Japanese coastal longline CPUE and catch-at-length for Pacific bluefin tuna: Update up to 2017 fishing year

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Summary

Japanese coastal longline CPUE and catch-at-length were updated up to 2017 fishing year. The CPUE was standardized by the best model based on Bayesian Information Criteria using the updated dataset until June 2018 in the same procedure used for the previous stock assessment in February 2016 and March 2018. The result showed considerable low value in 2018 which is likely to be caused by the constraint of operations due to fishery management for Pacific bluefin tuna in Japan. This paper, therefore, also presents an ad-hoc CPUE estimated by reduced data in accordance with constraint in 2017 fishing year. This result showed different trend from simply updated one in 2017 fishing year, but consistent trend in the other years, continuously increasing from 2011 fishing year. Additionally, catch-at-length by Japanese longliner was updated. This catch-at-length was also constrained by the same reason as CPUE, thus the catch-at-length using reduced data in accordance with constraint of longline operation was estimated. Moreover, one possible improvement for expanding strata in catch-at-length was described. These will help us to discuss about a direction for the next benchmark assessment in 2020.

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, ISC 2018).

Because of the changes of operational patterns of Japanese longliners, the CPUE was split into three time-series; fishing year (FY) 1952-1973 (Fujioka et al. 2012), 1974-1992 (Yokawa 2008), and after 1993. The current CPUE series (after 1993) used since 2016 assessment has been standardized by zero inflated negative binomial (ZINB) model (Sakai et al. 2016, Sakai and Tsukahara 2018). The ZINB model was applied to standardize the CPUE which was based on the aggregated data in fishing trip resolution. The cluster indicator in the current model as explanatory variable is based on the catch composition by species, except for PBF, in each fishing trip, which could represent the target shift of this fishery. Although the approach using cluster analysis is a common method for the CPUE analysis (e.g. He et al. 1997, McKechnie et al. 2014, Tremblay-Boyer et al. 2015), it was found that the clustering algorithms could be the cause for retrospective change of standardized CPUE (ISC 2017).

Additionally, the regulation for adult PBF, greater than 30kg, since 2015 FY has impacted Japanese longline fisheries, especially in 2017 FY. The great part of longliners stopped their operations and landings in the middle of main fishing season because their catch amount almost reached their own quota. The artificially imposed restriction of fishing operations led to disturbance of fishing information and misinterpretation of indices estimated from the information. It is therefore necessary to understand whether the lack of information led to bias in the standardization.

The primary purpose of this document is to show updated indices for the adult PBF population and catch-and-length. This document presents two kinds of updated CPUE series for detecting trends of adult PBF. One was using the same data filtering and procedure which were used for the previous stock assessment in 2018, hereinafter called “simple update”. The other was the same as the previous one, except that data in constraint period were filtered out from original data in 2017 FY, which could be regarded as without constraint, hereinafter called “ad-hoc update”. Three kinds of catch-at-length for checking the size composition of caught adult PBFs in the most recent year were also presented. In addition to the catch-at-length corresponding to the two CPUEs above, the third one was changing the area strata to correspond it in CPUE standardization.

Materials and Methods

1) CPUE

Data sources and filtering

Catch and effort data from logbooks of Japanese coastal longliners from 1994 to 2018 (calendar year) were used for the CPUE analysis. The data resolution is originally set-by-set, and each contains individual records of fishing operation: location (latitude and longitude) of longline set, the number of hooks per set, hooks per basket (hpb), and the number of fish caught of various species. The set-by-set data were filtered through the following criteria described by the previous documents and were aggregated in each trip (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.

The number of hooks and catches were added up, and median values of location and hpb were calculated 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).

The present paper also reports the impacts of regulation for adult PBF on CPUE by longline in 2017 fishing season. In the middle of the main fishing season in 2017 FY (May 2018), the catch amount by the nation-wide cooperative of longliners grew close to their annual catch quota. Therefore, the longliners in the cooperatives refrained from operations and landings after May 20th 2018 voluntarily. This would alter the nature of operation data because there was little information in almost half of analysis objectives only in 2017 FY. A standardization as “ad-hoc update” were therefore conducted using the data which have trips entering landing ports only before artificial constraint in 2017 FY (May 20th 2018). This index can avoid the issues of constraint of operation, though it seems to be somewhat biased compared to previous one because of difference in data period between 2017 FY and the others.

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 detail of the two types of data used for standardization were shown in Table 1. ZINB allows "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). The two standardization models were determined by exploration of "best model" which was selected by Bayesian Information Criteria (BIC). The candidate explanatory variables used in this analysis were as follows;

- **Year**: 25 calendar years, from 1994 to 2018 (1993 to 2017 FY);
- **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.1) 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 CPUEs were defined as the least square means (LSMEANS) estimated in best models. The CV was calculated using bootstrapping about 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

Data sources

The catch-at-length of PBF caught by Japanese longliners was estimated using size-measurement and sales slip data for longline which were obtained at 13 main landing ports (7 prefectures), mainly collected by the "Research Project on Japanese bluefin tuna (RJB)". These ports have some longliners who belong to local fishery cooperatives, which could continue the operation because of their separate catch quota from nation-wide fishery cooperative. Some size-measurement data from other research projects such as observer data were also used. The data from April to June during 1994 to 2018 calendar years (1993 to 2017 FY) was used, in accordance with the “simple update” CPUE. The data in the latest year should not be considered complete due to delay of data collection, thus the result of catch-at-length in 2017 FY is preliminary. In accordance with the “ad-hoc update” of CPUE, the catch-at-length using data only from 1st April to 19th May (data from 20th May to 30th June excluded) of 2017 FY was also estimated.

Estimating method

The catch-at-length was estimated using the same method as proposed by Hiraoka et al. (2015b) and one trial change only for area stratum was also examined. 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 estimating 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 number of 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 area stratum k at time stratum t for year y. w_{iykt} is the weight of them. c_{ykt} is the total catch weight in area stratum k at time stratum t for year y. As the time stratum, a quarter (1 stratum: only 2nd quarter of calendar year) was used. This estimating method and data from some longline operations which weren’t be constrained even after the voluntary cessation of nation-wide association enabled catch-at-length in 2017 FY to be estimated in a similar manner to those in the other years, unlike the CPUE data. For the area stratum, there are 2 candidates of stratification; one is “prefecture strata”, which is the same with previous works, using 6 groups (Miyagi, Chiba, Wakayama, Miyazaki, Okinawa, and Others); the other is “CPUE area strata”, using 3 groups (“CORE”, “NE”, and “SW”) defined at the CPUE analysis described above. Here, the size information for new area stratification was calculated using the whole data up to June 2018. The Area definition of size information more coherent with CPUE standardization may be an option which could be considered further for the next benchmark assessment.

Results and Discussion

Data and nominal CPUE

In total, 14,484 fishing trips were recorded in the dataset for “simple update”, among which 161 trips, that occurred after the date of voluntary closure, were excluded for “ad-hoc update” (Table 1). The data in recent years, especially in the latest year, is being updated continuously. The number of fishing trip in 2016 FY was above the one in 2015 FY by this update. The declining trend of number of fishing trips from 2008 FY seems to have stopped. Nominal CPUE in 2017 FY for “simple update” was lower than in 2016 FY, although it was higher for “ad-hoc update”. This inconsistency is due to the fact that Nominal CPUE after constraint of operations was much low (Fig. 2). Figure 3 shows the difference of the geographical patterns of sum of efforts in recent 3 year before and after the middle of May 2018. After middle of May, operations were concentrated in “core” area, while obliviously decreasing in the other area. Therefore, the restriction in 2017 would have reduced operations in “Core area” more than in the other two areas. The reduced data led to not only decreasing data but to change of the nature of data.

