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Decadal and spatial analysis of Japanese pole and line fisheries for improving catch per unit effort of skipjack tuna in the Western and Central Pacific Ocean (WCPO)

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Abstract

In this document, decadal and spatial changes of catch, effort and percentage of skipjack tuna (*Katsuwonus pelamis*) caught by the Japanese pole-and-line fisheries were analyzed based on logbook data between 1972 and 2012 to improve catch per unit effort (CPUE) in the western and central Pacific Ocean (WCPO). Spatial pattern of all variables has been shrinking remarkably for both of JPN PLOS and JPN PLDW due to decrease of number of vessels. Result from the cluster analysis based on the nominal CPUE time series; three and four areas were characterized for PLOS and PLDW, respectively. Year-quarter trends of standardized CPUE taking each cluster into consideration shows similar trend in that of the 2011 stock assessment.

Introduction

The last stock assessment of skipjack in the western central Pacific Ocean (WCPO) was conducted in 2011 (Hoyle, et al., 2011) using Multifan-CL. Skipjack catch per unit effort (CPUE) derived from the Japanese pole-and-line is an important index as representative of abundance and input data for skipjack stock assessment in the WCPO. Those indices was created by taking non-zero catch for a fishing day (binomial model and the non-zero skipjack catch for a fishing day (lognormal, non zero catch model) into account. Vessel ID effects were included to the model for considering ability of each vessel to explore fish schools. The delta-lognormal indices were calculated by multiplying the two sets of indices (Langley et al., 2010; Kiyofuji et al., 2011).

In this document, improving catch per unit effort (CPUE) of skipjack tuna caught by both of the Japanese offshore (PLOS) and distant water pole-and-line (PLDW) in the WCPO, decadal and spatial changes of skipjack tuna were examined based on logbook data between 1972 and 2012. We also applied cluster analysis to investigate spatial characteristics based on temporal trends in each grid. Standardized CPUE were estimated by the simple lognormal model with the addition of a small constant (lognormal, zero catch included model) and then compared to that estimated same configuration in 2011 stock assessment.

Data and Methods

Fisheries Data

The operational level of catch and effort data for the Japanese pole and line (JPN PL) from 1972 to 2012 with noon positions in equidistant 1°×1° grid cells was used. Date, number of poles, catches in weight and vessel size in gross register tonnage (GRT) was employed. In this document, JPN PL was categorized by vessel size and their equipment. Vessel size between 20-299 GRT is defined as offshore PL (JPN PLOS) and larger than 300 GRT as distant-water (**Table1**).

Japanese pole and line fisheries are categorized three, which are inshore, offshore and distant-Those categorized basically correspond to vessel size less than 20 GRT, 20-120GRT and larger 120 GRT based on fishing license. These can also be categorized into small, middle and large size vessel witch correspond to less than 20GRT, 20-199GRT and larger than 200GRT in vessel size 1999. Since 2000, categorization of vessel size has been changed to less than 20 GRT, 20-299 and larger than 300 GRT because one vessel (220 GRT) were launched and operated in same way

and equipment as the middle sized vessels. These characteristics are summarized in Table1.
of registered vessel calculated from logbook data is shown in **Figure 1**. Number of vessel shows gradual decrease from 1977 (596 in total) and recent number of vessel from 2007 is around 100 in total that is about 1/6 of 1977.

Inshore JPN PLs operate in coastal areas within approximately 60 n.m. from their landing port. Offshore and distant water JPN PL have different strategies of fishing, for example, offshore vessel conduct fishing activity in shorter cruise (approximately one week per one cruise) and distant water vessel conduct longer cruise (approximately more than month per one cruise). Distant water vessels can go much further area than the offshore vessel due to larger size of vessel and produce frozen fish.
Information on the fishing technology used by the fleet has been collected via interview, as described in Shono and Ogura (2000). Vessel specific information details the implementation of five important technological innovations only in the JPN PLDW: the low temperature live bait tank (LTLBT), onboard NOAA meteorological satellite image receiver (NOAA receiver), first and second generation bird radar, and sonar. The application of these components is described in detail in Ogura and Shono (1999a) and these technologies can be summarized as follows;

- **LTLBT:** Though there had been some method for keeping live bait as long as possible in each period of history of the fishery, the low temperature live bait tank (LTLBT) with cooling system and filtering, purifying, and bubbling tank developed in 1978 was the prototype of present live tank. The survival rate of anchovy in this type of live tank was reported in 1981 more than 85% after 30 days rearing, compared to 50% by the previous system with natural or mechanical water circulation system. Rearing density of one tank by the LTLBT was more than one point five times larger than that by previous systems. Keeping lots of baits and high survival rate for long period made fisherman spent an enough number of baits for one skipjack school, resulting being able to keep and excite the school more than before.

- **Bird radar:** In 1987, the bird radar that was radar adjusted to show a bird and birds school around 15 miles of the vessel (first bird radar) was developed. This meant that the ability of searching birds associated fish school progressed remarkably. The improved type of the bird radar (high powered bird radar) was introduced in 1991, with being searching area about 25 miles.

- **NOAA receiver:** The sea surface temperature is one of the indicators of fishing grounds. Onboard NOAA meteorological satellite image receiver (NOAA receiver) was begun to use for searching fish ground in 1988. In these days, except for fishing grounds near Japan, there was limited information on sea surface temperature for fisherman.
- **Sonar:** The sonar system is other important device for the pole and line fishery. The primitive sonar began to generalize throughout distant water pole and line vessel from 1960s. Low frequency scanning sonar for fishing vessel was developed early 1970s and higher frequency type had been started to develop from early 1980s. Both types of sonar have been sophisticated. The tilt scanning sonar that was popular for purse seiner has been introduced into pole and line vessels recently. The range of the low frequency sonar is about 1,500m with lower resolution and the range of high frequency one is up to 500 m with high resolution. This sonar is effective for searching fish schools without events on the surface and observing school behavior.

Identification of individual vessels
License number was applied to identify individual vessel and these number has changed in every years (1987, 1992, 1997 and 2007). For the distant-water pole and line fleet, a reference table has been created and updated that details the license number of an individual vessel in each year (Langley *et al.*, 2010; Kiyofuji *et al.*, 2011). Number of unique vessel in each year has been

since small number of unique vessel in 1987 was identified in the previous analysis (Kiyofuji et 2011). This is because license number in 1987 may not be updated appropriately due to year of license number update. As a result of updating license number in 1987 1992 and 1997, number of unique vessel of PLOS increased approximately eight times (from 22 to 177) in 1987 and of increased a little (from 61 to 74 in 1987 and from 33 to 38 in 1992) from the previous research, respectively (**Table 2 and Figure 2**).

Decadal and spatial pattern of effort (vessel-day), catch and proportion of skipjack catch

Effort (vessel-day), catch and proportion of skipjack catch for JPN PLOS and PLDW in decadal scale were aggregated to provide information of spatial changes for each parameter. Proportion of skipjack catch was simply calculated as skipjack / skipjack + albacore, since JPN PL mainly target on these two species especially in the northwester North Pacific (Kiyofuji *et al*., 2013).

Spatial characteristics based on cluster analysis by temporal trend

Cluster analysis was conducted to investigate spatial characteristics both of JPN PLOS and PLDW CPUE. Cluster analysis generally classify similar group based on similarity defined by distance between each variables. In this study, euclidean distance between each grid was applied to measure similarity of temporal trend of nominal CPUE. We applied ward's method as clustering. Number of class was finalized from dendrogram. As results of cluster analysis, three and four classes were selected for PLOS and PLDW and these classes were visualized in map with their temporal trends.

Estimate yearly trend of indices by GLM incorporated with the result of cluster analysis

Each cluster resulted from the cluster analysis described previous sections was included in the model as area effects and compared results from the same model configuration in 2011 stock assessment. Year-Quarterly indices were also calculated simply as exp (year coefficients) to compare with each index. Model configurations are described as follows.

(1) PLOS

$$log(CPUE + const.) = \mu + YrQtr + \varepsilon \quad (1)$$
$$log(CPUE + const.) = \mu + YrQtr + vessel\ ID + latlong + npoles + \varepsilon \quad (2)$$
$$log(CPUE + const.) = \mu + YrQtr + vessel\ ID + area + npoles + \varepsilon \quad (3)$$

(2) PLDW

$$log(CPUE + const.) = \mu + YrQtr + \varepsilon \quad (4)$$
$$log(CPUE + const.) = \mu + YrQtr + vessel\ ID + latlong + npoles + device + \varepsilon \quad (5)$$
$$log(CPUE + const.) = \mu + YrQtr + vessel\ ID + area + npoles + device + \varepsilon \quad (6)$$

where μ is overall mean, const. is 10% of overall mean of nominal CPUE, area in (3), (6) is cluster resulted from the cluster analysis and ε is error term with $N(0,\sigma^2)$. Model (1) and (4) is just for reference as comparison purpose.

