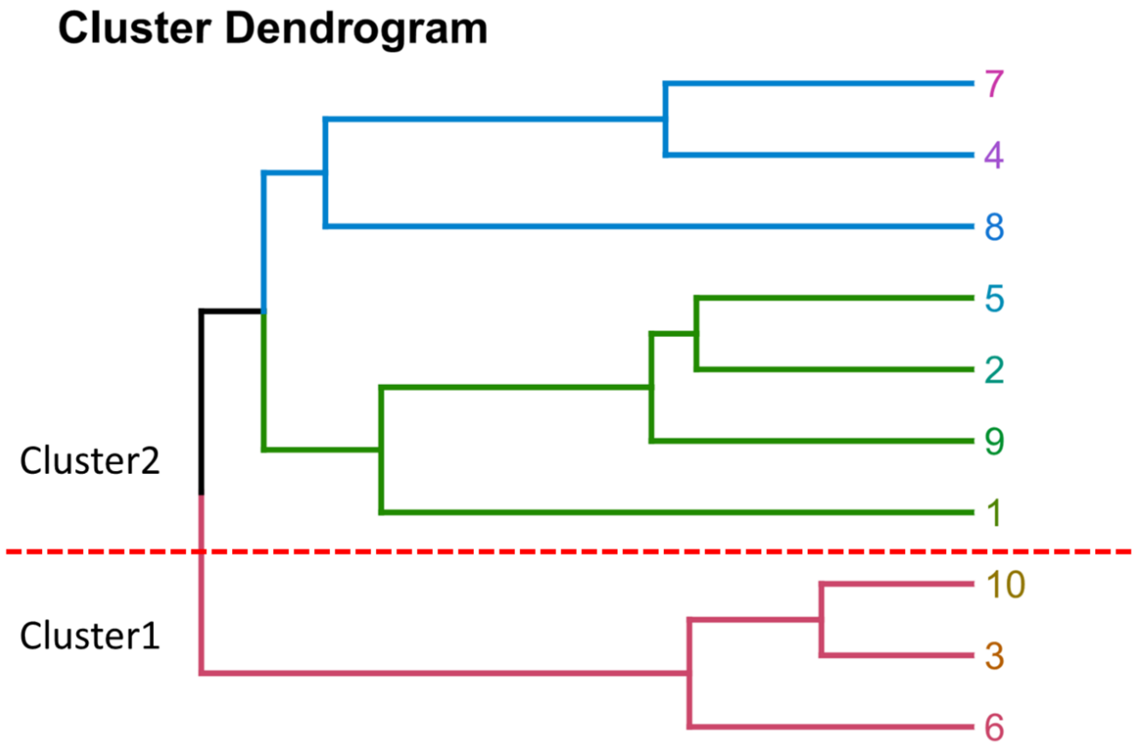

Figure 4. The hierarchical tree obtained from cluster analysis of the catch composition of Taiwanese distant-water longline (DWLL) fishery in the North Pacific Ocean (NPO) during 1995 - 2020. Cluster 1 represents the albacore targeting fleets, and Cluster 2 represents the non-albacore-targeting fleets.