Cluster analysis

The cluster analysis divided the fishing trips into three groups (Table 2). Species compositions of Cluster 1 and 3 showed that they generally represent targeting ALB and YFT, respectively. In Cluster 2, the highest proportion was other species. These characteristics of clusters were roughly consistent between “simple update” and “ad-hoc update”, although the rates of the number of trips divided into each cluster changed as shown in Table 3. Cluster 2 in “simple update” have second most trips while it has the fewest trips among three cluster in “ad-hoc update”. The number of trips among clusters in previous update (Sakai and Tsukahara, 2018) were similar to “simple update”. This difference could affect the result of standardization.

Update of standardized CPUE by previous model

ZINB models used for standardization of “simple update” and “ad-hoc update” were as below. BIC values for “simple update” and “ad-hoc update” were 59266.53 and 59004.01, respectively. Note that these were not comparable value because the numbers of data in each dataset were different due to filtering in 2017 FY.

[The best model for “simple update” standardization]

(Count model)

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

(Zero-inflation model)

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

[The best model for “ad-hoc update” standardization]

(Count model)

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

(Zero-inflation model)

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

These models had the interaction effects between Year and Area, thus the area weighting value for LSMEANS were calculated as the standardized CPUE. Both CPUEs matched closely to the index used in the 2018 assessment up to 2016 FY; in 2017 FY, the standardized CPUE in "simple update" showed decline while "ad-hoc update" CPUE showed continuous increasing trend (Fig. 4). As "simple update" CPUE contains data after voluntary closure for PBF, "ad-hoc update" CPUE is considered more appropriate to evaluate the trend of SSB in 2017 FY.

Figure 5 shows the effect of each explanatory variable in the "ad-hoc update". The Year*Area effects (Fig. 5-(1)) in "ad-hoc update" keeps increasing trends only in Core and NE area while trends in SW shows decrease. This is inconsistent with the previous update (Sakai and Tsukahara, 2018), where the indices in all three areas exhibited increasing trend. The Area*Day10 effects (Fig. 5-(2)) shows the peaks in SW area after the middle of May. It indicates that the year effect was underestimated only in 2017 FY because there were no records during their highest fishing season in SW. These vulnerability of "ad-hoc update" require further consideration on how to deal with effects of regulation for next benchmark assessment. The detailed result in the "simple update" are also shown in present paper (Appendix, Fig. A1, Fig. A2).

Catch-at-length for "simple" and "ad-hoc" updates

Estimated catch-at-length data for "simple update" shows that the main part of the Japanese coastal longline catch has been constituted by some strong cohorts (Fig. 7: blue lines). For example, the previous catch had been composed of the strong cohorts of 1990 and 1994 year-classes until 2011 FY. In addition, 2007 and/or 2008 year-class increased and started to consist a strong cohort in 2010 FY. These results correspond to the size and age compositions of PBF caught by Taiwanese longline (Shiao 2017), which reported that 2005-2009 year-cohorts increased in 2013-2015 after strong 1994 and 1996 year-cohorts decreased.

In 2017 FY, the main size of PBF caught by Japanese coastal longliners were 188-212 cm FL which would cover several cohorts consisted of not only 2007 and/or 2008 year-class but also 2010 and/or 2011 year-class, which has been seen since 2014 FY. In addition, the length frequencies indicate some moderate modes for relatively smaller fish since 2015 FY. Continuous recruitment for catch by longliners seems to be a positive sign for adult population of PBF. However, this inference on the modes of small fish almost depends on the measurement data in a few prefectures, where the coverage rate of the actual measurements to the total catch is relatively low. Thus, it is necessary to modify the number of actual measurement corresponding to catch for accurate estimation of the size composition.

Additionally, in accordance with the "ad-hoc update" of CPUE, the catch-at-length based on the data from 1st April to 19th May in 2017 FY was also estimated (Fig. 8: red line). Compared with that of "simple update" (1st April to 30th June, Fig. 8: blue line), the estimated number was greatly decreased for "ad-hoc update" in larger fish. It is considered that this reduction of the number was caused by excluded catch data at Okinawa prefecture, where larger fish are usually caught during the period of voluntary closure.

Catch-at-length with trial change of area stratum

In accordance with the CPUE standardization, the catch-at-length with “CPUE area strata” was also estimated, using data up to June 2018 (Figure 7: black lines). It is almost similar with that was estimated using the “prefecture strata” from the previous assessments, except that the number of smaller fish, which were usually caught in NE area, was lower in recent years (2014-2016 FY). Figure 9 and 10 show the change of catch at length by year by prefecture and by CPUE area, respectively. The catch-at-length estimated by CPUE area seems to reflect the changes of the mode due to the growth of fish of each area, as opposed to “prefecture” strata. For example, it can be seen that small fish which were caught in NE area, corresponding to in Miyagi and Chiba prefecture, and had been seen since 2009 FY grew gradually, and 3 years later these fish became larger and started to be caught also at CORE area, where much larger fish had been caught. The continuous appearance of small fish caught at NE area in recent years (since 2009 FY) is also observed clearly in this result.

Conclusion

Japanese longline CPUE were updated following the procedure of the last benchmark assessment. This update was much affected by constraint of operations in 2017 FY. The constraint of operations led to drastic change of Nominal CPUE before and after it was initiated. Therefore, “ad-hoc update” which uses data only before the restriction seemed to be appropriate for standardization. The result of “ad-hoc update” had some inconsistency with previous one, although it followed recent trends, increasing since 2011 FY.

Catch-at-length of PBF caught by Japanese longliners was also updated. Current strong cohorts were constituted with wide range of year classes and some moderate modes for relatively small fish were observed since 2015 FY. These results can be positive information for the PBF stock. In addition, catch-at-length was estimated by “CPUE area” in accordance with CPUE standardization as a trial change of the area stratum. It also showed similar trends, for example the increase of small fish at NE area in recent years, and it could be consistent with CPUE information.

The “ad-hoc update” CPUE was just an ad-hoc apporach for checking the trend of adult abundance in 2017 FY. This has had considerable vulnerability and different characteristic based on catch-at-length. It is necessary to consider how to deal with constraint of operations for next benchmark assessment.

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Table 1 Total number of fishing trips, hooks, PBF catch, nominal CPUE, and standardized CPUE for "simple update" and "ad-hoc update". The 2nd lowest row without asterisk showed "simple update" and the lowest one with asterisk showed "ad-hoc update" in most recent year.