Results and Discussions

Time series of effort, catch and nominal CPUE

Figure 3 shows effort (number of vessel-day x 1000), total skipjack catches (x 1000 tones) and nominal CPUE (skipjack catch/vessel-day) in each MFCL stock assessment region for both JPN PLOS (black) and PLDW (gray). Effort of PLOS in reiong1 shows gradual decrease from 1980's to date and of PLDW shows relatively sharp decrease from 1979 to 1982. PLDW Effort in 1982 is approximately one third of 1979. Region 2 and Region 3 are the area for mainly PLDW through whole period. Actually, there has been almost no fishing by PLOS in region 3. Effort by the PLDW in region 2 decreased gradually from middle of 1970s to 1990. JPDW effort in region 3 was high during 1975 and 1982 and then decrease gradually until 1990.

Although total skipjack catch by PLOS in region 1 shows gradual decrease from middle of 1980s date, catch by PLDW keep at the same level around 20.000 tones and both catch by PLOS and

PLDW is same level in 2012. Total skipjack catch in region 2 and region 3 by PLDW shows trends. Skipjack catch in region 2 had been decreasing after 1974 to 1991 and then keep at the level around 20,000 tones. The highest catch (98,000 tones) was recorded in 1974. Skipjack catch region 3 is different trend from it in region 2. It was at the same level around 60,000 tones between 1976 and 1988 and then decreased sharply. It keeps at the same level around 10,000 tones after

Nominal CPUE defined as dividing total skipjack catch by the total effort are shown in **Figure 3 (c)** for all areas. Nominal CPUE by JPOS in region 1 shows gradual increase after1980 and then keep at the same level around 5 (tones/vessel-day), but nominal CPUE by the PLDW changed annually. It was low level between 1972 and 1983, and then increased until 1993. After 1993, nominal CPUE did not show remarkable changes. Nominal CPUE in region 2 and region 3 by the PLDW shows similar trend that it was at the same level around 5 and 10, respectively.

Decadal and spatial pattern of effort, catch and proportion of skipjack catch

Decadal and spatial patterns of effort (total number of vessel) and catch (tonnes) by aggregated in 1x1 degree both for PLOS and PLDW were shown in **Figure 4** and **5**. Spatial pattern of all variables has been shrinking remarkably for both of PLOS and PLDW due to decrease of number of vessels (**Fig.1**). Core area of PLOS is the northwestern North Pacific ranging between 30°N – 45°N and 140°E – 160°E). Fishing areas by PLOS in recent years were not identified in region 2, especially around (10°N – 20°N, 130°E – 140°E) (**Fig.4 (e)** and **Fig.5 (e)**). Two core fishing areas were identified for the PLDW. One is equatorial region between 140°E and 160°W and another of the same area as the PLOS core area but extended to 180°E. Its core area in equatorial region likely disappeared after 1991 and moved to the area between 0° **-** 20°N and 130°E **-** 170°E. One another feature of fishing area changes is that it was formed around (10°S, 170°E) after 2000, where is across the border of the MFCL regions.

Figure 6 and **Figure 7** represents time series of skipjack catch proportion calculated as (skipjack/skipjack + albacore) and its spatial pattern aggregated in 1x1 degree, respectively. The PLOS in region 1, PLDW in region 2 and region 3 targets mainly on skipjack, but PLDW in region 1 and PLOS likely target both species of skipjack and albacore. In region 2, skipjack ratio by the PLDW increased from 1980 to 1991 and slightly decreased. Spatial pattern of skipjack ratio shows interesting features especially in the northern area. Skipjack ratio was low in broad area in the earlier decade (**Fig. 7 (a)**). Interestingly, area was divided north and south at approximately 35°N by the targeting during 1981 and 1990 (**Fig. 7 (b)**). They target mainly on skipjack in the northern part and albacore in the southern part in this decade. No such features has been identified since 1991 and PLDW likely targets on albacore.

Spatial distribution of each class derived from cluster analysis

Figure 8 and **Figure 9** show spatial pattern (a) and its time series (b) of each class for PLOS and PLDW, respectively. Their spatial and temporal characteristics are also summarized in **Table 3**.

Spatial patter of cluster 1 (red) of the PLOS was found in the area between (10°N – 30°N) and (120°E – 142°E), which temporal trend kept at the lower levels. Cluster 2 (blue) of PLOS was located area ranging between (25°N – 40°N) and (138°E – 155°E) where is core area for the PLOS. Its temporal trend was increasing. Cluster 3 (gray) was found only in marginal areas and its temporal trends keep at the lower level.

Cluster 1 (red) of the PLDW had the largest distribution of all the classes but only found in areas and its temporal trend kept lower level with no significant changes. Cluster 2 (gray) appears both of tropical and northern areas at the medium level with no significant temporal changes. 3 (blue) was found in equatorial area between 150°E and 160°W and around (10°N–20°N, 140°E – 150°E) with remarkable decline after 1990 from the high level between 1978 and 1989. Cluster 4 (yellow) was similar to those of cluster 2 but mainly formed around subtropical area with relatively higher level.

Figure 10 represents total effort (number of vessels) and skipjack 0 catch ratio in each cluster. Skipjack 0 catch ratio for all clusters except cluster 2 (blue) shows relatively similar trend, however, skipjack catch 0 ratio of cluster 2 shows sharp increase after 1990. Additionally, number of effort has declined since 1990. The area of cluster 2 corresponds to the core fishing area in equatorial area. The timing of increasing 0 catch ratio is almost same timing as increasing the purse seiner recruitment in the WCPO. Further research should be considered to present more precise abundance indices in the equatorial area.

Year-Quarter trends of relative indices

Figure 11 shows estimated standardized CPUE of PLOS in region 1 (a), PLDW in region 2 (b) and PLDW in region 3 (c) with different model configurations. Overall trends both standardized CPUE of 2011 stock assessment and this study. Relative indices of PLOS in region1 increased slightly after 1990, however, no device information was included in this model because no such data were available. This should be prepared in near future and conducted in same manner to provide more accurate and realistic abundance indices in this area. Taking these effects into considerations as PLDW, trends of indices from PLOS would be changed in region 1. Further analysis should be necessarily for improving model configuration in this region. Indices from PLDW in region2 during 1973 and 1982 decreased and slightly increased until 1990. It has been decreasing since 1990. Indices from PLDW in region3 show no remarkable changes through whole period. Year-quarter trends in this study shows similar trend of those in 2011 stock assessment. Appling delta-lognormal model are necessarily in near future.

Summary

In this document, decadal and spatial changes of catch, effort and percentage of skipjack tuna (*Katsuwonus pelamis*) caught by the Japanese pole-and-line fisheries were analyzed based on logbook data between 1972 and 2012 to improve catch per unit effort (CPUE) in the western and central Pacific Ocean (WCPO). Spatial pattern of all variables has been shrinking remarkably for both of JPN PLOS and JPN PLDW due to decrease of number of vessels. Result from the cluster analysis based on the nominal CPUE time series; three and four areas were characterized for PLOS and PLDW, respectively. Year-quarter trends of standardized CPUE taking each cluster into consideration shows similar trend in that of the 2011 stock assessment.

Reference

Kiyofuji, H., Uosaki, K. and Hoyle, S. (2011) Update CPUE for skipjack caught by Japanese distant and offshore pole and line fisheries in the western central Pacific Ocean. WCPFC-SC7-2011/SA-IP-13. 32p.

Kiyofuji, H. (2013) Reconsideration of CPUE for albacore caught by the Japanese pole and line fishery in the northwestern North Pacific Ocean. ISC/13/ALBWG-01/11, 24pp.

Langley, A., Uosaki, K., Hoyle, S. and Shono, H. (2010) A standardized CPUE analysis of the Japanese distant-water skipjack pole and line fishery in the western and central Pacific Ocean (WCPO). WCPFC-SC6-2010/SA-WP-08. 93p.

Ogura, M. and Shono, H. (1999a) Factors affecting the fishing effort of the Japanese distant water pole and line vessel and the standardization of the skipjack CPUE. Part B. Calculation of CPUE standardization. SCTB12.

Shono and Ogura (2000) The standardized skipjack CPUE, including the effect of searching of the Japanese distant water pole and line fishery in the western central Pacific Ocean. Col. Vol. Pap. ICCAT, 51: 312-328.

Table 1. Categorization of JPN PL by license and equipment and their characteristics.

Category	Vessel size		Days per cruise	area and equipment
	by license	by equipment		
Coastal PL	< 20 GRT		1 or 2	Near landing port
Offshore PL	20 – 119 GRT	20 – 299 GRT	2 – 10	Only in northern area, water cooler and unload fresh fish
Distant Water PL	120 GRT <	300 GRT <	30 – 50	Both in north and south area, brain and deep freezer, unload frozen

Table 2. Number of unique vessel used in 2011 SKJ stock assessment and in this study. Note that * represent year of license update.