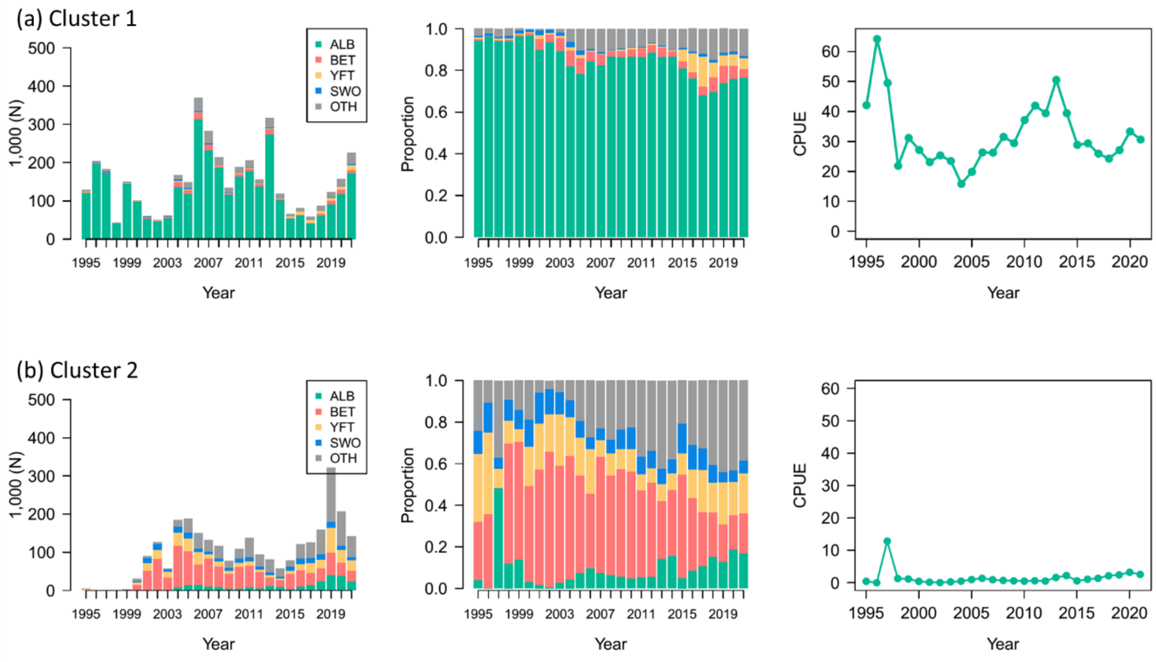

Figure 5. Catch (in numbers), catch composition, and albacore CPUEs (N/1,000 hooks) of the two clusters from 1995 - 2020. Cluster 1 represents the albacore targeting fleets, and Cluster 2 represents the non-albacore-targeting fleets.

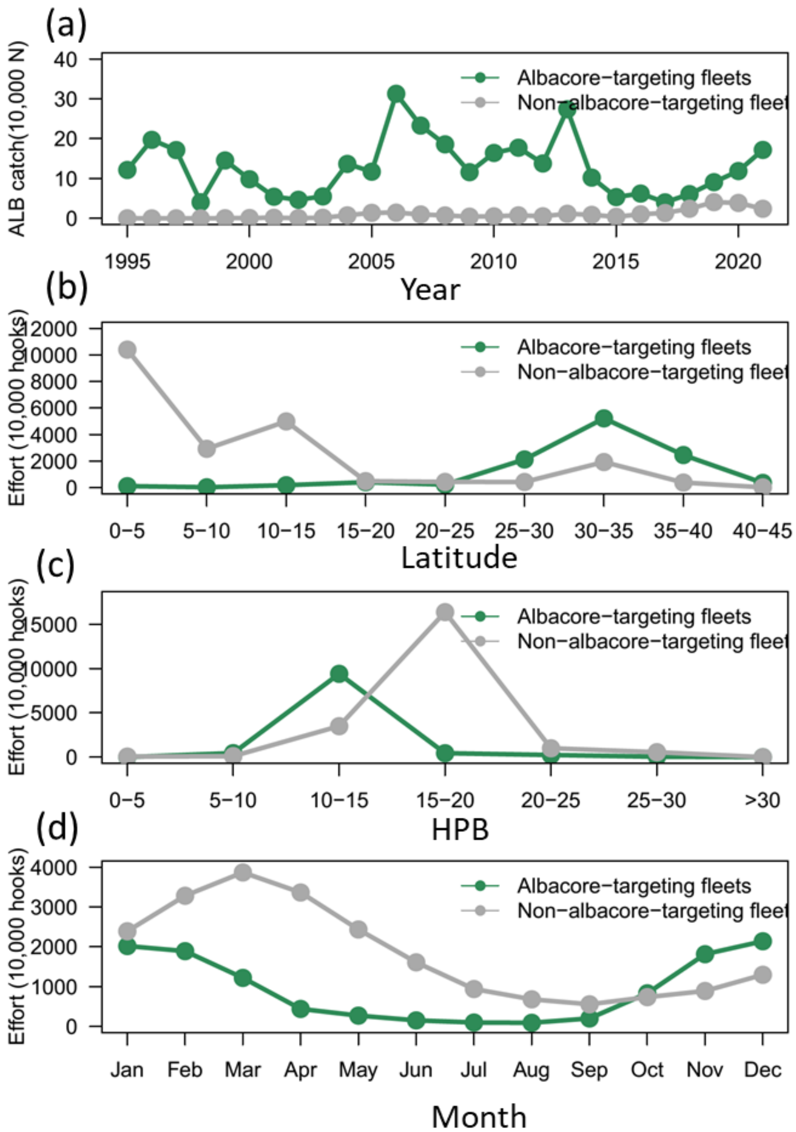

Figure 6. Characteristics of Taiwanese DWLL fishery in NPO during 1995 - 2020. (a) Annual albacore catch numbers by clusters; (b) Latitudinal distribution on fishing efforts by clusters. (c) Efforts in hooks per basket (HPB) by clusters; (d) Efforts in month by clusters.

