Japanese coastal longline CPUE and catch-at-length for Pacific bluefin tuna: Update up to 2016 fishing year

Osamu Sakai and Yohei Tsukahara

National Research Institute of Far Seas Fisheries,
Japan Fisheries Research and Education Agency
5-7-1, Orido, Shimizu-ku, Shizuoka 424-8633, JAPAN

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Summary

Japanese coastal longline CPUE and catch-at-length were updated. The CPUE was standardized using the model which was used for the previous stock assessment in February 2016. In addition, a "best model" was explored based on BIC as reference. In the standardization, the effect of target shift was addressed by the indicator from cluster analysis. The cluster indicator was based on the species composition except for PBF by fishing trip, and it was used for the explanatory variable of the standardization model. Zero inflated negative binomial (ZINB) model was applied as the model to standardize the CPUE, which was based on the aggregated data in fishing trip resolution. Both CPUEs which were standardized by previous model and best model showed overall similar trend. Thus, it was considered not to be a problem using the previous model as "simple update". The updated CPUE showed a consistent increase after 2011 fishing year. Catch-at-length indicated a new mode of smaller fish in the catch. These are positive information for the adult stock population of PBF.

Introduction

Catch per unit effort (CPUE) is a relative abundance index, which is commonly used to draw inferences about fish population dynamics (Pope et al. 2010). For Pacific bluefin tuna (PBF) assessment, some series of longline CPUE has been used as important monitoring indices for the adult population; Japanese longline CPUE and Taiwanese longline CPUE (ISC 2016).

Because of the change of operational patterns of Japanese longliners, the CPUE has been split up into three time-series; fishing year 1952-1973 (Fujioka et al. 2012), 1974-1992 (Yokawa 2008), and after 1993. Current CPUE series (after 1993) is standardized using zero inflated negative binomial (ZINB) model, including the indicator from cluster analysis as an explanatory variable (Sakai et al. 2016). The cluster indicator is based on the catch composition by species (except for PBF) in each fishing trip, which can address the effect of target shift of this fishery. The ZINB model was applied as the model to standardize the CPUE which was based on the aggregated data in fishing trip resolution. The approach using cluster analysis is a standard method for the CPUE analysis (e.g. He et al. 1997, McKechnie et al. 2014, Tremblay-Boyer et al. 2015).

This document presents a simple update of the current Japanese CPUE series using same standardizing model with same data filtering and preparing procedure which were used for the previous stock assessment in 2016. For the purpose of reference, we also include a result using another standardizing model which was selected as "best model" by BIC using current data-set. To help understanding the longline catch information, this document also includes the catch-at-length data of Japanese longliners in addition to CPUE. Both the CPUE and catch-at-length are presented up to the 2016 fishing year (June 2017 calendar year).

Materials and Methods

1) CPUE

Data sources and filtering

Catch and effort data from logbooks of Japanese coastal longliners from 1994 to 2017 (calendar year) were used for the CPUE analysis. The data resolution is originally set-by-set, and it refers to individual records of fishing operation, whereby on a given date and location (latitude and longitude) of longline set, the number of hooks set, hook per basket (hpb), and the number of fish caught of various species were reported. The data were filtered through the following criteria described by the previous studies (Ichinokawa and Takeuchi 2012, Hiraoka et al. 2015a);

- April to June (spawning season);
- Fishing trip that was operated at 1x1 degree grids in latitude and longitude where at least one PBF per year has been caught for more than 10 years.

We aggregated the data by trip level to use for the cluster analysis and standardization by ZINB method. The number of hooks and catches were added up, and location and hpb were calculated median values for each fishing trip. In accordance with Hiraoka et al. (2015a) and Sakai et al. (2016), we divided the fishing location into three sub-areas ("CORE", "SW", and "NE" area: Fig. 1). The definition of each area was described by Oshima et al. (2012): The "CORE" area is located around Nansei-islands which includes a major spawning ground of PBF (Suzuki et al. 2011), where higher CPUE of PBF tends to be observed compared to the other two areas. The border between "SW" and "NE" area was defined by Ichinokawa and Takeuchi (2012).

Cluster analysis

Cluster analysis is generally used to assign fishing activity to general categories representing the different targeting practices (He et al. 1997, McKechnie et al. 2014, Tremblay-Boyer et al. 2015). In this document, clustering was based on the relative number of key species except for PBF; the species composition in proportions of bigeye tuna (BET), yellowfin tuna (YFT), albacore (ALB) and other fishes (billfish and shark species). We used a hierarchical clustering using Ward's method (Ward 1963) on Euclidean distance. The analysis was conducted using algorithm of "hclust" (available in R package "stats") for R software ver. 3.4.3 (R Core Team 2017).

Standardization of CPUE

The data used for standardization are trip resolution (Table 1). ZINB allows for "excess zeros" in count models through the splitting process, one where members always have zero counts (count model), and one where members have zero or positive counts (zero-inflation model). For the update of standardized CPUE, previous standardization model which was used for 2016 assessment was applied to current data-set. Moreover, we explored "best model" which was selected by BIC as reference. The explanatory variables used in this analysis were as follows;

- **Year**: 23 calendar years, from 1994 to 2017 (1993 to 2016 fishing year);
- **Day10**: Periods during the spawning season, from April to June, defined by 10 days interval (last period of May contained 11days);

- **Area**: Core area ("CORE"), Northeast area ("NE"), and Southwest area ("SW") of the fishing ground (three-area definition; Fig.1B) for the median position of each fishing trip;
- **Ship-size**: Small vessel (< 16 GRT; "Small") or large vessel (≥ 16 GRT; "Large");
- **Days per trip**: Short duration (< 14 days; "Short") or long duration (≥ 14 days; "Long").
- **Gear**: "Shallow set" (< 16 hooks per basket) and "Deep set" (≥ 16 hooks per basket) defined by median value of the hooks per basket for each fishing trip;
- **Movement**: Three categories defined by combining the total moving distance per trip with the mean moving distance per day ("Not moving": both total and mean distance were zero, "Short distance": total distance is <300 miles, and "Long distance": total distance is ≥300 miles).
- **Cluster**: Three clusters derived from the cluster analysis.