	PLOS (<200GRT)		PLDW (>=200GRT)	
	2011	this study	2011	this study
1972	230	230	120	120
1973	235	235	171	171
1974	236	236	204	204
1975	243	243	212	212
1976	308	308	238	238
1977	319	319	239	239
1978	294	294	233	233
1979	273	273	202	202
1980	280	280	170	170
1981	310	310	149	149
1982*	313	313	120	120
1983	255	255	102	102
1984	254	254	91	91
1985	214	214	85	85
1986	200	200	82	82
1987*	**22**	**177**	**61**	**74**
1988	166	166	57	57
1989	161	161	63	63
1990	164	164	62	62
1991	150	150	51	51
1992*	145	145	**33**	**38**
1993	132	132	35	35
1994	107	107	39	39
1995	109	109	37	37
1996	101	101	38	38
1997*	97	97	39	39
1998	94	94	37	37
1999	93	93	40	40
2000	91	91	40	40
2001	87	87	41	41
2002*	85	85	41	41
2003	81	81	40	40
2004	75	75	38	38
2005	75	75	39	39
2006	64	64	29	29
2007*	62	62	29	29
2008	55	55	28	28
2009	57	57	28	28
2010	54	54	28	28
2011	49	49	28	28
2012	-	39	-	33

Table 3. Summary of spatial pattern and temporal trend of each cluster based on the results of cluster analysis for (a) PLOS and (b) PLDW.

(a) PLOS

Cluster	Spatial pattern	Temporal trends
1 (red)	10°N – 30°N, 120°E – 142°E	Keep at the medium level around 1.8
2 (gray)	25°N – 40°N, 138°E – 155°E (core area of PLOS)	increasing trend
3 (blue)	marginal areas	Keep at the lower level

(b) PLDW

Cluster	Spatial pattern	Temporal trends
1 (red)	Broader areas but in marginal areas	Keep at the lower level with no significant change
2 (gray)	tropical, northwestern North Pacific around Japan and around 10°S,	Keep at the medium level with no significant change
3 (blue)	Equatorial and around (10°N–20°N, 140°E –150°E).	High level during 1975 and 1990 but decreased sharply after 1990 and keep at lower level
4 (yellow)	Subtropical and northern area	Keep at the relatively higher level with no significant change

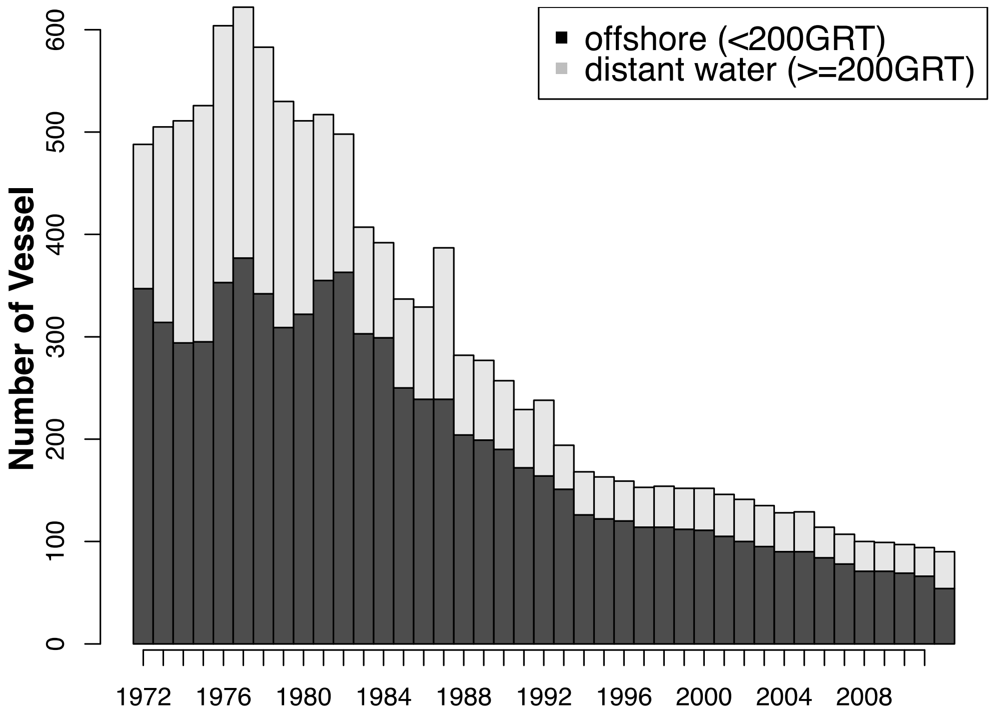

Figure 1. Number of registered vessel of Japanese offshore (<200GRT) and distant water (>200 GRT) pole-and-line fisheries.

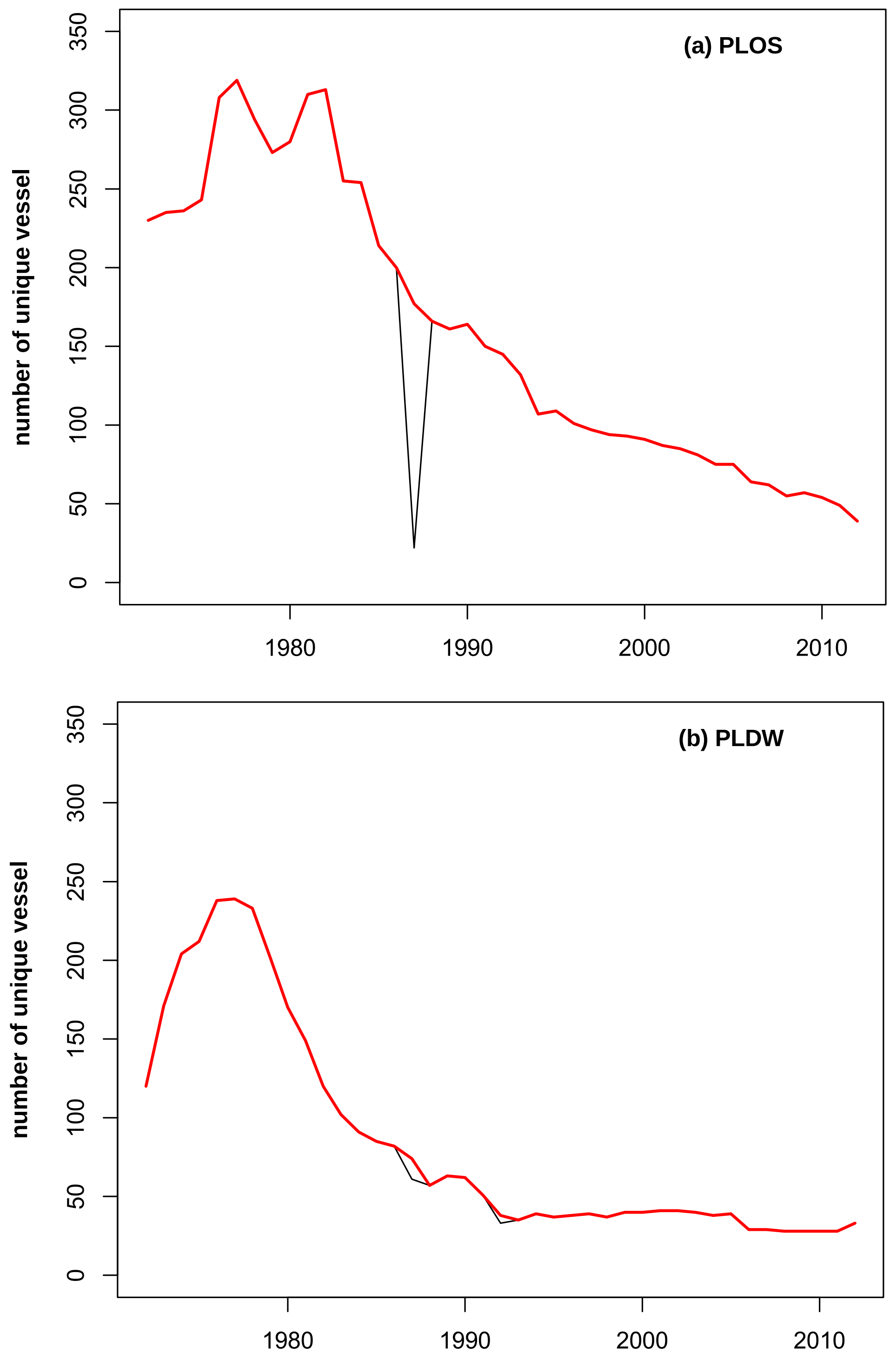

Figure 2. Number of unique vessel used in 2011 stock assessment (black) and updated in this study (red) for (a) PLOS and (b) PLDW.