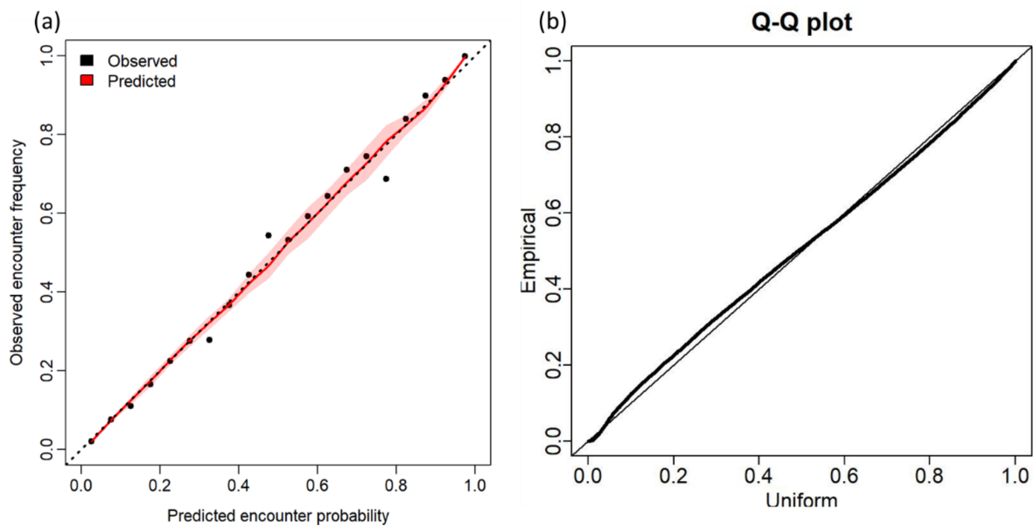

Figure 7. Model diagnostics plots for (a) encounter probability and (b) positive catches component of Northern Pacific Ocean (NPO) albacore for Taiwanese (DWLL) fishery during 1995 - 2020.

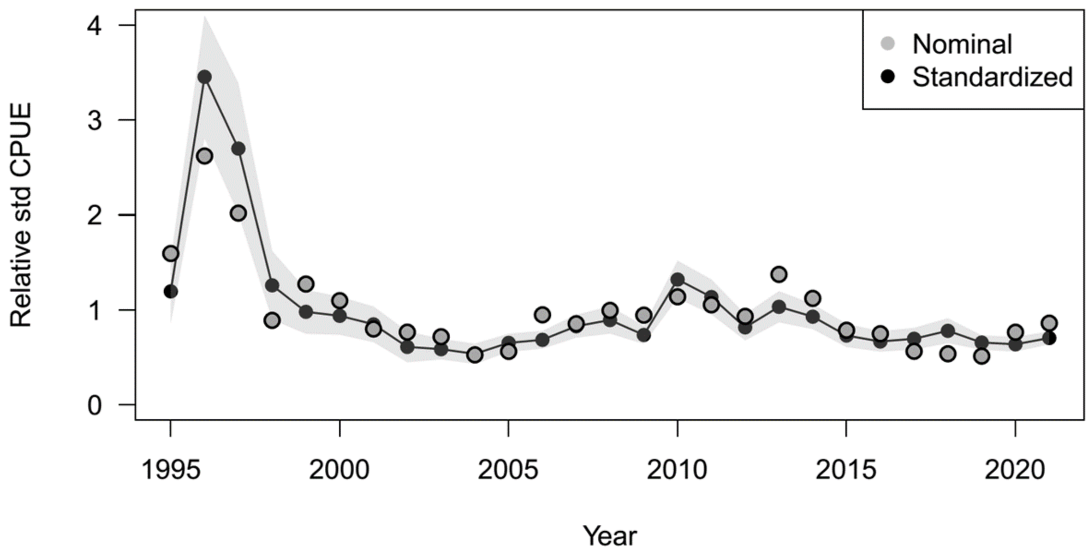

Figure 8. Relative scales (centered to mean) of the nominal and standardized indices for the Northern Pacific Ocean (NPO) albacore for the Taiwanese distant-water longline (DWLL) fishery during 1995 - 2020. Shaded area indicates the 95% confidence intervals.