The standardized CPUE was calculated from the least square means (LSMEANS) using the same estimation procedure as the SAS package. The CV was calculated using bootstrapping 1000 times. The analysis was conducted using the "zeroinfl" algorithm (available in R package "pscl") for R software ver. 3.4.3 (R Core Team 2017).

2) Catch at length

The catch-at-length of PBF which were caught by Japanese longliners were estimated using exactly the same method as proposed by Hiraoka et al. (2015b) and used in 2016 assessment. In this method, the length frequency (fork length) was estimated by "number" of actual measured fish with relative "weight" for measured fish and total catch. When fish weight was not measured for the size measurement, the weight of measured fish was calculated from measured length using existing weight-length relationship (Kai 2007). The estimation method can be described by the following equations:

$$N_{iy} = \sum_{k=1}^{K} \left(n_{iykt} \times c_{ykt} / w_{iykt} \right)$$

where N_{iy} is the fish at the length bin of i occurred in the population at 2nd quarter of calendar year y. K is the total number of special stratification. n_{iykt} is the number of measured fish at the length bin of i in prefecture stratum k at time stratum t for year y. w_{iykt} is the weight of them. c_{ykt} is the total catch weight in prefecture stratum k at time stratum t for year y. We used 6 groups as the prefecture strata (Miyagi, Chiba, Wakayama, Miyazaki, Okinawa, and Others). As the time stratum, a quarter (1 stratum: only 2nd quarter of calendar year) was used. The great part of size measurement data for longline is based on the "Research Project on Japanese bluefin tuna (RJB)" which has obtained at 13 main landing ports (7 prefectures). Some data of size measurement from other research projects such as observer data was also used. Note that the data in the latest year should not be considered complete, thus the result of catch-at-length in latest year is preliminary.

Results and Discussion

Data and nominal CPUE

In total, 14,484 fishing trips were recorded in the data-set we used for the cluster analysis and CPUE standardization (Table 1). Of these, 549 records are the fishing trip in 2016 fishing year. This is about 91% of the previous year (2015 fishing year). After 2009, the number of fishing trip is on a declining trend. Nominal CPUE had a downward trend since 2007 and hit a record low (0.045) in 2011 fishing year. In recent years, the nominal CPUE turned an upward trend, and the level of terminal year was around the 2008 and 2009 fishing year level (0.143) (Fig. 4).

Cluster analysis

The cluster analysis divided the fishing trips into three groups (Table 2, Fig. 2). Species compositions of Cluster 1 and 3 showed that they generally represent targeting ALB (78.7%) and YFT (83.9%), respectively. In Cluster 2, the highest proportion was “Other” species (42.7%).

The yearly changes of the number of fishing trips by Clusters are shown in Fig. 3. The number of fishing trips of Cluster 3 (targeting YFT) had increased and reached a peak in 2009 fishing year, and then decreased. After 2013 fishing year, it has been increasing again. Meanwhile, those of Cluster 1 (targeting ALB) dropped in 2009 fishing year. Those of Cluster 2, which have high proportion of “Other” species, were relatively stable. These trends would reflect the changes of targeting of the longline fishermen after 2005, which was pointed out by Oshima et al. (2012).

Update of standardized CPUE by previous model

ZINB model which we used for standardization was as follows. This model is “final model” used for previous assessment. Its BIC value under the current data-set was 57123.08.

[Standardization model used for previous assessment]

(Count model)

Log(μ) = intercept + Year + Day10 + Area + Ship-size + Days-per-trip + Movement + Cluster + Year*Area + Area*Ship-size + Day10*Area + Area*Cluster + error term,

(Zero-inflation model)

Logit(p) = intercept + Year + Day10 + Area + Ship-size + Days-per-trip + Cluster + Ship-size*Cluster + error term

This model had the interaction effects between Year and Area, thus the area weighting value for LSMEANS was calculated as the standardized CPUE. The standardized CPUE showed a very similar pattern compared to the previous result which was used in 2016 assessment (Fig. 4). There was decreasing trend in early period (1995-2000 fishing year), then turned upward and peaked in 2004, and decreased again. There has been continual upward trend since 2011 fishing year.

Compared to the previous CPUE (Sakai et al. 2016), there was some difference in early period. As discussed in ISC-PBFWG in Feb. 2017, the cause of these difference would be the algorithms of “data filtering” and “clustering” process which we used in the procedure of standardization (ISC 2017). In the updated process, most recent years’ data which were added to the previous data can affect the filtering of past years' data. These updated data could affect the cluster grouping even if we used the same procedure. Actually, the number of fishing trips belong to Cluster 3 decreased after the update, despite the increase of the total number of trips (Table 3).

Fig. 5 shows the effect of each explanatory variable in the standardization model. Year*Area interaction shows impact on the yearly trend by area for the standardized CPUE (Fig. 5-(1)). Area*Cluster interaction means the different impacts of targeting by areas (Fig. 5-(3)). Ship-size*Cluster interaction shows very little impact by the cluster for the effect of ship-size in current data-set (Fig. 5-(5)). The Pearson residual patterns are not distinctly different among years (Fig. 6).

Exploring of best model for CPUE standardization

As reference, "best model" was explored. The procedure for model selection needed to be improved because we got stuck in a local minimum by the previous procedure: At the step of selection of main effect, we check the all combinations of explanatory variables instead of stepwise backward method.

1st) All combinations of explanatory variables were checked for both count model and zero-inflation model and determined as main effects based on BIC.