Calender year	Fishing year	Dataset for update analysis				Standardized CPUE by "simple update"			Standardized CPUE by "ad-hoc update"			Standardized CPUE in previous document		
		N of trip	N of hooks (x1000 hooks)	N of PBF catch	Nominal CPUE	Std. CPUE	Scaled Std. CPUE	CV	Std. CPUE	Scaled Std. CPUE	CV	Std. CPUE	Scaled Std. CPUE	CV
1994	1993	362	5275	2899	0.550	0.391	2.374	0.030	0.437	2.294	0.038	0.435	2.307	0.039
1995	1994	323	4679	1710	0.365	0.251	1.526	0.037	0.289	1.516	0.047	0.280	1.484	0.034
1996	1995	363	5180	2561	0.494	0.407	2.473	0.035	0.442	2.319	0.045	0.439	2.329	0.029
1997	1996	383	5477	2526	0.461	0.352	2.136	0.033	0.385	2.022	0.061	0.377	2.002	0.034
1998	1997	420	6307	3010	0.477	0.311	1.889	0.030	0.351	1.842	0.059	0.339	1.797	0.035
1999	1998	713	9866	4028	0.408	0.211	1.279	0.034	0.254	1.334	0.036	0.251	1.333	0.031
2000	1999	636	8895	2366	0.266	0.198	1.203	0.030	0.229	1.205	0.030	0.222	1.176	0.031
2001	2000	611	10002	1878	0.188	0.138	0.836	0.027	0.159	0.835	0.035	0.158	0.836	0.031
2002	2001	643	10353	2151	0.208	0.155	0.940	0.026	0.184	0.964	0.055	0.182	0.967	0.025
2003	2002	692	10684	2882	0.270	0.217	1.318	0.026	0.244	1.280	0.029	0.238	1.260	0.025
2004	2003	750	10953	3852	0.352	0.253	1.537	0.022	0.292	1.532	0.024	0.283	1.503	0.031
2005	2004	668	10807	4081	0.378	0.283	1.719	0.021	0.330	1.736	0.040	0.324	1.720	0.024
2006	2005	705	10453	2139	0.205	0.133	0.808	0.029	0.156	0.818	0.059	0.152	0.807	0.030
2007	2006	682	10121	3311	0.327	0.144	0.877	0.034	0.166	0.874	0.041	0.166	0.882	0.036
2008	2007	683	10311	1705	0.165	0.111	0.677	0.035	0.131	0.686	0.060	0.126	0.670	0.035
2009	2008	744	11947	1481	0.124	0.059	0.361	0.077	0.073	0.382	0.159	0.068	0.361	0.089
2010	2009	722	11375	808	0.071	0.034	0.209	0.071	0.041	0.216	0.085	0.040	0.214	0.065
2011	2010	687	10250	693	0.068	0.044	0.267	0.089	0.050	0.265	0.128	0.043	0.228	0.078
2012	2011	682	11108	497	0.045	0.031	0.191	0.064	0.037	0.196	0.126	0.035	0.188	0.065
2013	2012	648	10432	816	0.078	0.051	0.309	0.059	0.059	0.312	0.061	0.057	0.302	0.065
2014	2013	644	10553	810	0.077	0.052	0.316	0.040	0.060	0.317	0.046	0.057	0.301	0.040
2015	2014	654	9840	681	0.069	0.064	0.386	0.048	0.071	0.372	0.049	0.064	0.337	0.051
2016	2015	623	9178	905	0.099	0.074	0.451	0.051	0.085	0.448	0.075	0.080	0.426	0.057
2017	2016	712	10399	1383	0.133	0.096	0.581	0.039	0.112	0.586	0.055	0.107	0.569	0.034
2018	2017	429	5508	693	0.126	0.056	0.337	0.138						
2018*	2017*	268	4063	655	0.161				0.124	0.650	0.187			

Table 2 Species composition by each cluster for "simple update" and "ad-hoc" update.

	simple update			ad-hoc update		
	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
Yellowfin tuna	4.1%	35.1%	83.4%	4.5%	29.2%	73.2%
Albacore	81.5%	20.9%	4.0%	79.8%	12.7%	11.1%
Bigeye tuna	8.6%	2.0%	0.6%	8.3%	1.8%	1.0%
Other species	5.7%	41.9%	12.0%	7.3%	56.3%	14.7%

Table 3 The number of trips allocated into clusters.

fishing year	simple update			ad-hoc update			2018 assesment		
	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3	Cluster 1	Cluster 2	Cluster 3
1993	221	132	9	258	77	27	273	80	9
1994	163	146	14	183	110	30	205	104	14
1995	252	87	24	265	53	45	277	64	22
1996	269	106	8	284	56	43	299	76	8
1997	223	192	5	276	122	22	309	108	3
1998	339	279	95	382	135	196	386	237	90
1999	393	178	65	416	81	139	428	147	61
2000	364	189	58	398	126	87	415	141	55
2001	355	231	57	395	153	95	423	167	52
2002	450	178	64	469	118	105	479	145	64
2003	358	273	119	376	182	192	391	248	107
2004	415	181	72	453	118	97	468	131	64
2005	464	184	57	471	149	85	467	171	55
2006	393	208	81	405	148	129	403	191	75
2007	410	148	125	418	85	180	418	140	116
2008	460	171	113	463	120	161	466	174	103
2009	286	181	255	297	74	351	300	172	247
2010	307	142	238	320	49	318	323	129	226
2011	334	164	184	342	57	283	352	155	174
2012	295	216	137	315	78	255	329	194	124
2013	363	181	100	371	93	180	374	156	99
2014	327	149	178	349	59	246	348	135	166
2015	302	90	231	308	48	267	295	87	221
2016	336	154	222	343	69	300	286	101	162
2017	147	88	194	160	12	96			
Whole Rate	54%	28%	18%	58%	16%	26%	60%	24%	16%

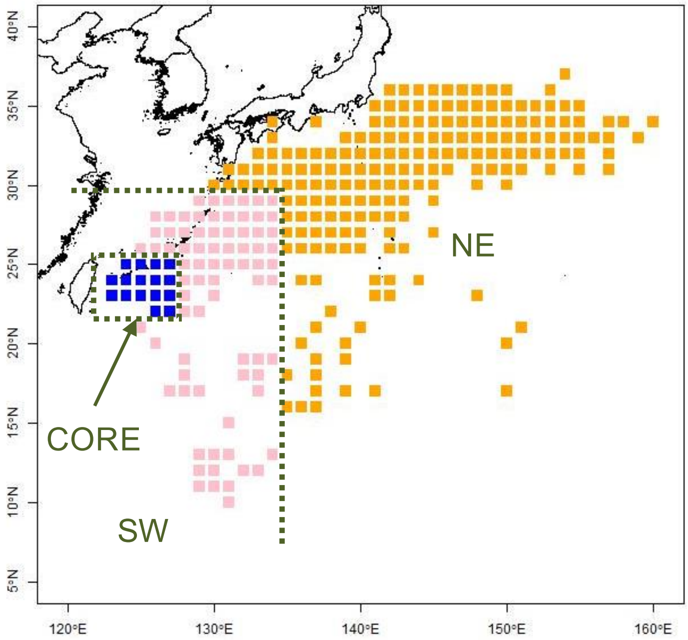


Fig. 1 Area definition for the analysis. According to Hiraoka et al. (2015a), the fishing ground was divided into three sub-area ("CORE", "SW", and "NE") for the standardization of CPUE.