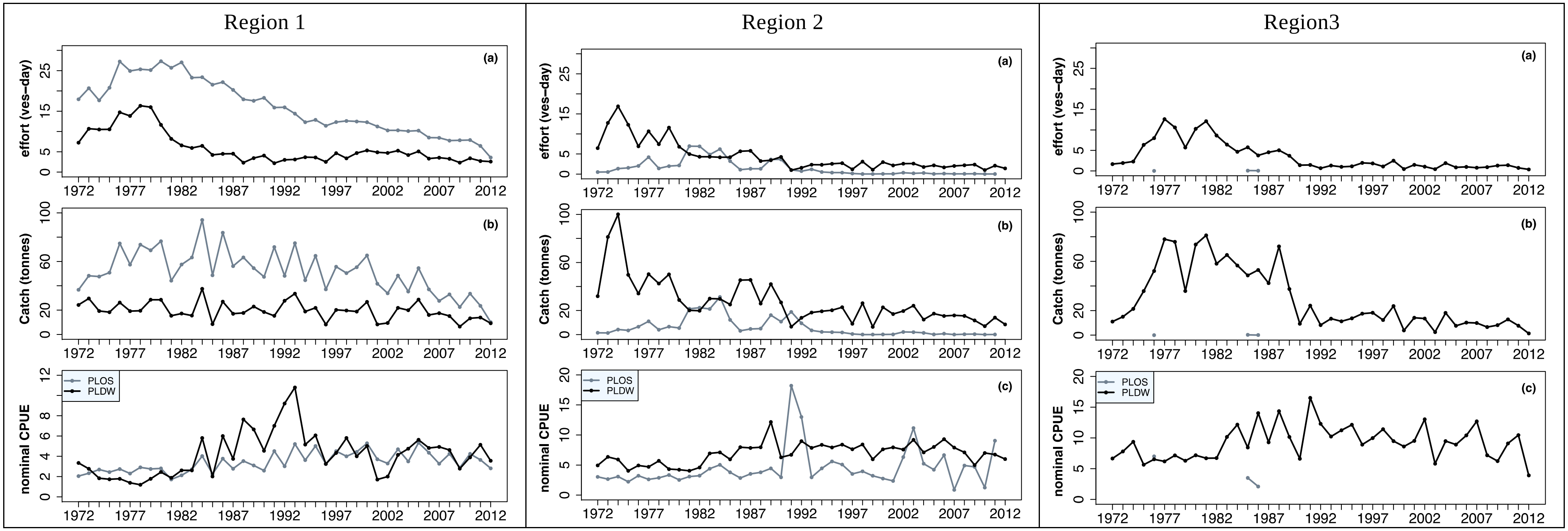

Figure 3. Time series of effort (×1000 vessel-day), catch (×1000 tonnes) and nominal CPUE (tonnes/vessel-day)in each region. Black and gray lines represent JPN PLDW and PLOS, respectively.

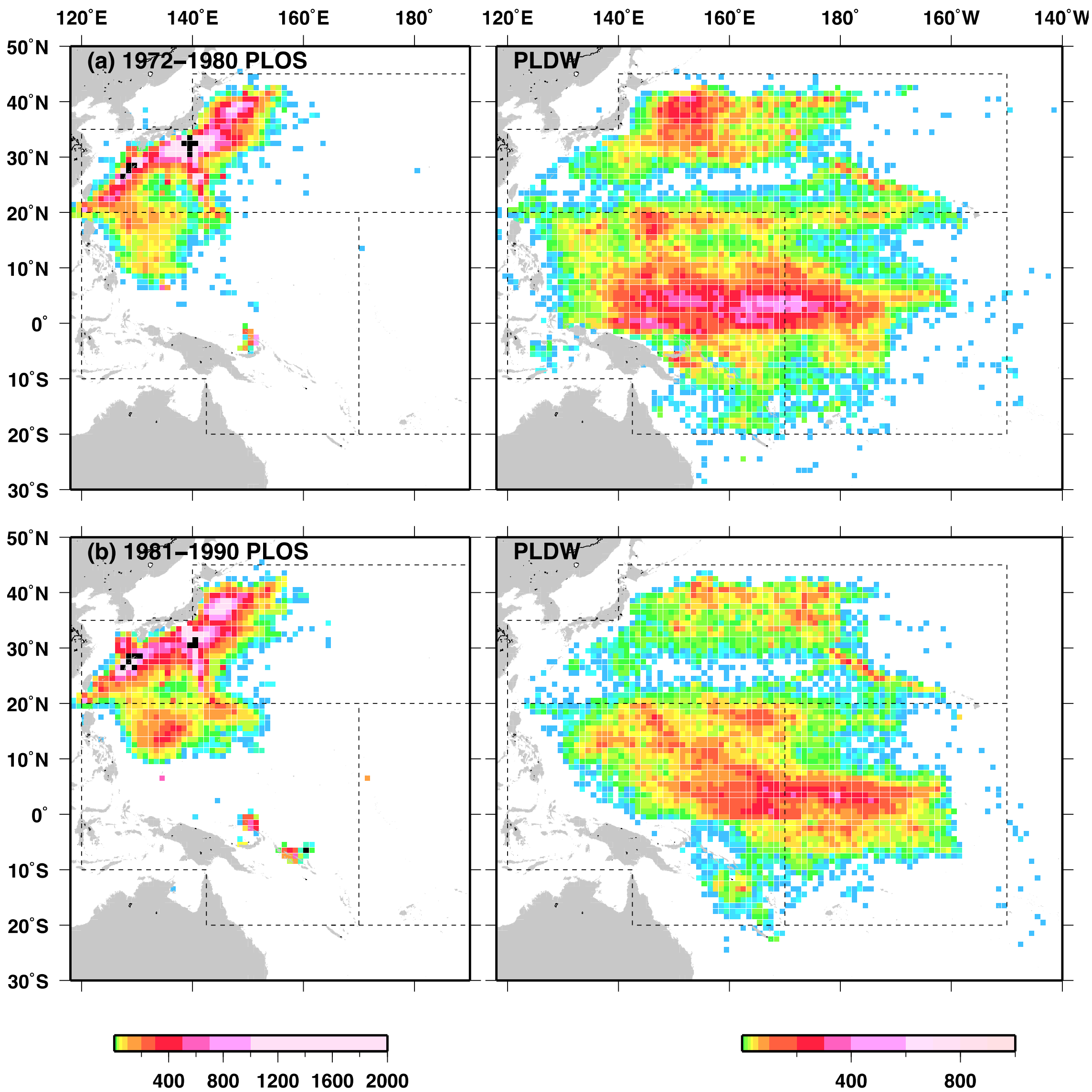

Figure 4. Total effort (vessel-day) in each period and grid caught by the JPN PLOS (left) and JPN PLDW (right). Note that dashed lines represent spatial structure for skipjack stock assessment in the Western and Central Pacific Ocean. (a) 1972 – 1980. (b) 1981 – 1990.

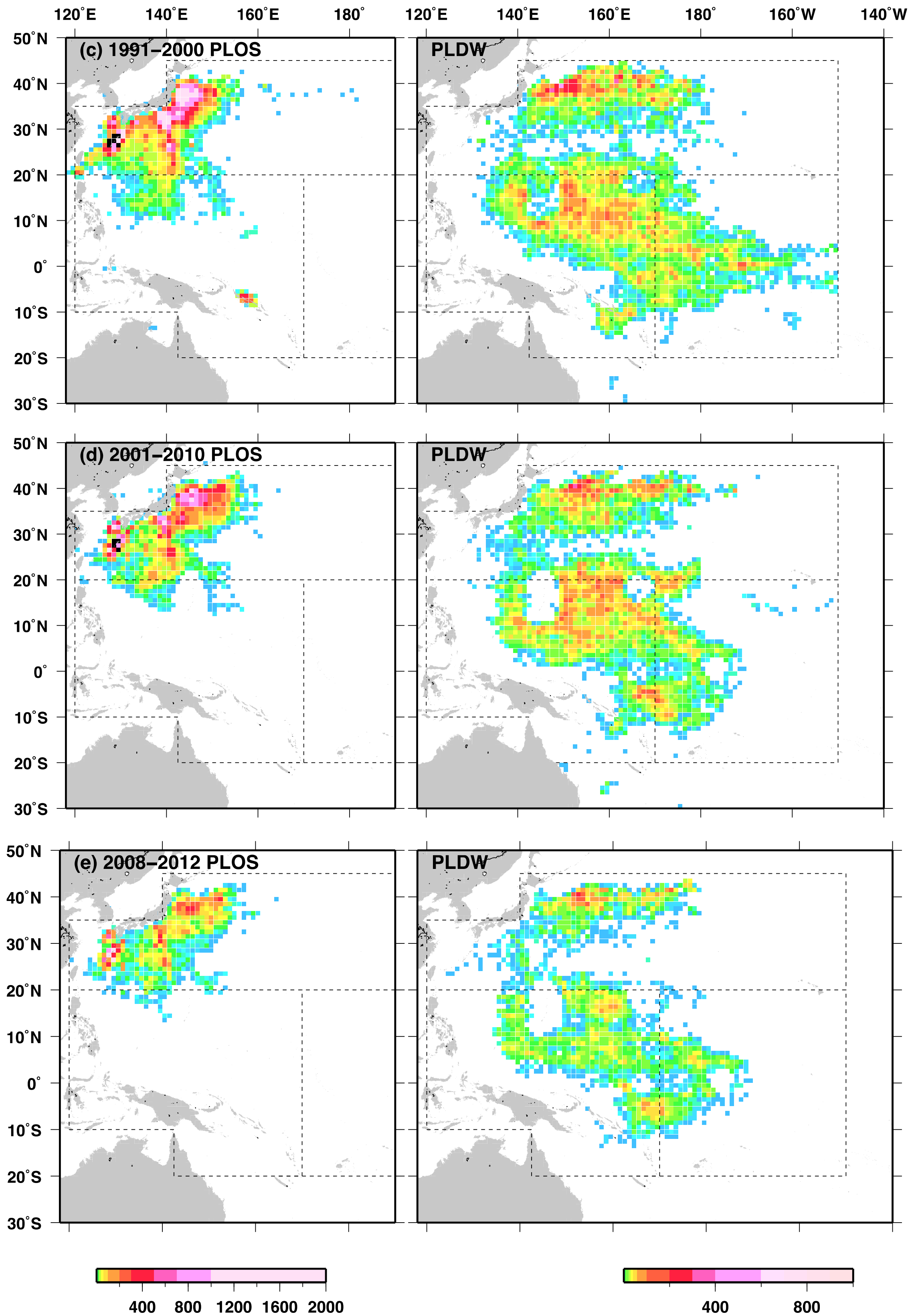

Figure 4. (continued). (c) 1991 – 2000, (d) 2001 – 2010 and (e) 2008 – 2012.