2nd) The first-order interaction which consists of selected main effects was determined through the forward method (increasing variables) for both count model and zero-inflation model.

We selected "Best model" including main effects and 1st order interactions using BIC (BIC=57076.27);

[Best model]

(Count model)

Log(μ) = intercept + Year + Day10 + Area + Gear + Days-per-trip + Movement + Cluster + Year*Area + Day10*Area + error term,

(Zero-inflation model)

Logit(p) = intercept + Year + Day10 + Area + Ship-size + Days-per-trip + Cluster + Day10*Cluster + Area* Days-per-trip + Area*Cluster + error term

Selected explanatory variables and 1st order interactions were different from previous model used for the 2016 assessment; "Gear" and "Area*Cluster" were selected in the "best model" instead of "Ship-size" and "Area*Ship-size" in count model, and "Day10*Cluster", "Area* Days-per-trip", and "Area*Cluster" were selected instead of "Ship-size*Cluster". The BIC value for the "best model" was lower than that of the previous model: The BIC of the best model was 57076.27, whereas that of previous model was 57123.08. There were small differences between the CPUEs which were standardized by the "best model" and the previous model, and their overall trend was very similar (Table 1, Fig. 4). Detailed information for the effects of explanatory variables are included in Appendix 1.

Catch-at-length

Estimated catch-at-length data show that the main part of the Japanese coastal longline catch has been constituted by some strong cohorts (e.g. 1990 and 1994 year classes), but these catches have not been composed of only a single cohort (Fig. 7). In 2016 fishing year, the main size of PBF caught by Japanese coastal longliners were 176-218 cm FL which would cover several cohorts consisted from 2007 and/or 2008 and 2010 and/or 2011 year classes —these year classes have been seen since 2011 and 2015, respectively. In addition, the length frequencies indicate some relatively strong mode of smaller fish in the catch of 2015 fishing year. These modes depend on measurement data in Miyagi prefecture where the catch has increased since 2015, even though the number of actual measurement remain low since 2011, low catch era.. It means that the modes of smaller fish in recent years certainly exist, but have somewhat low reliabilities and somewhat bias in the degree of their constitution. It is important to modify the number of actual measurement corresponding to catch increase or decrease.

Conclusion

The difference between the two standardized CPUEs ("previous model" and "best model") was small, and their overall trend was almost similar. From this result, it was considered that there would be minimal risk of serious miss-interpretation for the stock trend of adult PBF due to the difference of standardization model. Thus, it could be recommended to use the previous model for the standardization of CPUE as a "simple update" for 2018 assessment.

Current increase trend has been found since 2011 fishing year. Current strong cohorts is constituted by wide range of year classes (2007 and/or 2008 year classes and 2010 and/or 2011 year classes) and they have been caught by longliners since 2011 and 2015 fishing year, respectively. In addition, there seems to be catch of relatively small fish in the longline catch after 2014 fishing year. From these observations, we can say that the strong cohorts are still remaining, new cohorts are coming, and as the results, the adult population is recovering continuously. These are positive information for the PBF stock.

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Table 1 Total number of fishing trips, hooks, PBF catch, nominal CPUE, and standardized CPUE for "Previous model" and "Best model" of ZINB. Data set was based on logbook from Japanese coastal longliner in 2nd quarter (April-June) of 1994-2017 calendar year (1993-2016 fishing year).

Calender year	Fishing year	Data set used for this analysis					Standardized by previous model used in 2016 assessment			Standardized by best model for current data			Standardized CPUE used in 2016 assessment	
		N of trip	N of hooks (x1000 hooks)	N of PBF catch	Nominal CPUE	Nominal CPUE (scaled)	Standardized CPUE	Standardized CPUE (scaled)	CV	Standardized CPUE	Standardized CPUE (scaled)	CV	Standardized CPUE (scaled)	CV
1994	1993	362	5275	2899	0.550	2.236	0.435	2.307	0.039	0.377	2.276	0.037	1.999	0.029
1995	1994	323	4679	1710	0.365	1.487	0.280	1.484	0.034	0.262	1.579	0.044	1.389	0.033
1996	1995	363	5180	2561	0.494	2.011	0.439	2.329	0.028	0.389	2.349	0.038	1.966	0.033
1997	1996	383	5477	2526	0.461	1.876	0.377	2.002	0.033	0.354	2.137	0.050	1.723	0.032
1998	1997	420	6307	3010	0.477	1.942	0.339	1.797	0.034	0.334	2.014	0.052	1.650	0.032
1999	1998	713	9866	4028	0.408	1.661	0.251	1.333	0.031	0.222	1.342	0.033	1.332	0.033
2000	1999	636	8895	2366	0.266	1.082	0.222	1.176	0.030	0.190	1.143	0.038	1.065	0.036
2001	2000	611	10002	1878	0.188	0.764	0.158	0.836	0.030	0.138	0.835	0.034	0.845	0.021
2002	2001	642	10327	2150	0.208	0.847	0.182	0.967	0.025	0.141	0.850	0.054	1.059	0.024
2003	2002	688	10587	2872	0.271	1.104	0.238	1.260	0.025	0.219	1.324	0.028	1.296	0.027
2004	2003	746	10852	3844	0.354	1.441	0.283	1.503	0.031	0.258	1.558	0.029	1.499	0.024
2005	2004	663	10675	4065	0.381	1.549	0.324	1.720	0.023	0.267	1.609	0.039	1.749	0.022
2006	2005	693	10171	2111	0.208	0.844	0.152	0.807	0.029	0.120	0.726	0.054	0.802	0.030
2007	2006	669	9843	3287	0.334	1.358	0.166	0.882	0.036	0.140	0.846	0.043	0.919	0.034
2008	2007	674	10104	1668	0.165	0.672	0.126	0.670	0.035	0.099	0.599	0.060	0.698	0.037
2009	2008	743	11927	1481	0.124	0.505	0.068	0.361	0.089	0.051	0.309	0.122	0.368	0.074
2010	2009	719	11313	807	0.071	0.290	0.040	0.214	0.063	0.032	0.191	0.088	0.256	0.058
2011	2010	678	10039	644	0.064	0.261	0.043	0.228	0.074	0.036	0.216	0.088	0.212	0.097
2012	2011	681	11079	495	0.045	0.182	0.035	0.188	0.065	0.028	0.170	0.103	0.178	0.059
2013	2012	647	10406	815	0.078	0.319	0.057	0.302	0.065	0.051	0.310	0.061	0.320	0.044
2014	2013	629	10432	793	0.076	0.309	0.057	0.301	0.040	0.050	0.304	0.039	0.344	0.038
2015	2014	649	9747	668	0.069	0.279	0.064	0.337	0.052	0.059	0.356	0.046	0.331	0.054
2016	2015	603	8851	875	0.099	0.402	0.080	0.426	0.057	0.070	0.422	0.058		
2017	2016	549	8441	1203	0.143	0.580	0.107	0.569	0.034	0.089	0.535	0.051		