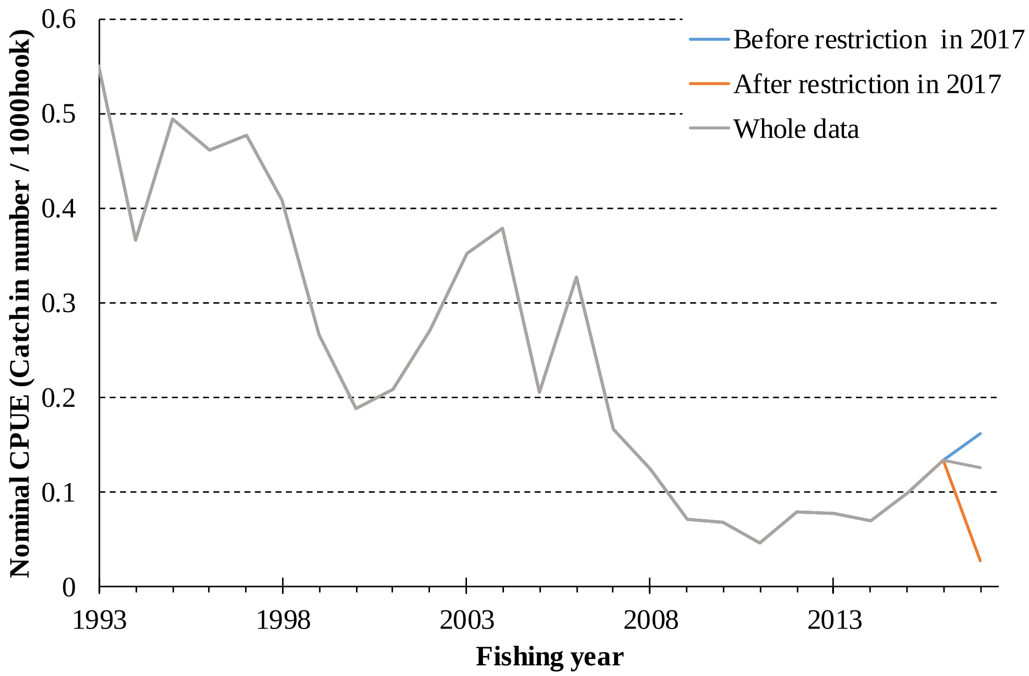


Fig. 2 Time series of Nominal CPUE. Nominal CPUEs are different because of constraint in 2017 Fishing year.

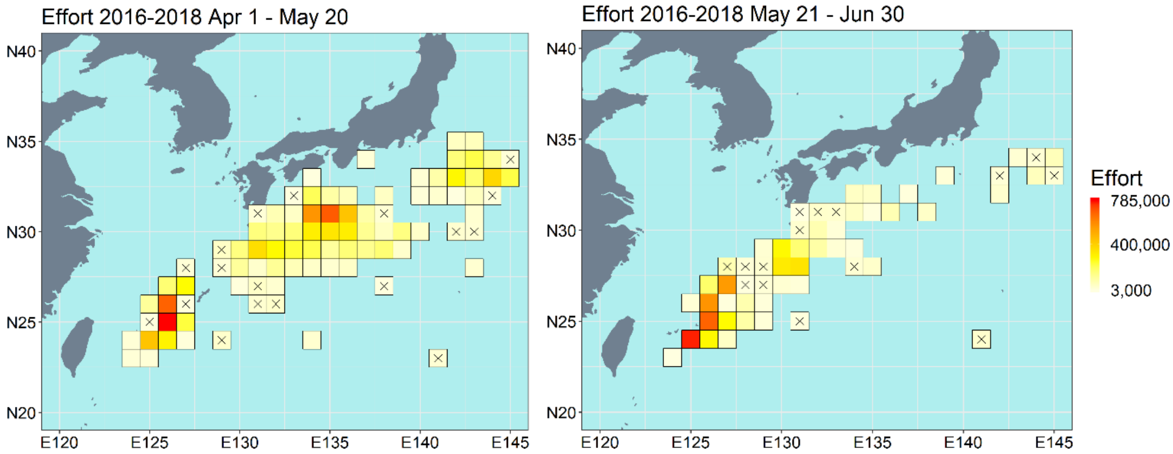


Fig. 3 Spatial distribution of efforts (hooks) by longliner. Left panel shows the operation before May 20th, middle of May where the constraint of operation would start. Right panel shows after May 21th.

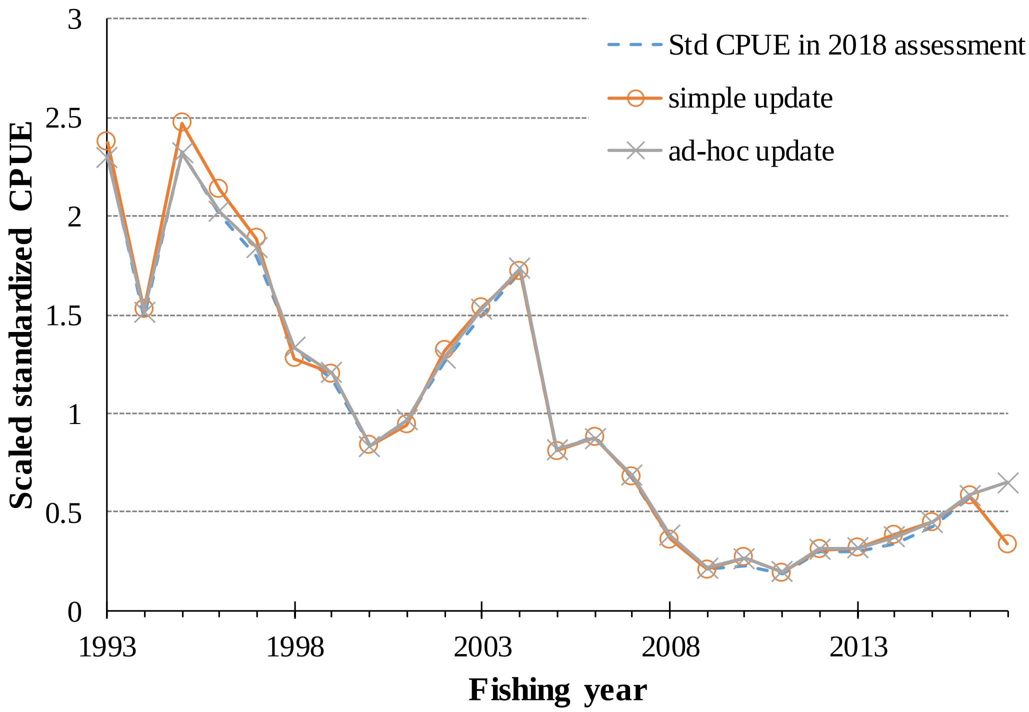
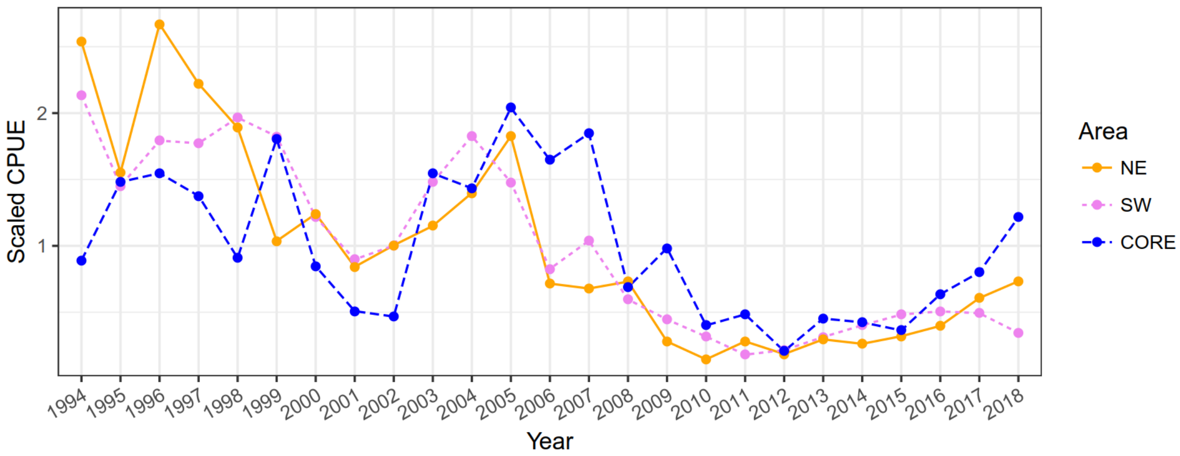
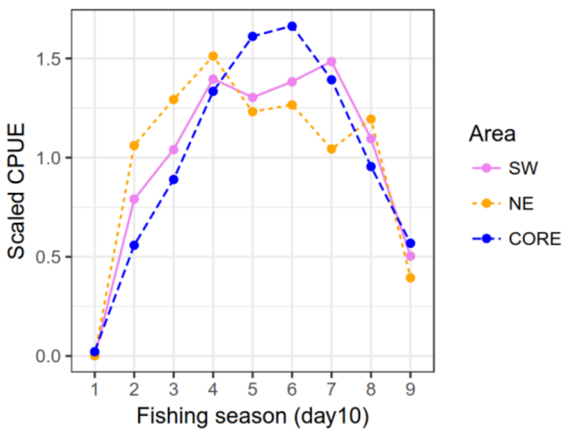


