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Size distribution of blue shark (*Prionace glauca*) collected by Japanese fleet and research program in the North Pacific.[1]

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Abstract

In this document, I summarised the size distribution of blue shark (*Prionace glauca*) caught by Japanese fishery and research cruise, based on the several sources. Totally, 894,060 size data was collected between 1967 and 2020. 67% of them was from commercial Kinkai-shallow longline (port sampling), followed by research data with deep-set longline (23%) and the ratio of other type of fishery was less than 5%. Generally, blue shark caught by deep-set longline (median and mode: larger than 160 cm precaudal length: PCL) tends to be larger than that of other type of fishery (median and mode: smaller than 150 cm PCL). From the perspective of ontogenetic composition, ratio of juvenile was different depending on the type of fishery. Generally, juvenile ratio in coastal fishery (longline and driftnet) was higher than deep-set longline operated in the offshore/distant water for both sexes, while juvenile rate in deep-set longline for males was lower than females.

Annual change of PCL (sex-combined) by data sources indicated no major or continuous trend for commercial longline (Kinkai-shallow, deep-set, and coastal) and driftnet fishery between 2008 and 2020, and research shallow-set (2000-2020) and deep-set (1967-2020) longline. Annual trend of sex ratio (female ratio) was variable depending on the type of fishery. The annual trend of female ratio in Kinkai-shallow was stable around 25% across years , while that in research deep-set longline (10-60%) was higher and more variable. Distribution of mean PCL supported known distribution pattern of North Pacific blue shark that smaller shark dominates northern area and that of larger shark extends to southern and eastern area.

Introduction

Blue shark (*Prionace glauca*) is a wide-ranging shark distributed from tropical to temperate oceans throughout the world. In Japan, blue shark is caught as target and bycatch in the longline and driftnet fishery and utilized as the material of fish paste product and other portion such as vertebrae and fin are used for medicinal product and shark fin soup domestically. Landing of this species (mostly, North Pacific population) in the main domestic port between 1992 and 2019 ranges from 5,100 to 16,000 ton and 81% of the catch is from longline fishery, followed by driftnet fishery in 2019 (Kai and Fujinami 2021).

In Japan, Kesen-numa fishing port, located in the northern Miyagi Prefecture, is fishing port with the largest amount of blue shark landing in Japan, where fresh-state product (fins attached, head and guts removed) is landed from various fisheries including shallow-set longline, coastal longline and coastal driftnet. Among these fisheries, shallow-set longline vessel (hereafter expressed as “Kinkai-shallow”) which operates from coastal to offshore waters, targeting blue shark in summer and swordfish (*Xiphias gladius*) in winter since 2005 (Yokawa 2009), dominates domestic catch of this species. Fisheries Resources Institute (FRI) launched the port-sampling system to collect size and sex information of blue shark from the landing of these fisheries since 2008. In the fishing port, blue shark

landed was classified into several category, based on size, sex, and freshness and lumped in large container. As it is not allowed to break this lump, 5-10 blue sharks on the surface are randomly measured and recorded with sex information by container as much as possible. The detailed location and date of catch is not available in port-sampling (commercial landing) data. Other than this data, size and sex data has been collected in longline observer program, research and training vessel operating longline (indicated as "RTV" hereafter), and longline and driftnet research cruise by chartered vessel and research vessel.

For the stock assessment of blue shark in the North Pacific, size composition of catch by various fishery is important information to categorize "fleet" and estimate selectivity in the size or age-based stock assessment model such as "Stock Synthesis". Regarding the distribution of North Pacific population, segregation by ontogenetic stage and/or sex has been proposed to occur (Nakano 1994, Sippel et al. 2016). In past, spatio-temporal characteristic of blue shark caught by Japanese fishery was described in Sippel et al. (2016) with other fleets based on size data. However, its annual trend was not available as document. The aim of this document is to describe the size frequency and its annual change for the blue shark caught by Japanese commercial fishery and research program based on updated dataset for the upcoming benchmark stock assessment on North Pacific blue shark.

Materials and Method

Data

The details of each data source are described below;

1) Port-sampling data

Size data between 2008 and 2020 was available for this analysis. As head was removed, dorsal length (between origin of the first dorsal fin and second dorsal fin) was measured by customized caliper to the nearest cm and converted to precaudal length (PCL) using the conversion equation (Fujinami et al. 2017).