Table 2 Species composition and number of fishing trip by each cluster.

	Cluster 1	Cluster 2	Cluster 3
Yellowfin tuna	4.9%	41.3%	83.9%
Albacore	78.7%	14.4%	4.1%
Bigeye tuna	7.8%	1.6%	0.6%
Other species	8.5%	42.7%	11.4%
Number of fishing trip	8,714	3,453	2,317

Table 3 Comparison of the number of trips used in the standardization between previous analysis and current update.

fishing	Previous analysis using 2016 assessment				Current update			
year	Cluster 1	Cluster 2	Cluster 3	Total	Cluster 1	Cluster 2	Cluster 3	Total
1993	260	91	11	362	273	80	9	362
1994	188	115	20	323	205	104	14	323
1995	273	61	29	363	277	64	22	363
1996	295	76	12	383	299	76	8	383
1997	283	130	7	420	309	108	3	420
1998	387	213	113	713	386	237	90	713
1999	423	134	78	635	428	147	61	636
2000	399	148	64	611	415	141	55	611
2001	352	187	61	600	423	167	52	642
2002	375	138	76	589	479	145	64	688
2003	352	222	145	719	391	248	107	746
2004	406	126	85	617	468	131	64	663
2005	411	169	64	644	467	171	55	693
2006	344	173	104	621	403	191	75	669
2007	368	103	157	628	418	140	116	674
2008	418	148	131	697	466	174	103	743
2009	234	133	287	654	300	172	247	719
2010	286	93	266	645	323	129	226	678
2011	299	134	201	634	352	155	174	681
2012	298	150	176	624	329	194	124	647
2013	284	134	112	530	374	156	99	629
2014	205	89	154	448	348	135	166	649
2015					295	87	221	603
2016					286	101	162	549
Total	7140	2967	2353	12460	8714	3453	2317	14484

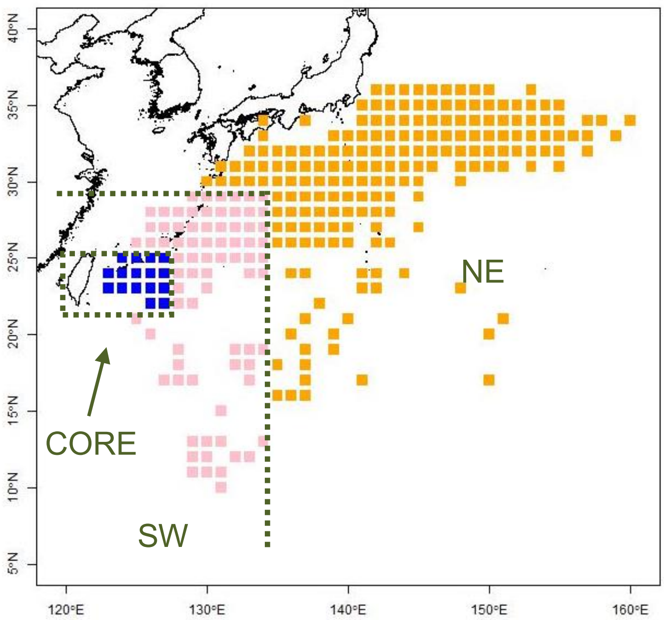


Fig. 1 Area definition for the analysis. According to Hiraoka et al. (2015a), the fishing ground was divided into three sub-area ("CORE", "SW", and "NE") for the standardization of CPUE. "CORE" area was defined by Oshima et al (2012) as the higher CPUE area for PBF.