Fig. 4 Time series of three scaled standardized CPUEs. Orange circles and solid line indicate the result of updated CPUE of "simple update". Gray crosses and solid line indicate the result of updated CPUE of "ad-hoc update". The blue dashed line shows standardized CPUE used in 2018 stock assessment for abundance index of adult PBF.

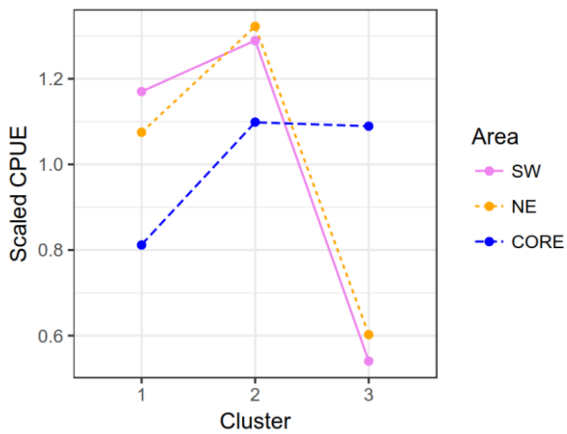
(1) Year*Area effect



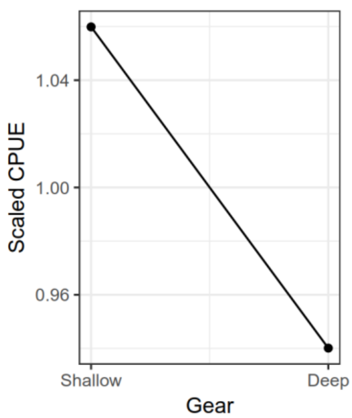
(2) Day10*Area effect



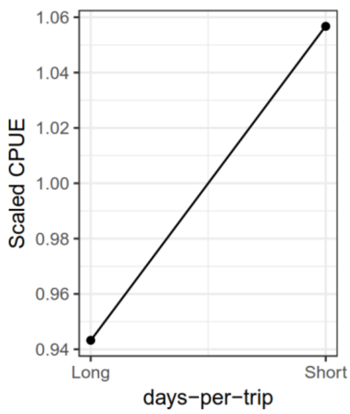
(3) Area*Cluster effect



(4) Gear



(5) Days-per-trip



(6) Movement

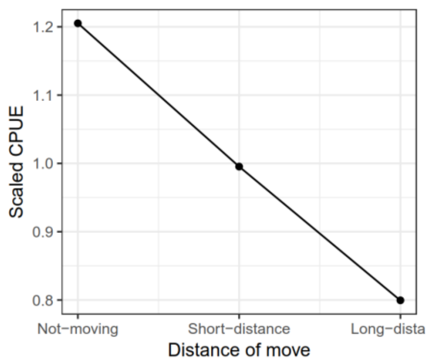


Fig. 5 Least squared means for each effect estimated by "ad-hoc update".

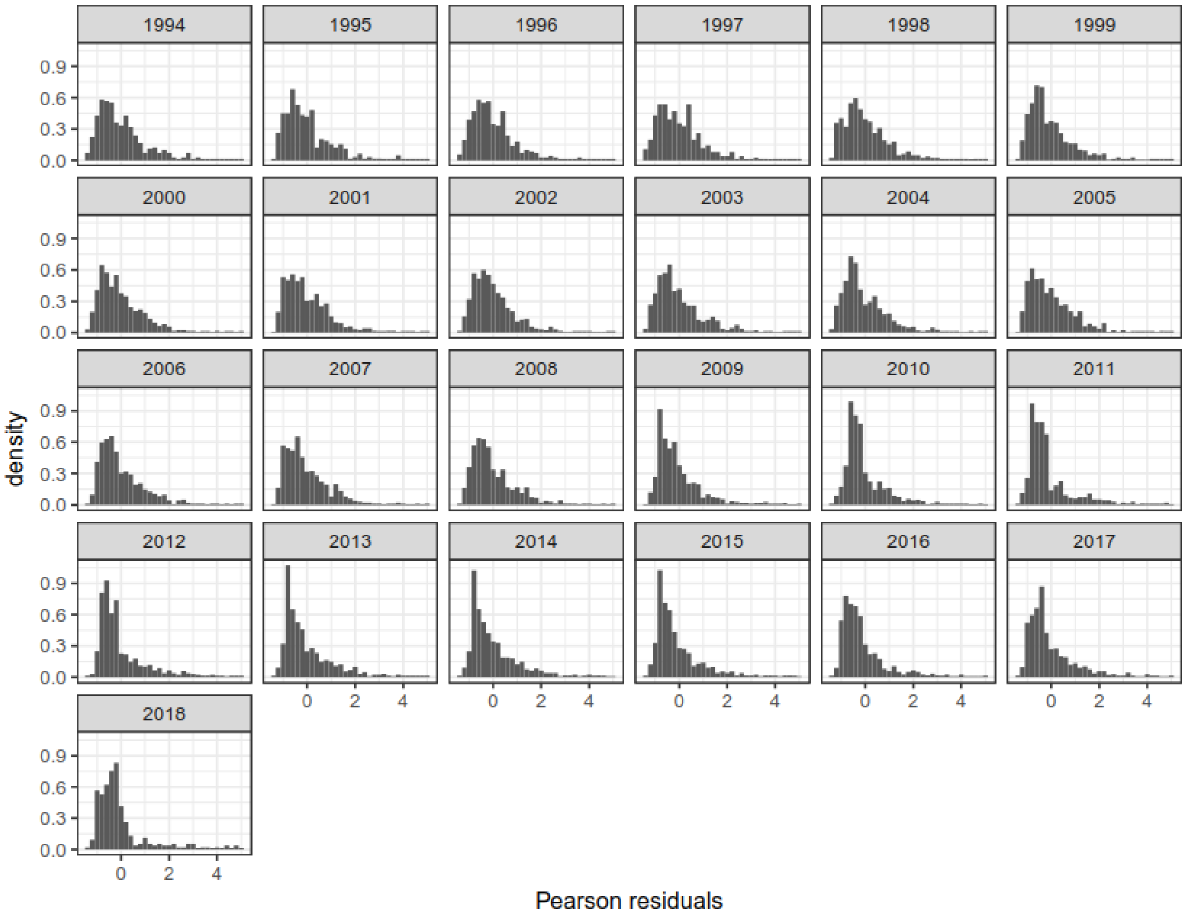


Fig. 6 Pearson residual distribution for ZINB for "ad-hoc update" by year.