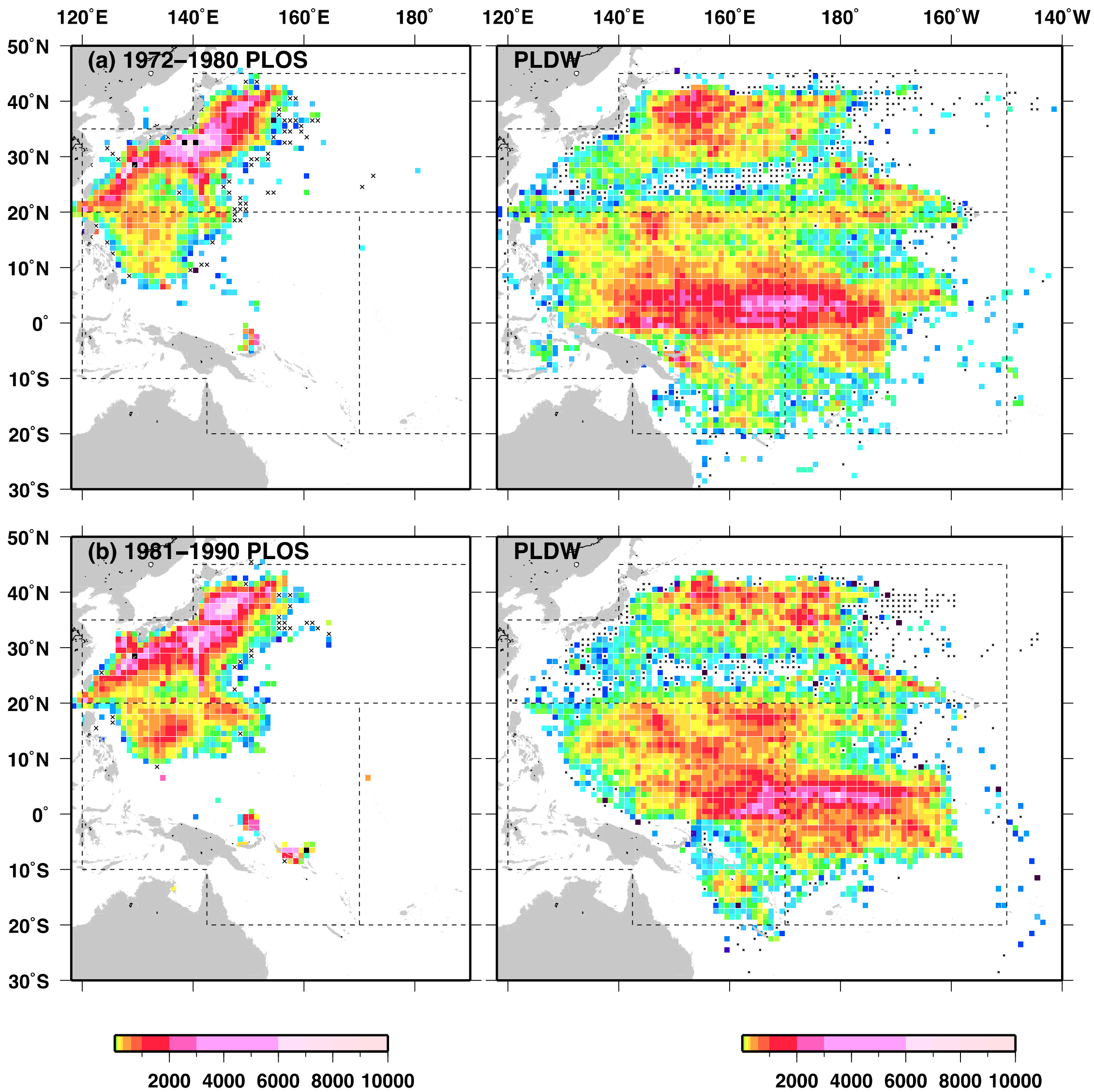

Figure 5. Total skipjack catch (tonnes) in each period and grid caught by the JPN PLOS (left) and JPN PLDW (right). Note that dashed lines represent spatial structure for skipjack stock assessment in the Western and Central Pacific Ocean. (a) 1972 – 1980. (b) 1981 – 1990.

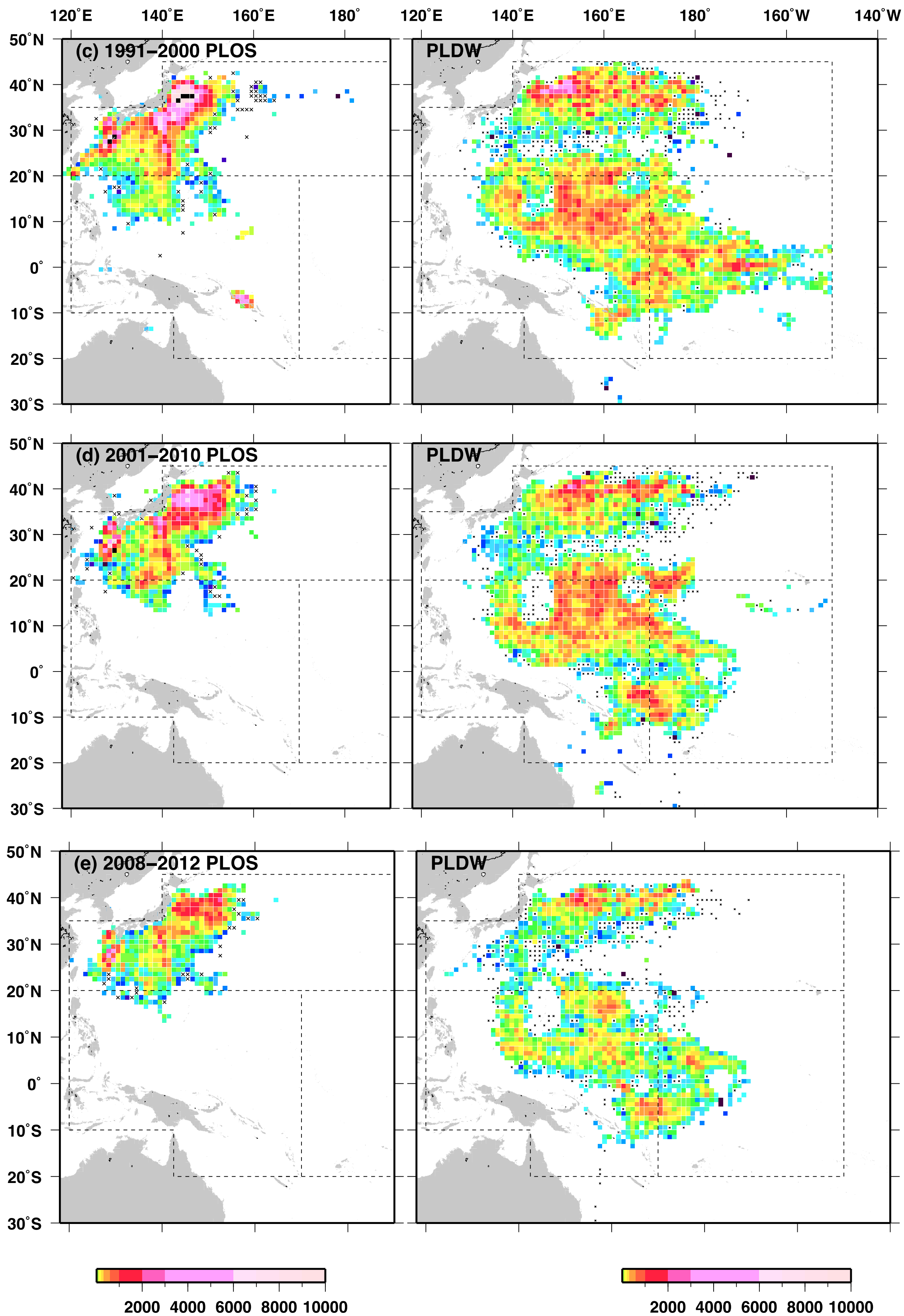

Figure 5. (continued). (c) 1991 – 2000, (d) 2001 – 2010 and (e) 2008 – 2012.