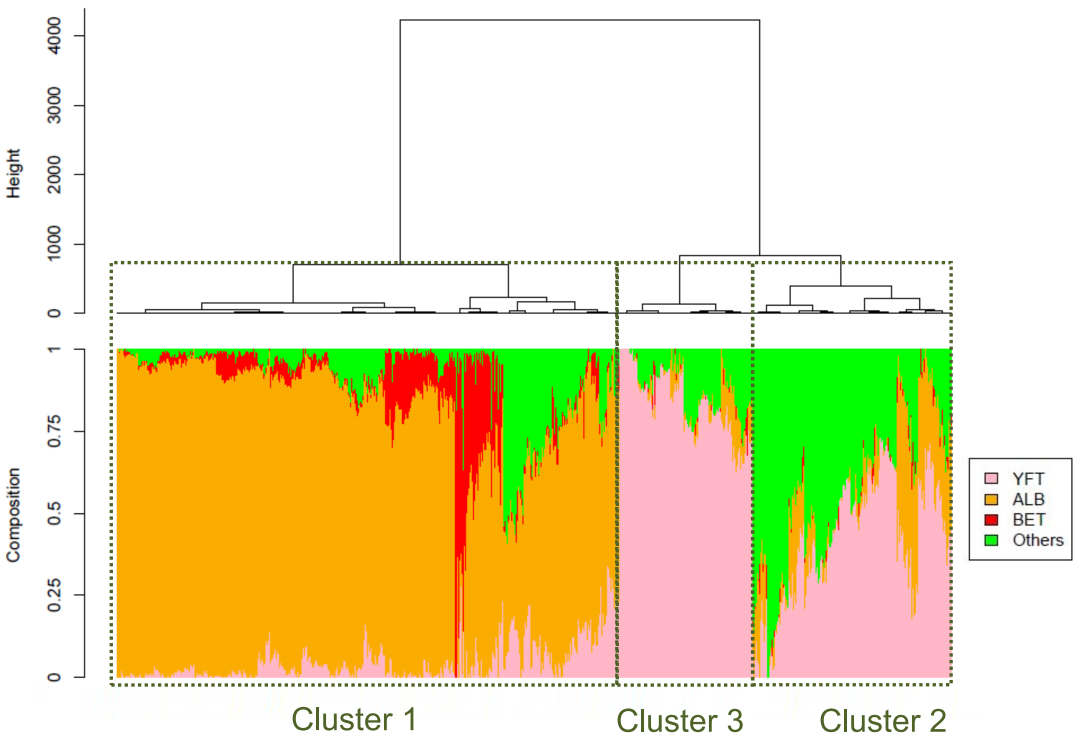
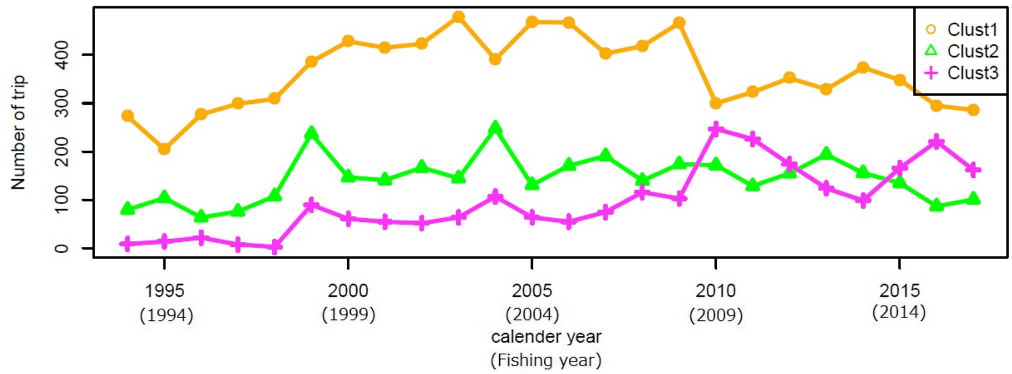


Fig. 2 Result of cluster analysis (Word's methods). Upper panel shows the dendrogram obtained by cluster analysis and the lower panel shows the species composition by fishing trip corresponding to each cluster.



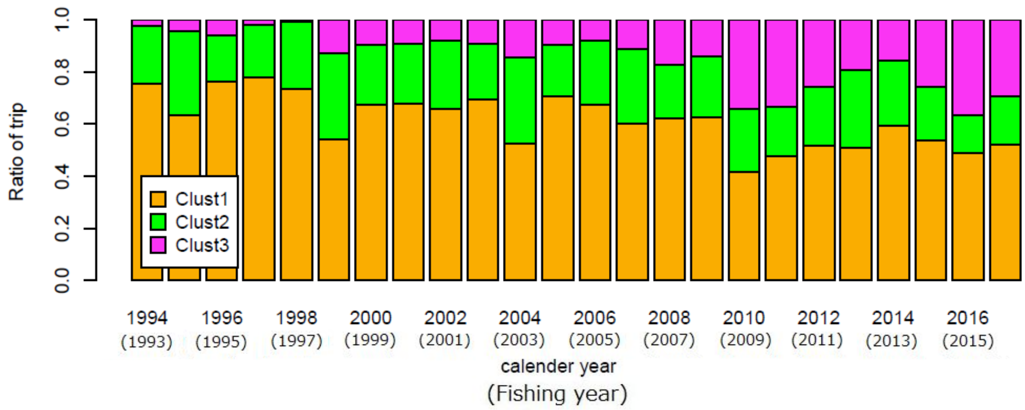


Fig. 3 Yearly change of the number and ratio of fishing trip grouped in each cluster.