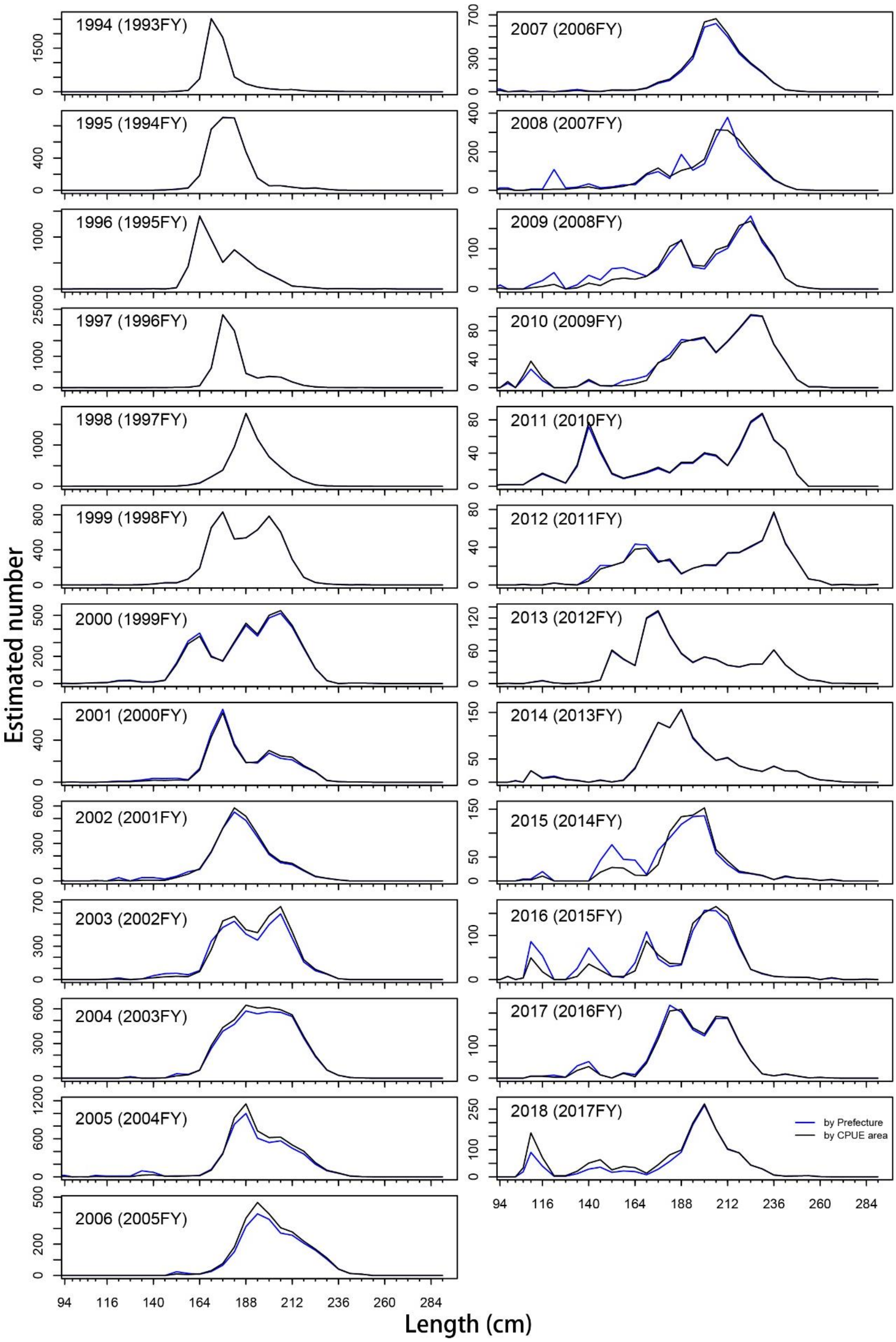


Fig. 7 Estimated catch-at-length of PBF caught by Japanese coastal longliners in 2nd quarter of calendar year. Blue and black lines indicate fish numbers estimated by prefectures and by CPUE areas, respectively. The catch-at-length of 2017 FY is preliminary.

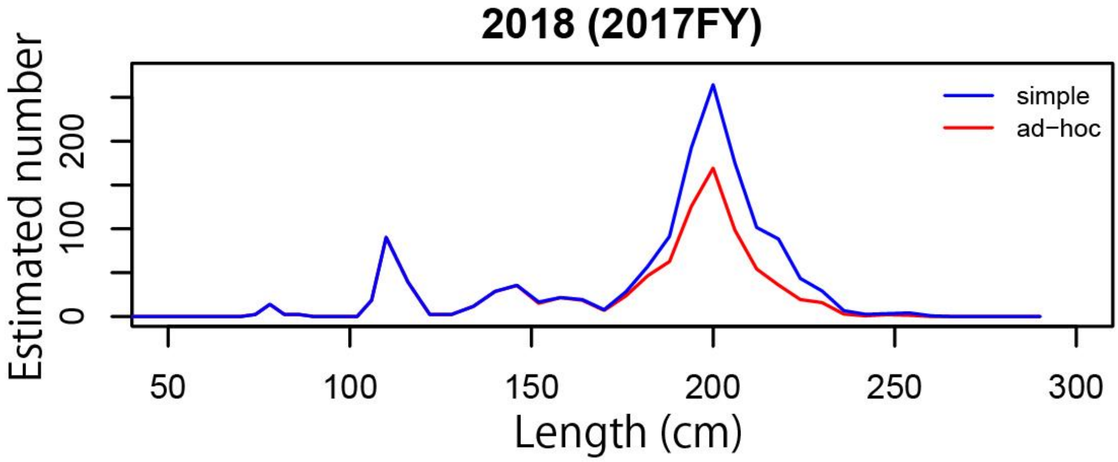


Fig. 8 Preliminary catch-at-length of 2017 FY in accordance with "simple" (blue) and "ad-hoc" (red) updates of CPUE.