Regarding longline fishery, offshore longline fishery treated in this analysis deploy shallow and night setting style and thus categorized as "shallow-set longline". This fishery corresponds to Kinkai-shallow in CPUE standardization of Japanese data. Most of small-scale longline vessel used in this analysis is smaller than offshore longline vessel and their target is suggested to be variable depending on its registry or independent vessel. As detailed information such as operation area and gear configuration is not available, size data from this fishery was treated as "small-scale (coastal) longline". Driftnet fishery is developed in coastal area of Japan and mainly targets swordfish, billfish and sharks.

Spatial resolution (i.e., location of catch) of these size data is variable such as 1 degree by 1degree, 5 degrees by 5 degrees, and 10 degrees by 20 degrees (latitude by longitude).

2) RTV data

The size data with sex from RTV research was available for 1967-2020. As the main target of RTV research is bigeye tuna (*Thunnus obesus*) and/or yellowfin tuna (*Thunnus albacares*), deep-set (hooks per basket: mostly ≥12) and daytime setting has been adopted. Most of operation with gear depth information (i.e., hooks per basket) could be categorized into shallow or deep-set longline, but some operation without gear information was categorized as "other-type longline", which was removed from the analysis because of small sample size. Spatial resolution of this data is 1 degree by 1 degree and PCL is measured to the nearest cm for all individuals as much as possible.

3) Other research data

Other than RTV, size and sex data was available from shallow-set longline survey and driftnet survey for 1978-2021. Driftnet survey was conducted during limited period and majority data was collected before the moratorium. In the longline survey, fishing vessels were chartered and most of the operation deployed was shallow (hooks per basket: 4-6) and night setting. Thus, the operation in this survey was categorized as "shallow-set longline". Spatial resolution of this data is 1 degree by 1 degree and PCL is measured to the nearest cm for all individuals as much as possible. Estimated size data (visual estimation before release) was removed from the analysis.

4) Longline observer data

In the North Pacific, longline observer program began in 2008 but size data of blue shark has been available since 2009. Spatial resolution of this data is 1 degree by 1 degree and PCL is measured to the nearest cm for all individuals as much as possible. Observer data consists of both deep-set (hooks per basket: 13-24) and shallow-set (hooks per basket: 3-4) longline operation and can be divided into each operation type. Some operation for which operation pattern is unknown was categorized as "coastal longline".

Analysis

Size frequency and basic statistics are summarized by fishery type and sex. Annual change of sex aggregated size frequency and sex ratio was plotted for each fishery type.

In order to compare the juvenile ratio among fishery type, the ratio of juvenile was calculated by sex and fishery type based on the maturity size estimated by Fujinami et al. (2011).

Distribution of mean PCL and number of size data was plotted for main fleet (Kinkai-shallow and research deep-set LL). As three types of spatial resolution exists in Kinkai-shallow size data, size data with 1 by 1 was converted to 5 by 5 degree data and aggregated with original 5 by 5 data. Size data with 10 by 20 was treated separately and mean PCL was calculated for 5 by 5 and 10 by 20 degree data by seasonally. Although research deep-set LL data is set-level, it was shown as 5 by 5 degree for

comparison with results of Kinkai-shallow. Here season was divided into four quarters (quarter1: Jan.-Mar., quarter2: Apr.-Jun., quaeter3:Jul.-Sep., quarter4:Oct.-Dec.).

Results and Discussion

Totally, 894,060 size data was collected between 1967 and 2020. 67% of them was from commercial Kinkai-shallow longline, followed by research data with deep-set longline (23%) and ratio of other type of fishery was less than 5% (Table 1). As shown in Table2 and Figure 1, blue shark caught by deep-set longline (median and mode: larger than 160 cm precaudal length: PCL) tends to be larger than that of other type of fishery (median and mode: smaller than 150 cm PCL) in general. From the perspective of ontogenetic composition, ratio of juvenile was different depending on the type of fishery (Table 3). Generally, for females, 90% of shark was juvenile in coastal fishery (longline and driftnet), while juvenile ratio was about 40% in deep-set longline operated in offshore/distant water. Similar trend was confirmed in males, but juvenile rate in deep-set longline was lower than that of females.