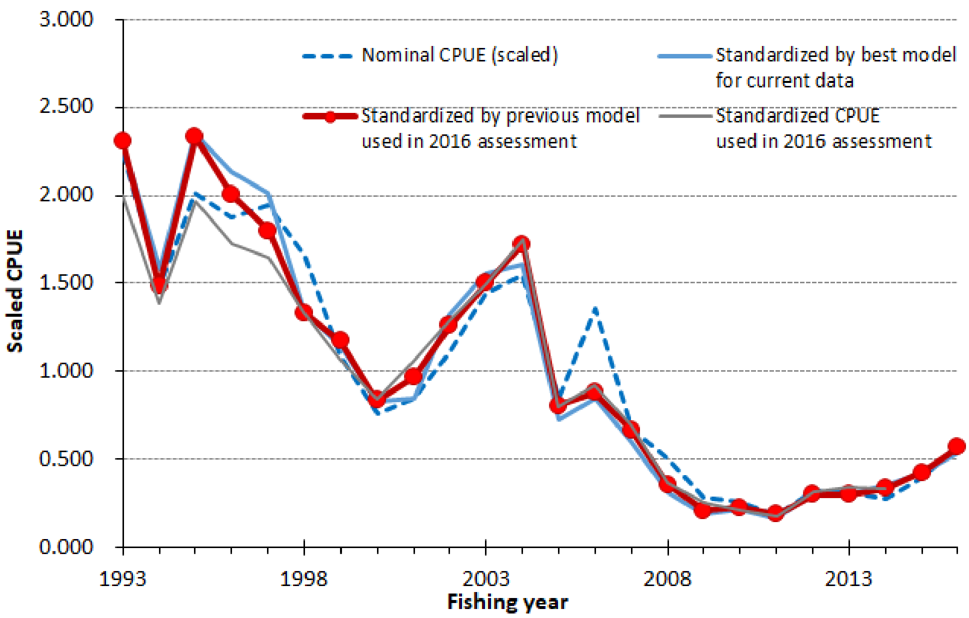


Fig. 4 Scaled standardized CPUE and nominal CPUE. Red circle and solid blue line indicate the result of updated CPUE standardized by previous model and best model, respectively. Gray line indicates the standardized CPUE used in the stock assessment in 2016. Dotted line shows the nominal CPUE.

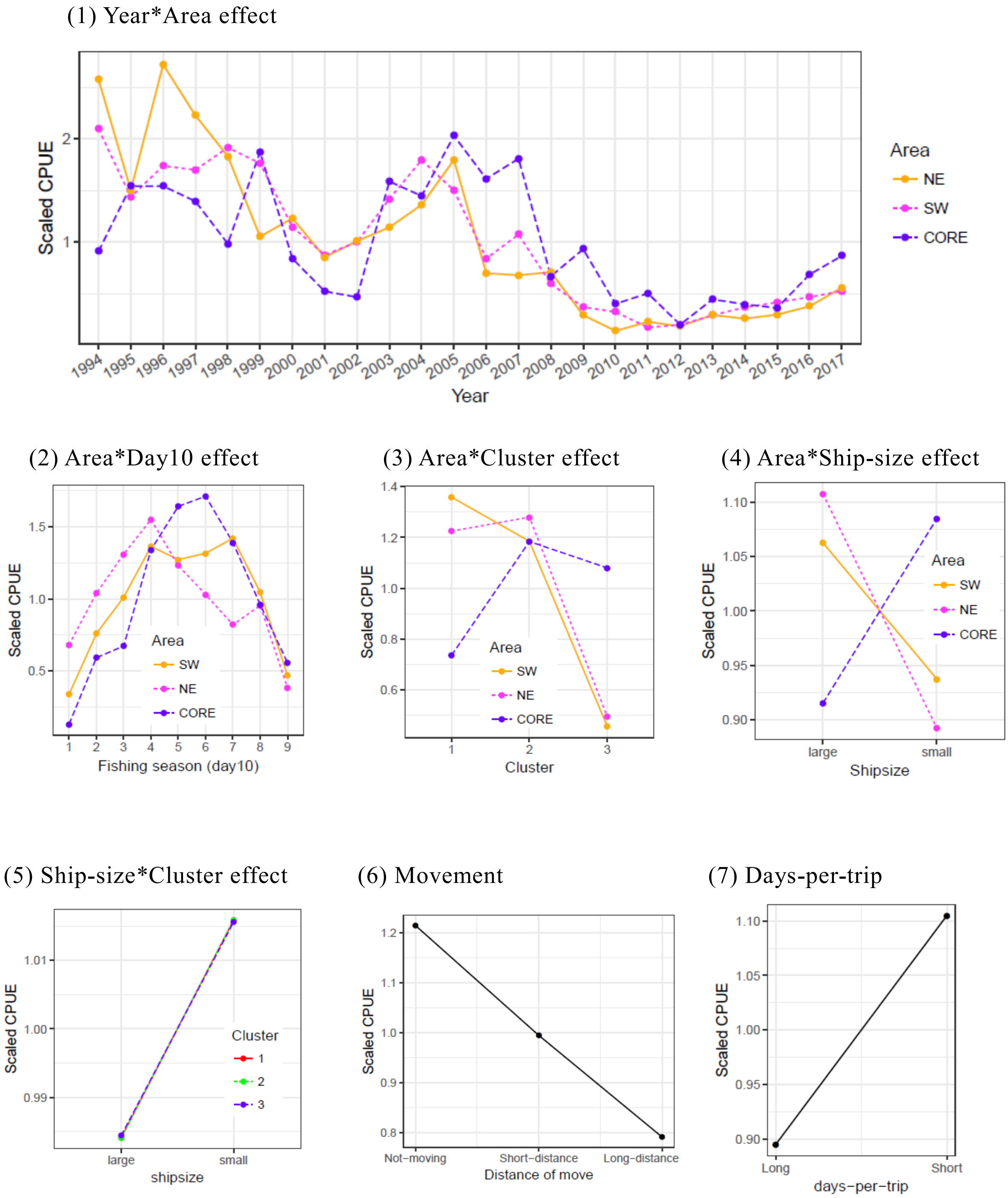


Fig. 5 Least squared means for each effect estimated by “Previous model”.