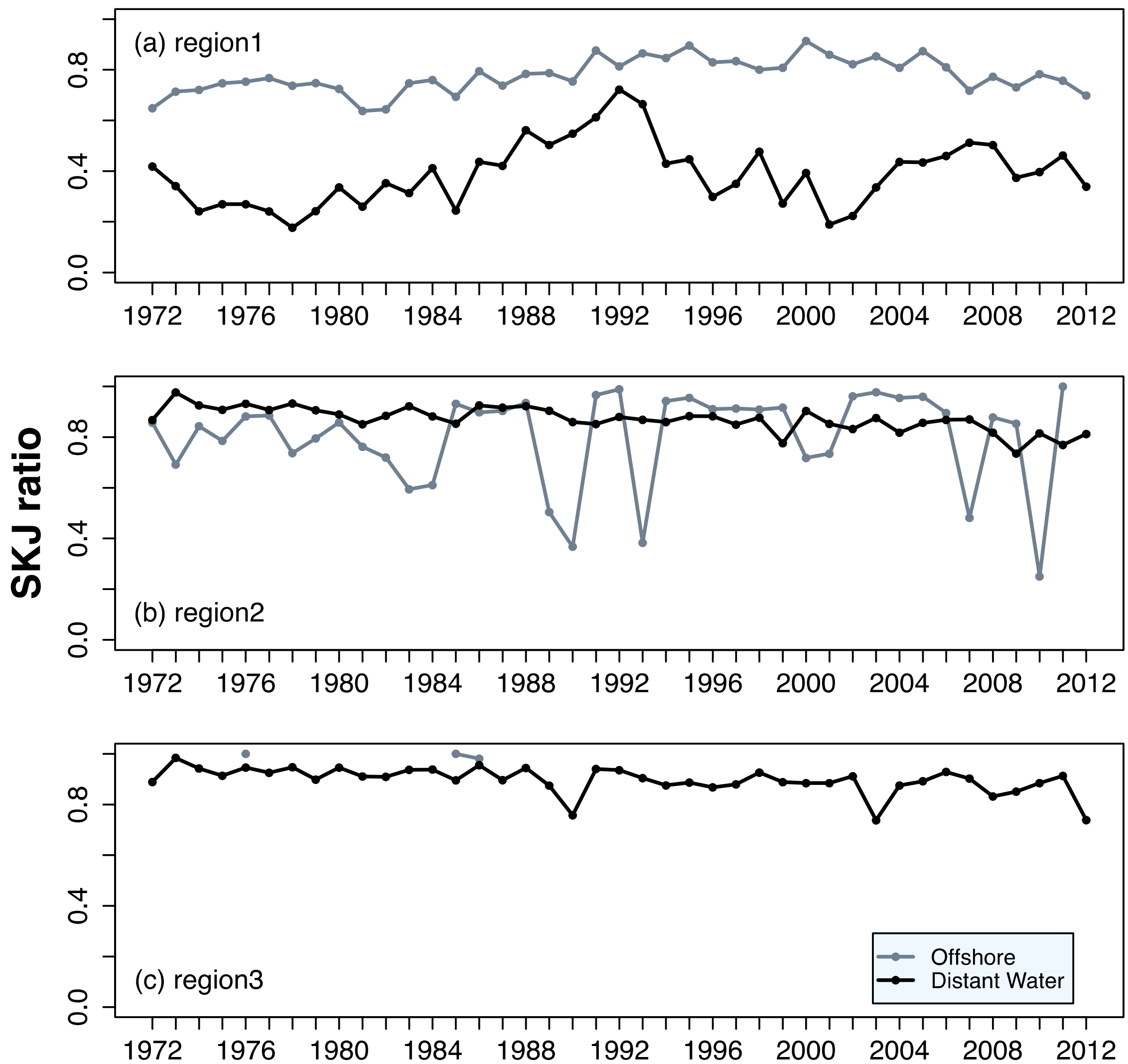

Figure 6. Time series of skipjack catch proportion to sum of skipjack and albacore in each region. Black and gray lines represent JPN PLDW and PLOS, respectively.

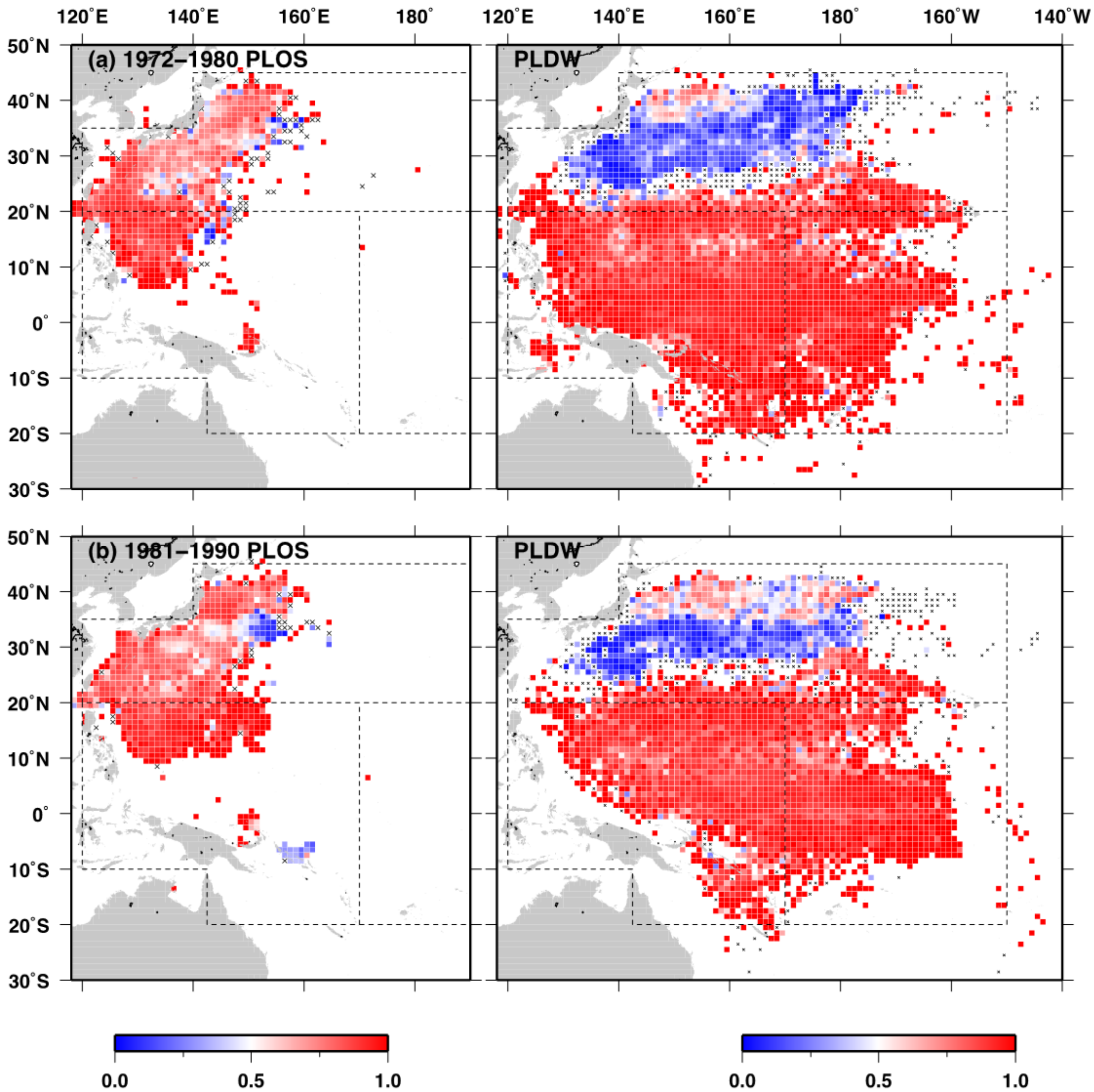

Figure 7. Proportion of skipjack catch to sum of skipjack and albacore catch by the JPN PLOS (left) and JPN PLDW (right). Note that dashed lines represent spatial structure for skipjack stock assessment in the Western and Central Pacific Ocean. (a) 1972 – 1980. (b) 1981 – 1990.