Annual trend of size frequency data indicates relatively stable trends for Kinkai-shallow, commercial coastal longline, commercial deep-set longline and commercial driftnet fishery (Figure2). In Kinkai-shallow, size between 2008 and 2010 (i.e., before the Great East Japan Earthquake) was smaller than that after 2011. Between 2011 and 2020, both median and mean were stable, small blue shark (i.e., outlier) was seen after 2016. Shift of body size before and after the Earthquake was also reported in shortfin mako (Semba 2017) and further examination and data collection is necessary to interpret the trend. Regarding research data, both mean and median in shallow-set longline increased between late 1970's and early 1980's, but they were stable after 1999 (Figure 3). Size frequency for deep-set longline was stable between 1967 and 2020 (Figure 3). Mean and median of size data from driftnet research showed increasing trend between 1980 and 1983, but there was not enough data to evaluate the trend after that. As driftnet fishery in distant water was banned in 1993, evaluation of effect of driftnet fishery is only available in commercial driftnet fishery data (within EEZ) at present.

Annual trend of sex ratio was variable depending on the type of fishery (Figure 4). Regarding main fleet, the ratio of female was stable around 25%, while the ratio in research deep-set longline was higher and more variable between 10-60%. In coastal fishery (longline and driftnet), the ratio was similar between 25-50%, while the ratio in commercial deep-set longline (0-25%) was lower than other type of fishery. The female sex ratio in research shallow-set longline and driftnet was highly variable.

Distribution of size data for Kinkai-shallow and research deep-set longline was shown by season (Figure 5). Size data of Kinkai-shallow covers the area north of 20 °N and west of the international dateline. Reflecting seasonal shift of target species, in quarter 3 and 4, size data was collected in the northern area (north of 30°N), while the area expanded to the east and south in quarter 1 and 2. Distribution of research deep-set longline covers more southern area (south of 30°N) across the North

Pacific.

Mean PCL in Kinkai-shallow supports the known distribution pattern that small sharks are distributed in the northern area and larger shark are distributed in more southern and eastern (from the viewpoint of Japan) area (Nakano 1994) as shown in Figure 6. In the data from research deep-set longline, small shark < 150cm PCL was not observed and larger shark dominated. The pattern of distribution of the large blue shark was mosaic-like rather than gradational within the area. More detailed examination considering several factors such as sex and year was left to be considered in the future work.

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Table1. Annual number of length data of blue shark in the North Pacific by Japanese fleet by type of data sources and sex. (a) and (b) is data collected from port commercial fishing vessel and research program, respectively. Processing of data in 2019-20 has been still undertaken (preliminary).

(a)

Port sampling and observer program

	Kinkai-shallow (offshore LL)			Coastal-longline			Deepset-longline			Driftnet		
Year	Female	Male	Unknown	Female	Male	Unknown	Female	Male	Unknown	Female	Male	Unknown
2008	456	427	98	-	-	-	-	-	-	-	-	-
2009	3,834	10,385	34	-	-	-	-	-	-	-	-	-
2010	3,836	9,631	3	-	-	-	-	-	-	-	-	-
2011	2,922	5,352	2	-	-	-	-	-	-	1,152	423	0
2012	16,518	66,061	2	388	904	0	-	-	-	2,531	4,731	0
2013	21,353	42,485	1	328	579	0	-	-	-	1,475	2,224	0
2014	19,527	45,652	2	284	252	1	-	-	-	1,838	2,782	1
2015	15,939	41,674	3	199	196	0	-	-	-	632	1,463	0
2016	17,650	47,014	12	296	900	0	301	664	7	595	1,901	0
2017	20,428	60,365	28	2,044	1,989	0	477	899	22	605	1,027	0
2018	12,696	50,476	10	1,511	2,201	0	269	3,196	20	1,301	1,302	0
2019	12,012	44,129	8	1,017	2,195	0	598	3,565	9	603	1,561	0
2020	9,015	21,991	3	88	154	0	45	76	0	-	-	-
total	156,186	445,642	206	6,155	9,370	1	1,690	8,400	58	10,732	17,414	1

(b)