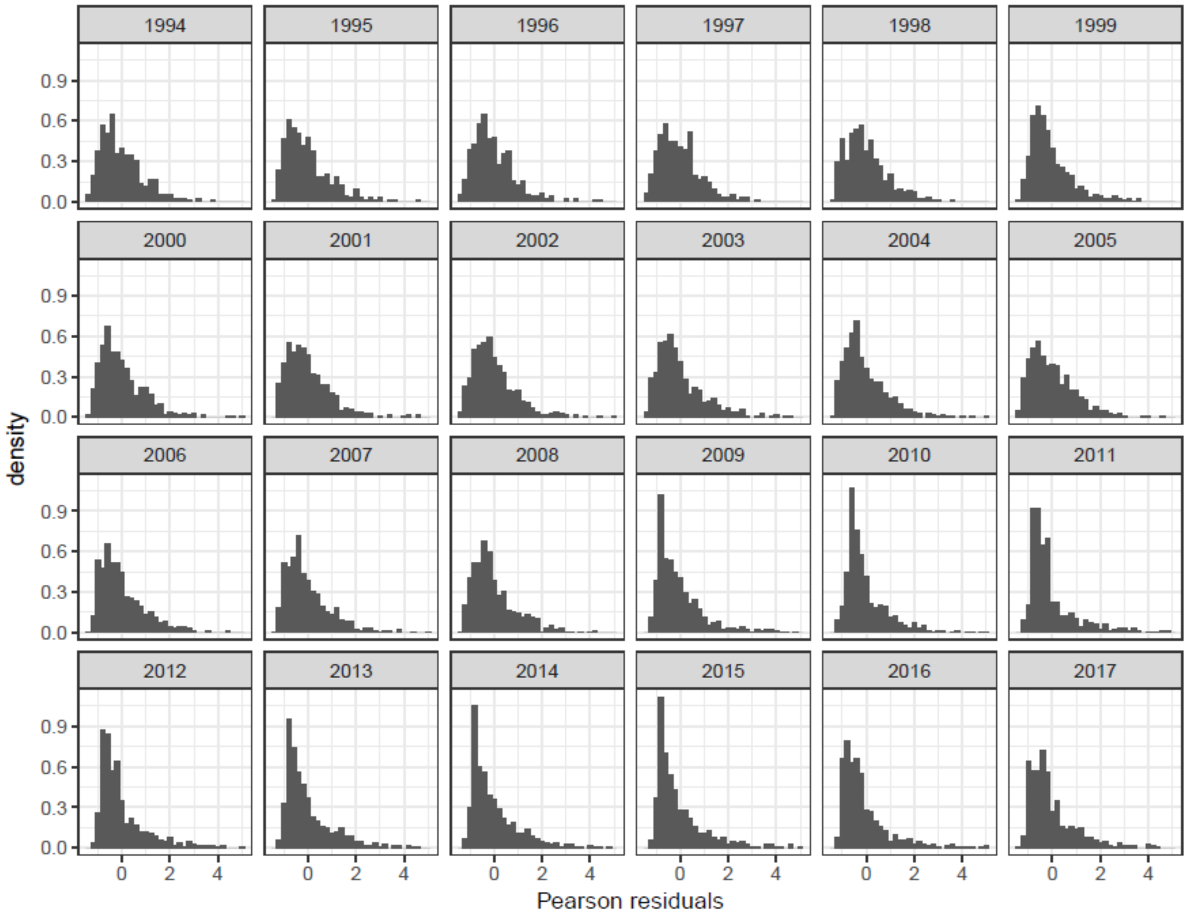


Fig. 6 Pearson residual distribution for ZINB for "Previous model" by year.

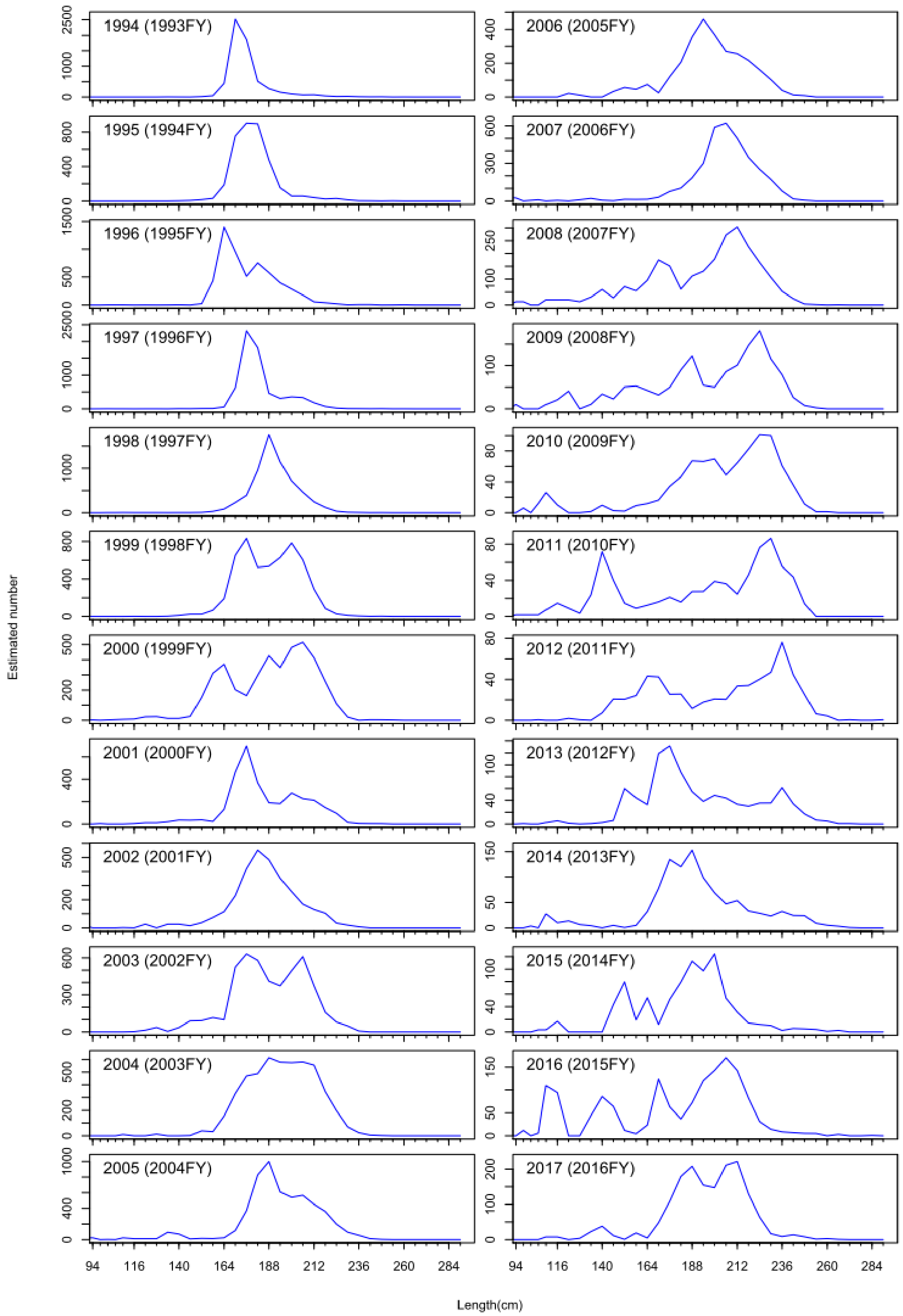
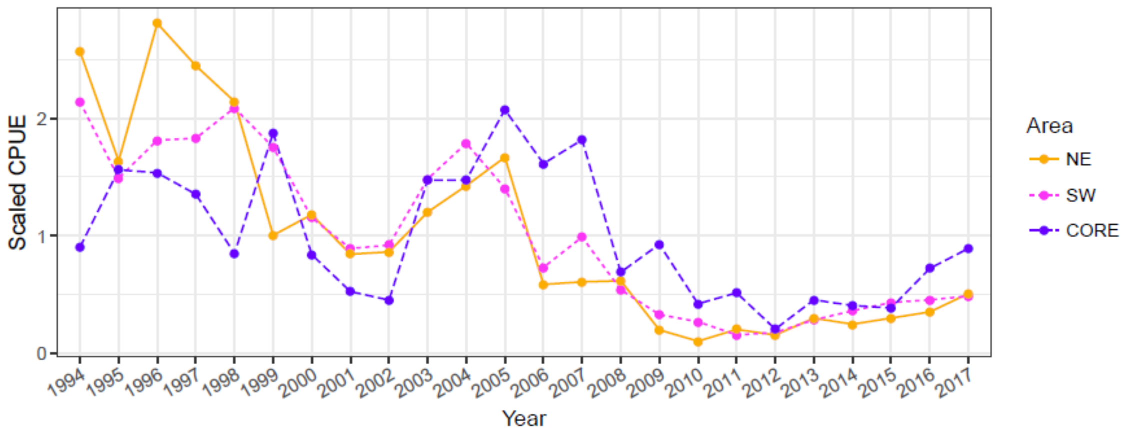