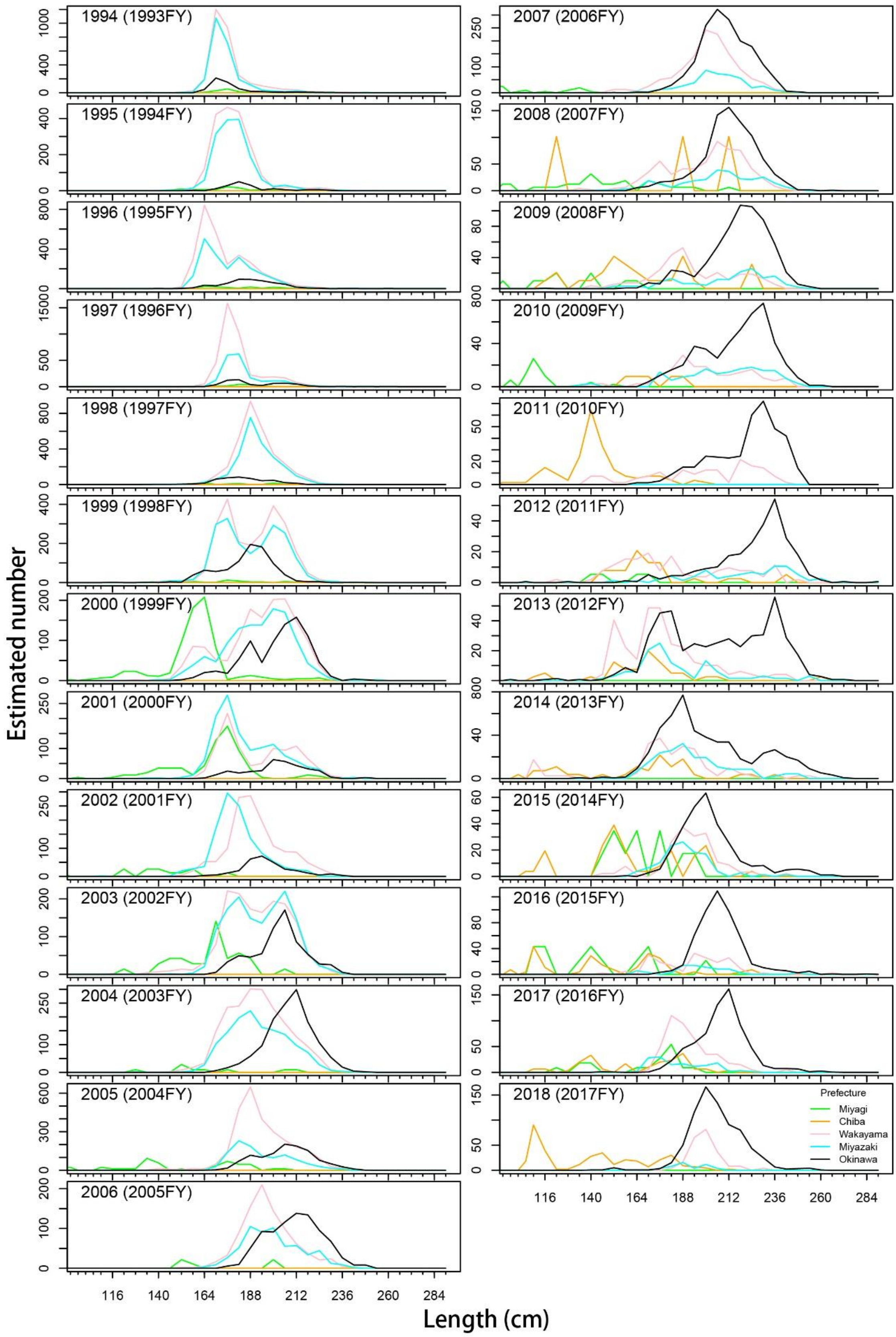


Fig. 9 Estimated catch-at-length for each "prefecture". Green, Miyagi; yellow, Chiba; pink, Wakayama; light blue, Miyazaki; black, Okinawa.

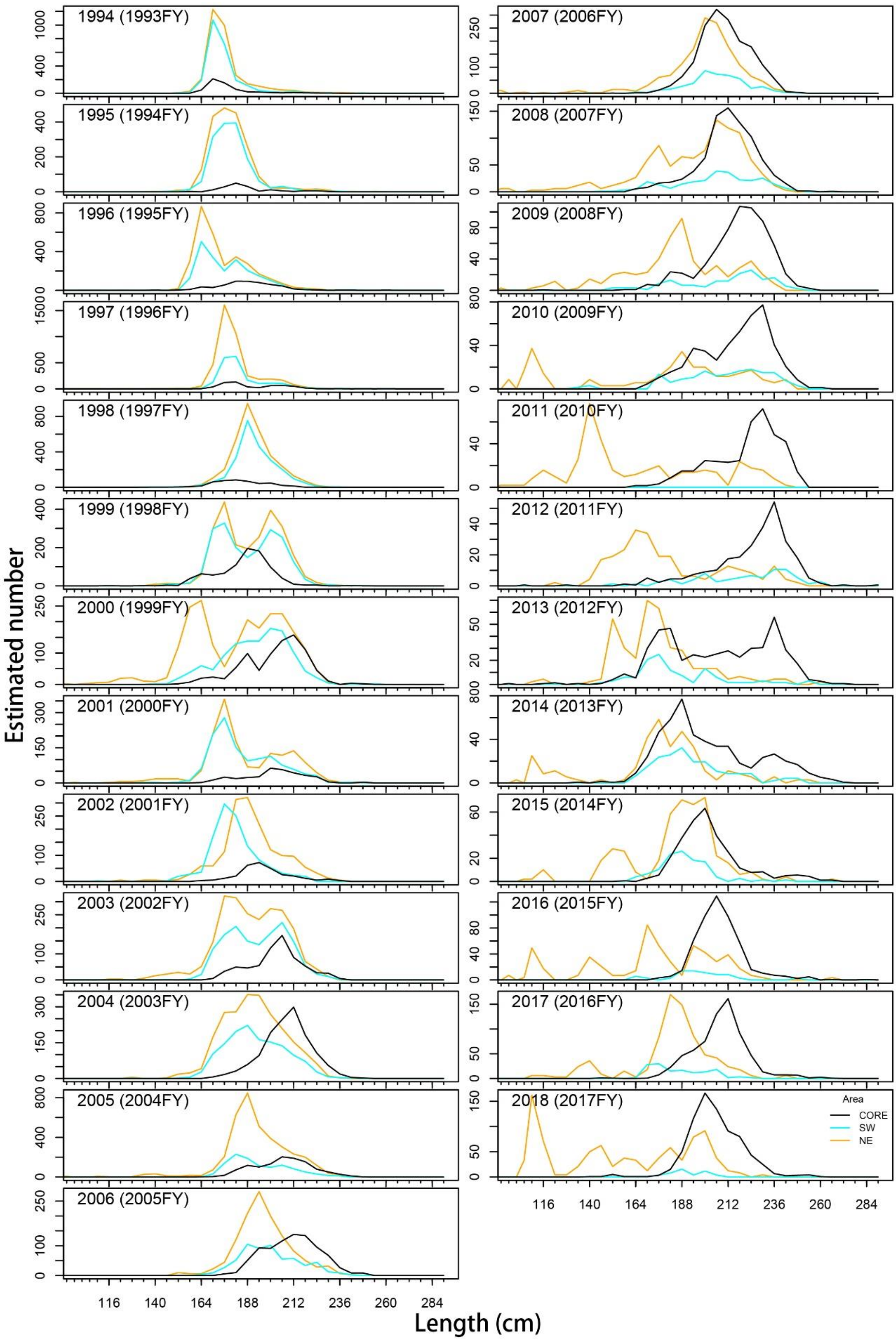
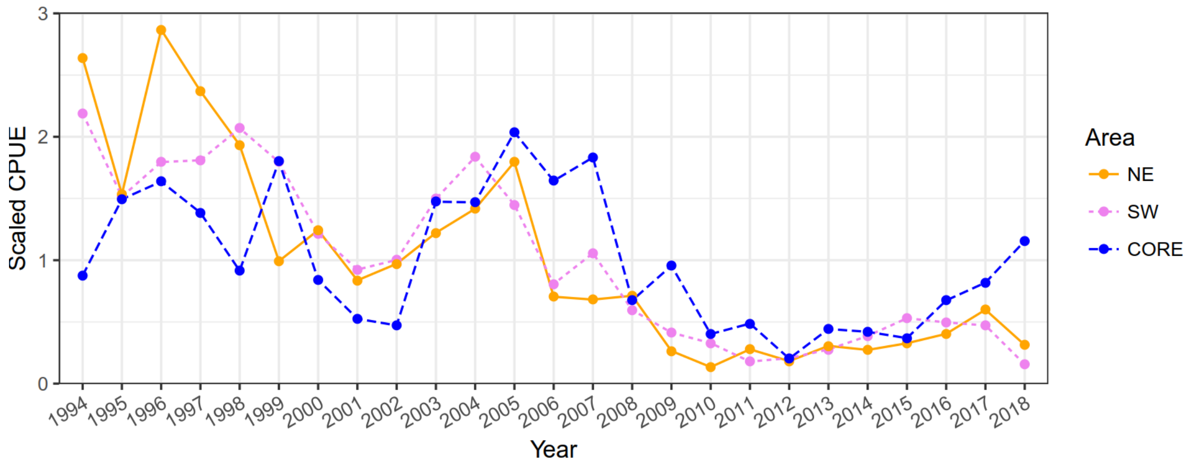