Research and RTV

	longline_shallow			longline_deep			driftnet		
Year	Female	Male	Unknown	Female	Male	Unknown	Female	Male	Unknown
1967	-	-	-	294	447	2	-	-	-
1968	-	-	-	487	941	4	-	-	-
1969	-	-	-	273	865	2	-	-	-
1970	-	-	-	134	381	0	-	-	-
1971	-	-	-	69	126	0	-	-	-
1978	1,639	1,001	0	-	-	-	-	-	-
1979	2,079	514	0	-	-	-	401	927	2
1980	3,625	3,322	0	-	-	-	1,256	999	16
1981	987	4,356	0	-	-	-	419	615	1
1982	208	762	0	-	-	-	0	18	0
1983	-	-	-	-	-	-	16	154	0
1992	-	-	-	9,144	10,037	105	-	-	-
1993	-	-	-	10,080	14,297	104	-	-	-
1994	-	-	-	9,279	12,376	125	42	54	1
1995	-	-	-	6,857	9,794	230	-	-	-
1996	-	-	-	6,257	10,438	158	5	8	0
1997	-	-	-	7,938	14,458	205	-	-	-
1998	-	-	-	4,704	7,611	85	7	5	0
1999	1	1	1	1,886	2,704	23	-	-	-
2000	7	35	0	2,319	6,523	262	-	-	-
2001	12	10	0	3,422	6,578	278	-	-	-
2002	23	136	8	3,836	5,834	241	-	-	-
2003	28	129	6	6,305	5,291	224	-	-	-
2004	31	297	7	4,727	4,601	250	-	-	-
2005	30	226	15	3,481	3,348	134	-	-	-
2006	10	79	9	2,661	2,244	252	-	-	-
2007	3	44	2	1,029	1,205	30	-	-	-
2008	32	280	13	413	383	24	-	-	-
2009	17	42	4	7	16	2	-	-	-
2010	76	101	5	15	116	5	-	-	-
2011	7	9	0	152	148	22	-	-	-
2012	103	137	4	15	42	6	-	-	-
2013	97	151	17	35	24	6	-	-	-
2014	35	366	10	67	111	5	-	-	-
2015	43	141	10	61	38	1	-	-	-
2016	-	-	-	83	72	6	-	-	-
2017	167	802	37	8	25	0	-	-	-
2018	7	33	0	63	48	3	-	-	-
2019	50	439	23	2	2	2	-	-	-
2020	35	249	11	1	3	1	-	-	-
2021	23	10	2	-	-	-	-	-	-
total	9,375	13,672	184	86,104	121,127	2,797	2,146	2,780	20

Table2. Basic statistics of length frequency (sex combined) by type of fishery.

Fishery	Min.	1st Qu.	Median	Mean	3rd Qu.	Max.
Kinkai Shallow LL_commercial	13.00	130.30	147.90	149.50	165.40	386.30
Coastal LL_commercial	72.98	122.76	135.86	137.14	151.58	256.38
Deep LL_commercial	66.00	157.00	168.00	167.60	178.00	291.00
Driftnet_commercial	70.06	117.75	130.30	131.45	142.85	413.58
LL shallow_research	39.00	118.50	138.50	138.40	160.00	319.70
LL deep_research	38.00	153.00	164.00	164.30	175.00	300.00
LL other_research	93.00	113.00	128.00	129.40	133.50	221.00
Driftnet_research	32.00	92.00	112.00	117.80	143.00	225.00

Table 3. Ratio of juvenile by fishery type and sex. LL is abbreviation of “longline”.

Female	No. of Juvenile (<156.6)	No. of Adult (>=156.6)	Ratio of Juvenile (%)
Kinkai-shallow LL (commercial)	95,562	64,394	60
Coastal_LL (commercial)	5,499	863	86
Deep-set_LL (commercial)	656	1,034	39
Driftnet (commercial)	13,525	758	95
Shallow-set LL (research)	8,452	923	90
Deep-set_LL (research)	34,952	51,152	41
Driftnet (research)	2,042	104	95
Male	No. of Juvenile (<160.9)	No. of Adult (>=160.9)	Ratio of Juvenile (%)
Kinkai-shallow LL (commercial)	316,983	134,215	70
Coastal_LL (commercial)	8,201	1,474	85
Deep-set_LL (commercial)	2,400	6,000	29
Driftnet (commercial)	21,031	1,685	93
Shallow-set LL (research)	8,538	5,134	62
Deep-set_LL (research)	42,293	78,834	35
Driftnet (research)	2,240	540	81