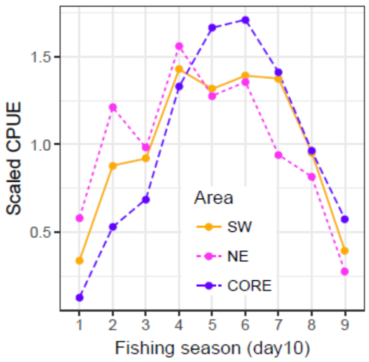
Fig. 7 Estimated catch-at-size of PBF caught by Japanese coastal longliners in 2nd quarter of calendar year. The catch-at-size in 2017(2016FY) is preliminary.

Appendix 1

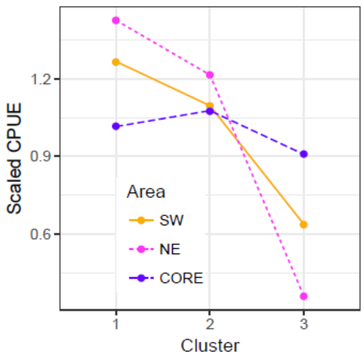
(1) Year*Area effect



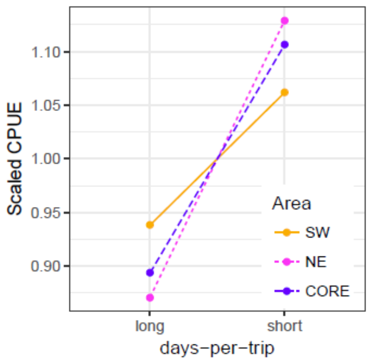
(2) Area*Day10 effect



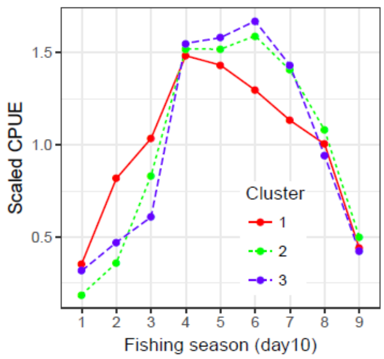
(3) Area*Cluster effect



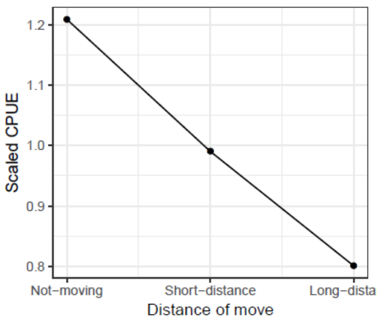
(4) Area*Day-per-trip effect



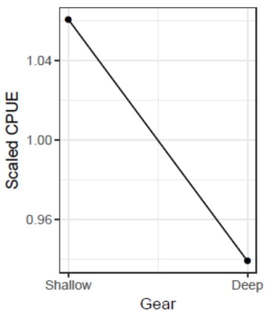
(5) Day10*Cluster effect



(6) Movement



(7) Gear



(8) Ship-size

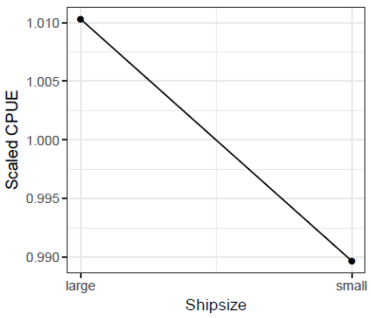


Fig. Least squared means for each effect estimated by "Best model".