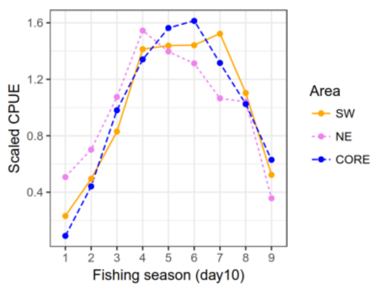
Fig. 10 Estimated catch-at-length for each "CPUE area". Black, CORE; light blue, SW; yellow, NE

Appendix

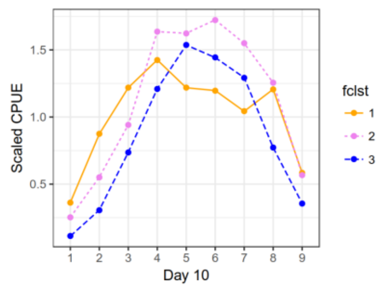
(1) Year*Area effect



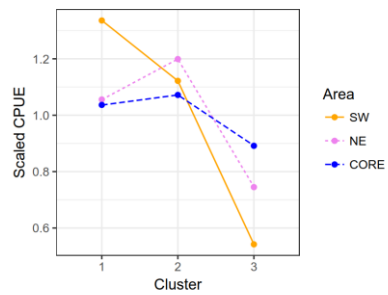
(2) Day10*Area effect



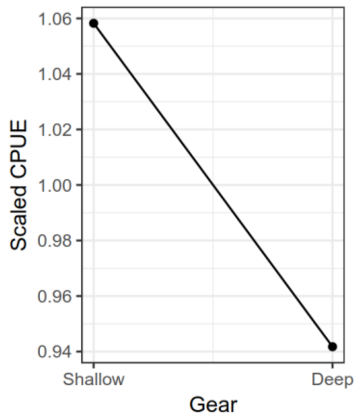
(3) Day10*Cluster effect



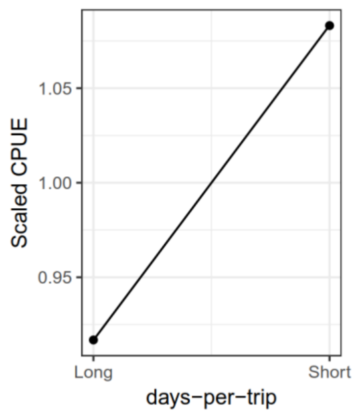
(4) Area+¥*Cluster effect



(4) Gear



(5) Days-per-trip



(6) Movement

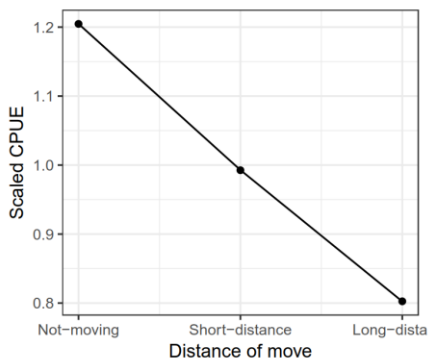


Fig. A1 Least squared means for each effect estimated by “simple update”.

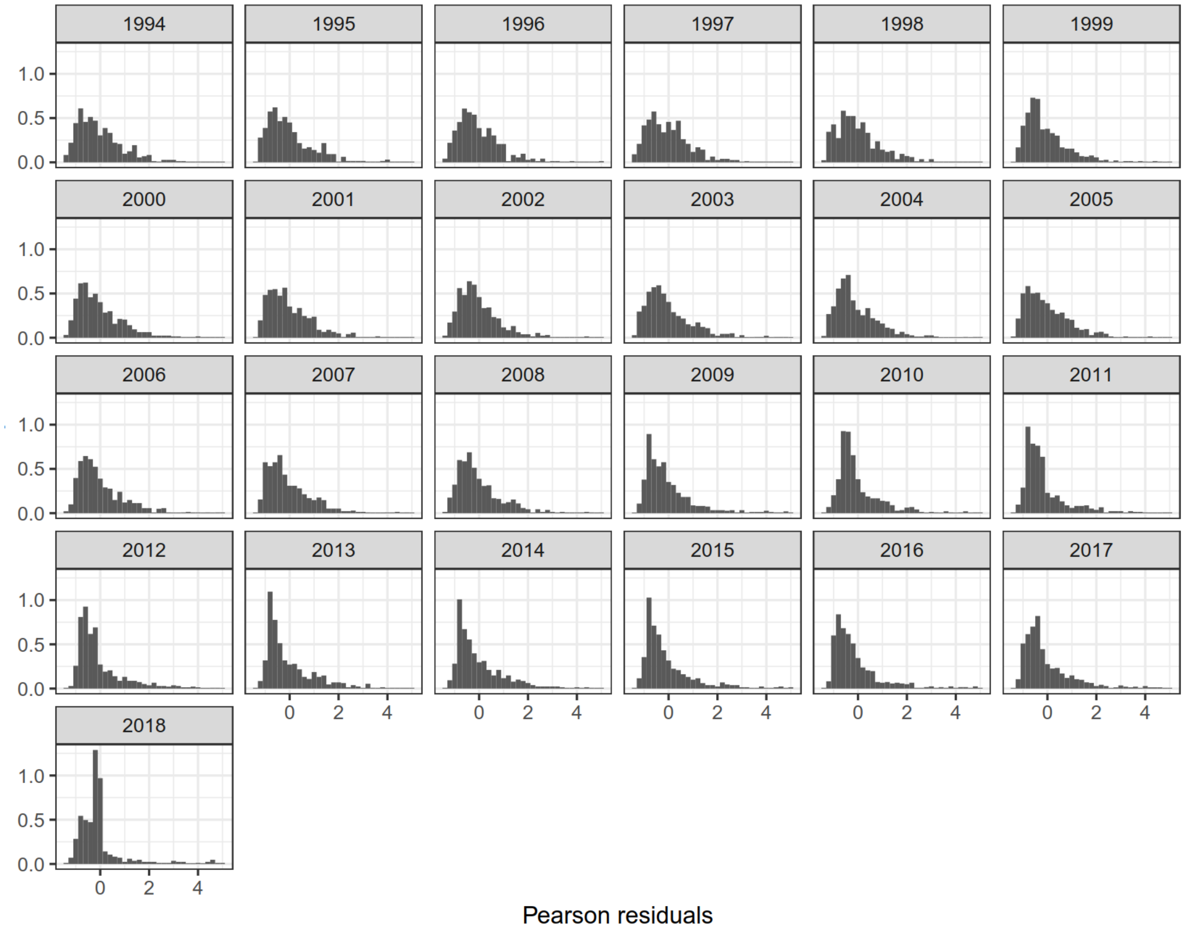


Fig. A2 Pearson residual distribution for ZINB for "simple update" by year.