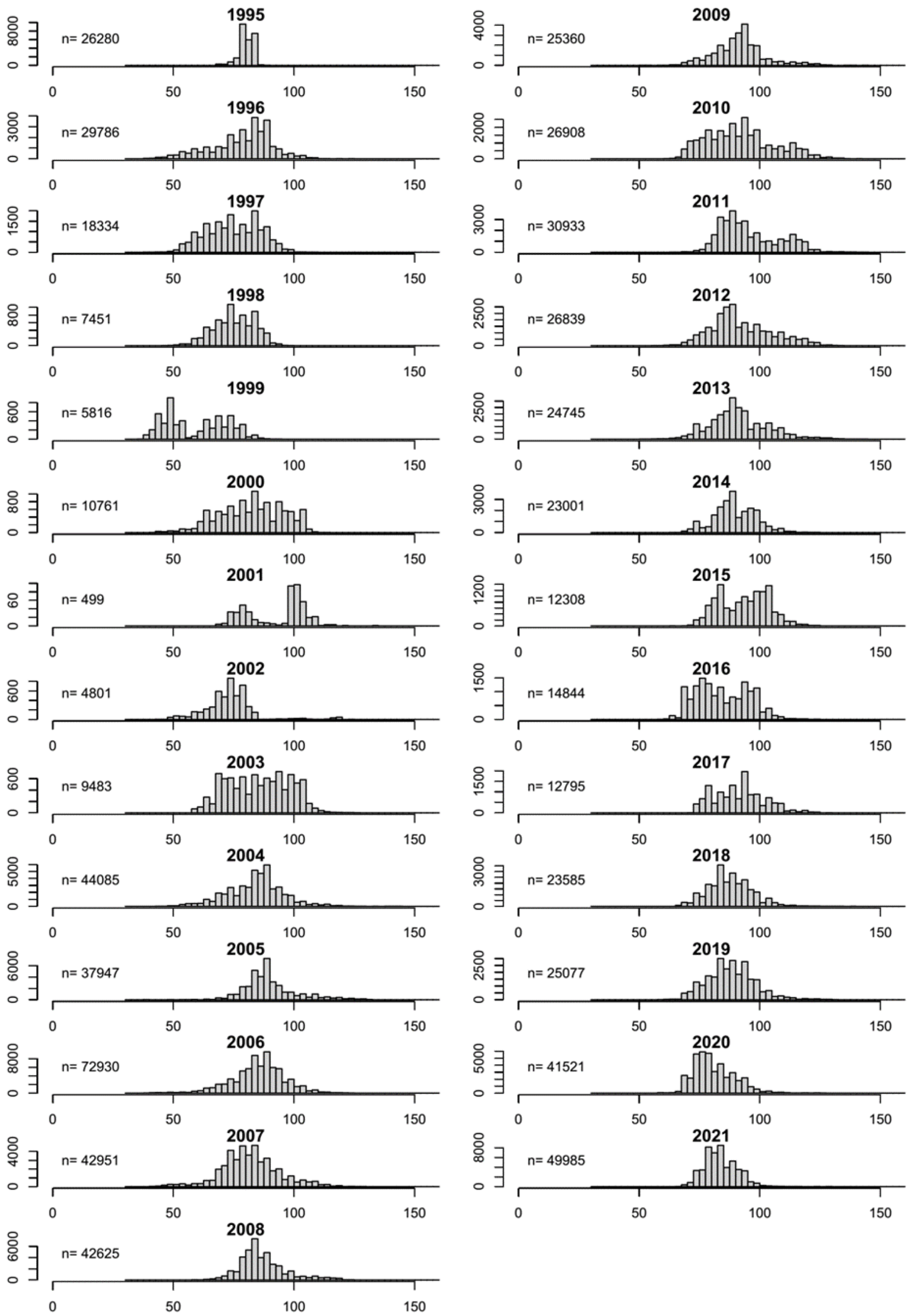

Figure 9. Annual length frequency distribution of albacore collected by Taiwanese distant-water longline (DWLL) fishery in the Northern Pacific Ocean (NPO) from 1995 - 2021. The sample sizes were shown on the left of the histograms.