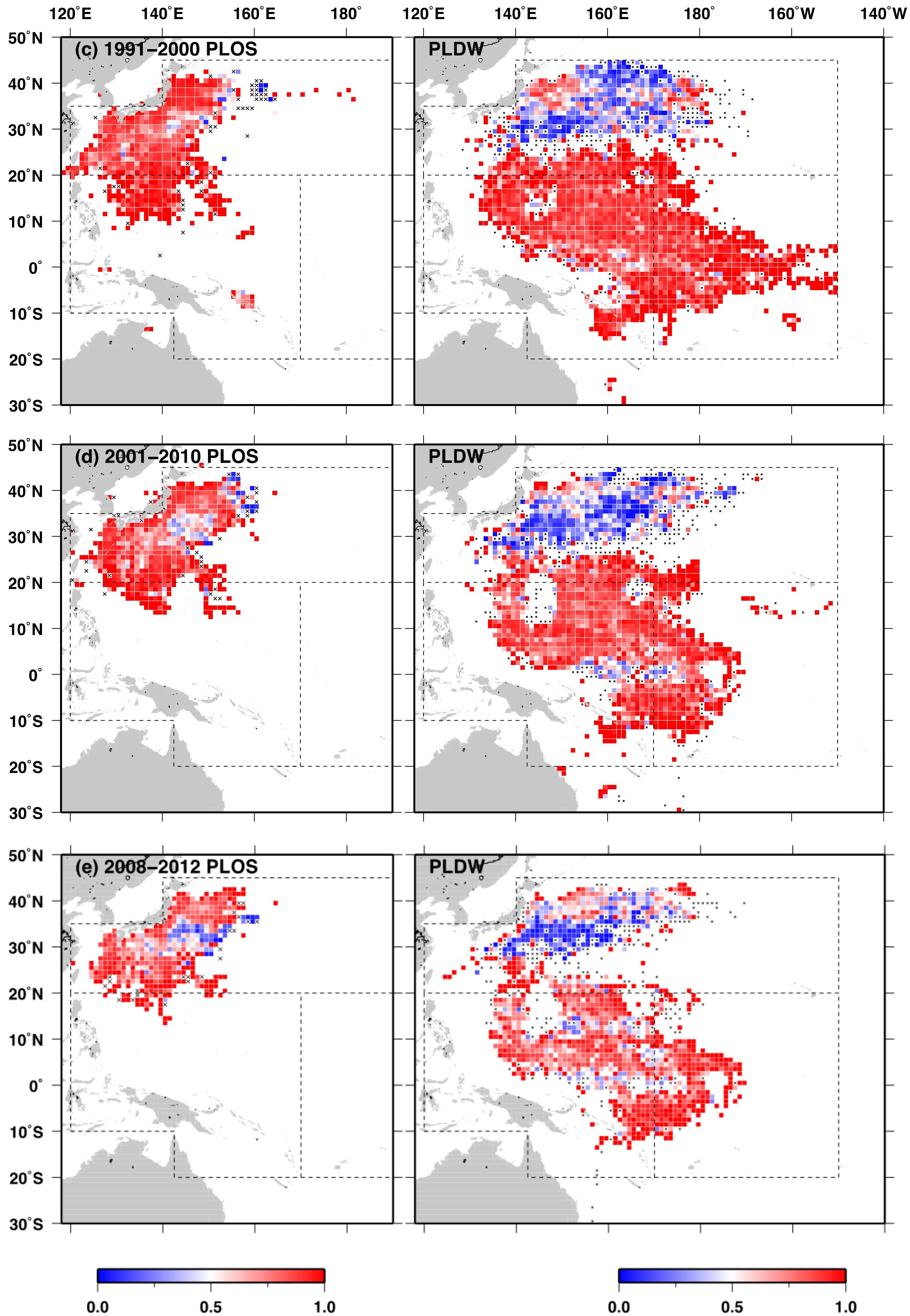

Figure 7. (continued). (c) 1991 – 2000, (d) 2001 – 2010 and (e) 2008 – 2012.

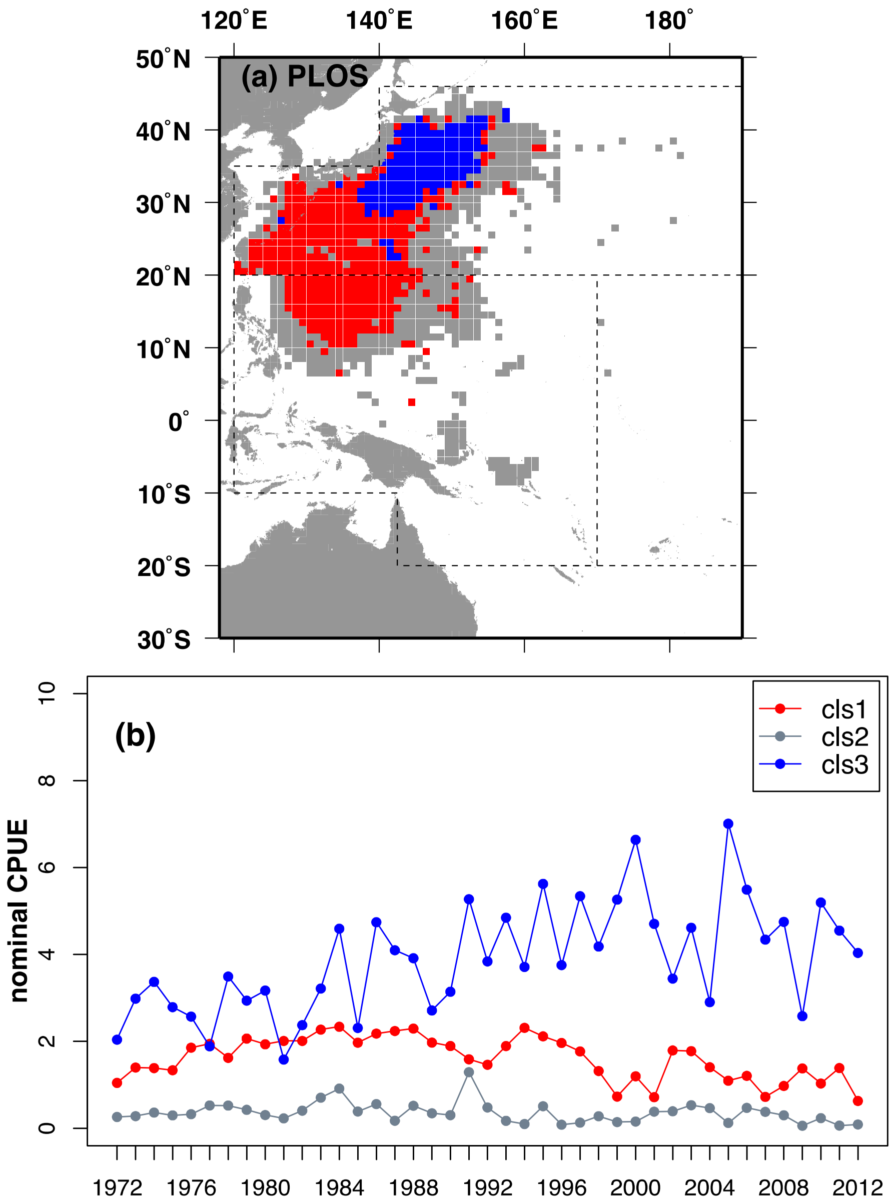

Figure 8. (a) Spatial distribution and (b) average SKJ catch trend in each cluster based on cluster analysis for JPN PLOS. Note that color in (a) and (b) is compatible with each other.

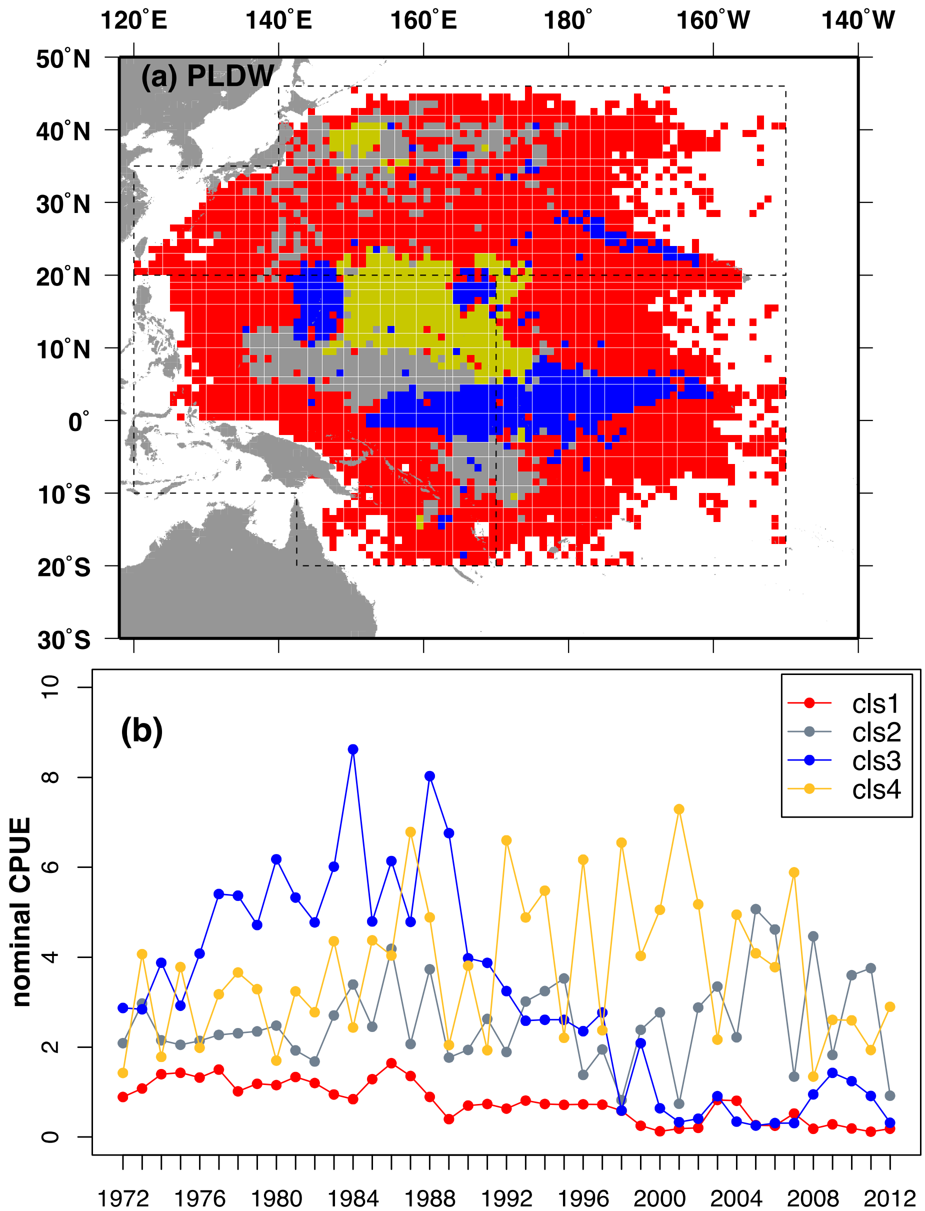

Figure 9. (a) Spatial distribution and (b) average SKJ catch trend in each cluster based on cluster analysis for JPN PLDW. Note that color in (a) and (b) is compatible with each other.

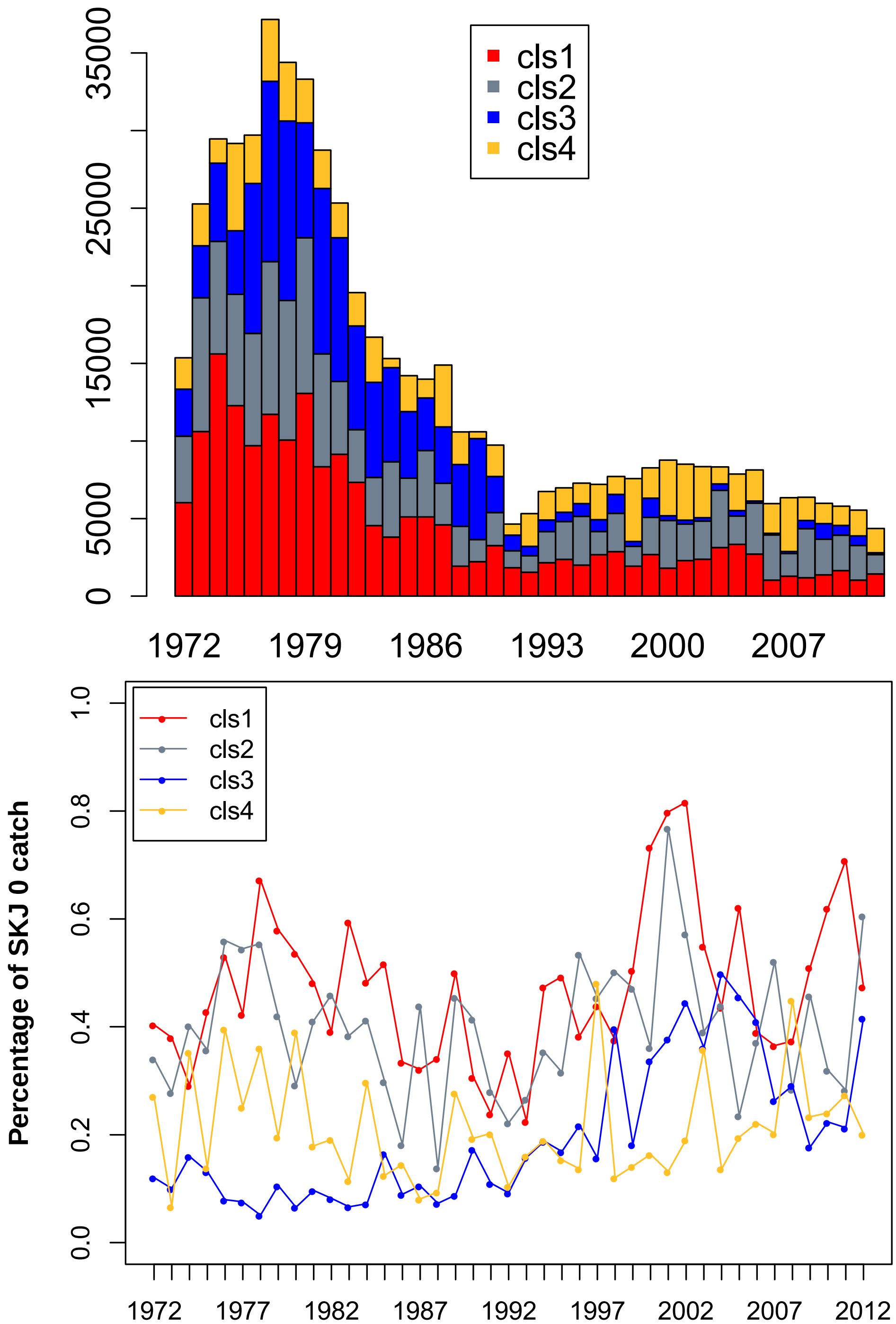

Figure 10. Total effort (number of vessels) (upper) and percentage of 0 catch ratio (lower) in each class.

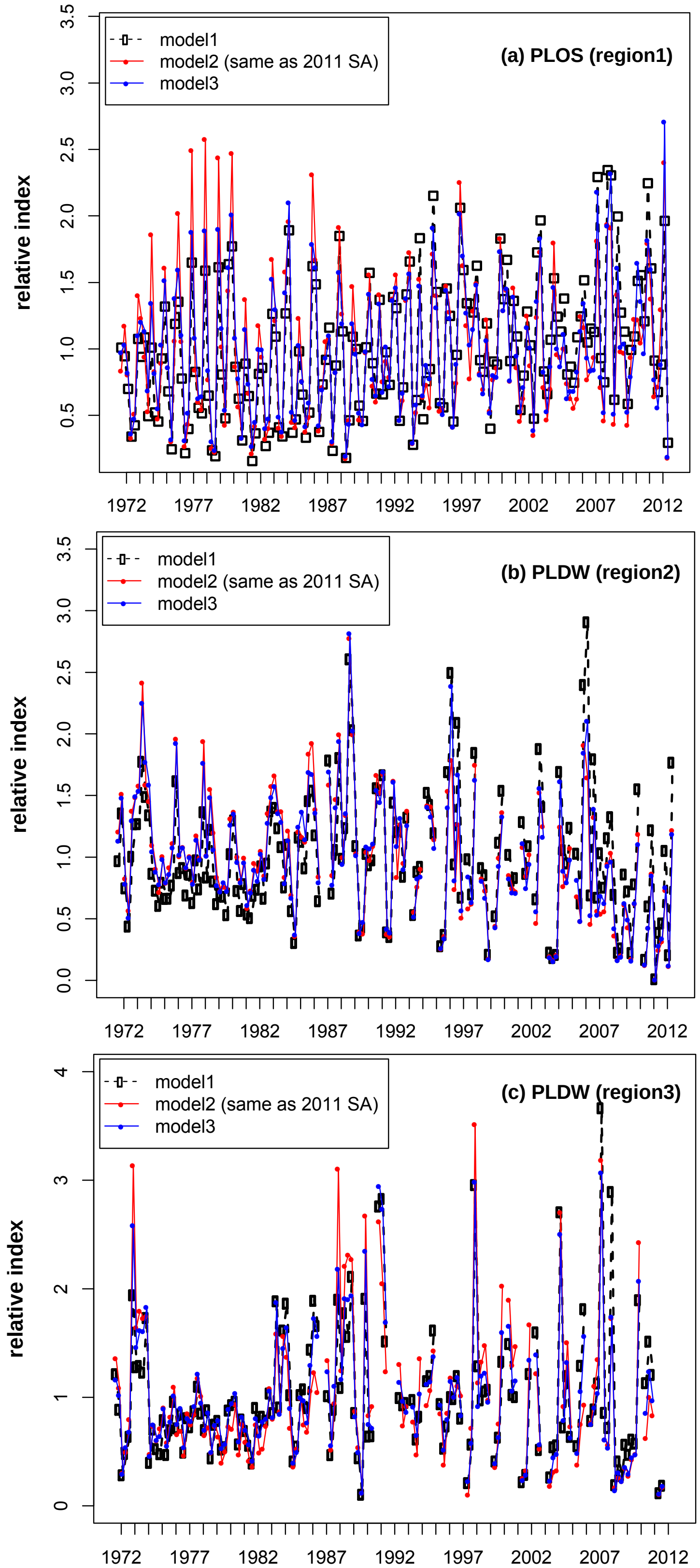

Figure 11. Yearly trends of relative indices in each region from the different model configurations. (a) PLOS (region1), (b) PLDW (region2) and (c) PLDW (region3).