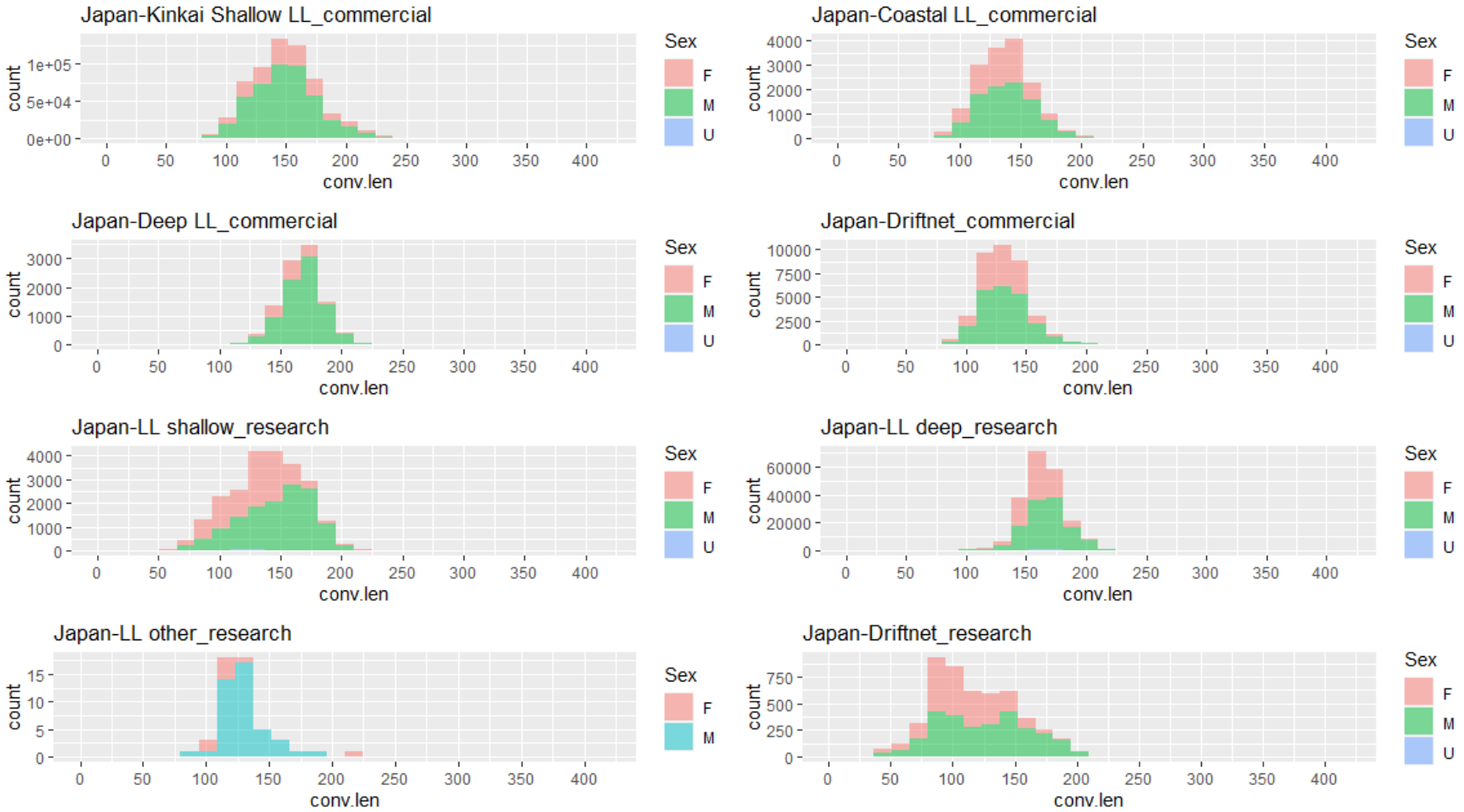

Figure 1. Length frequency of blue sharks by fishery type and sex.

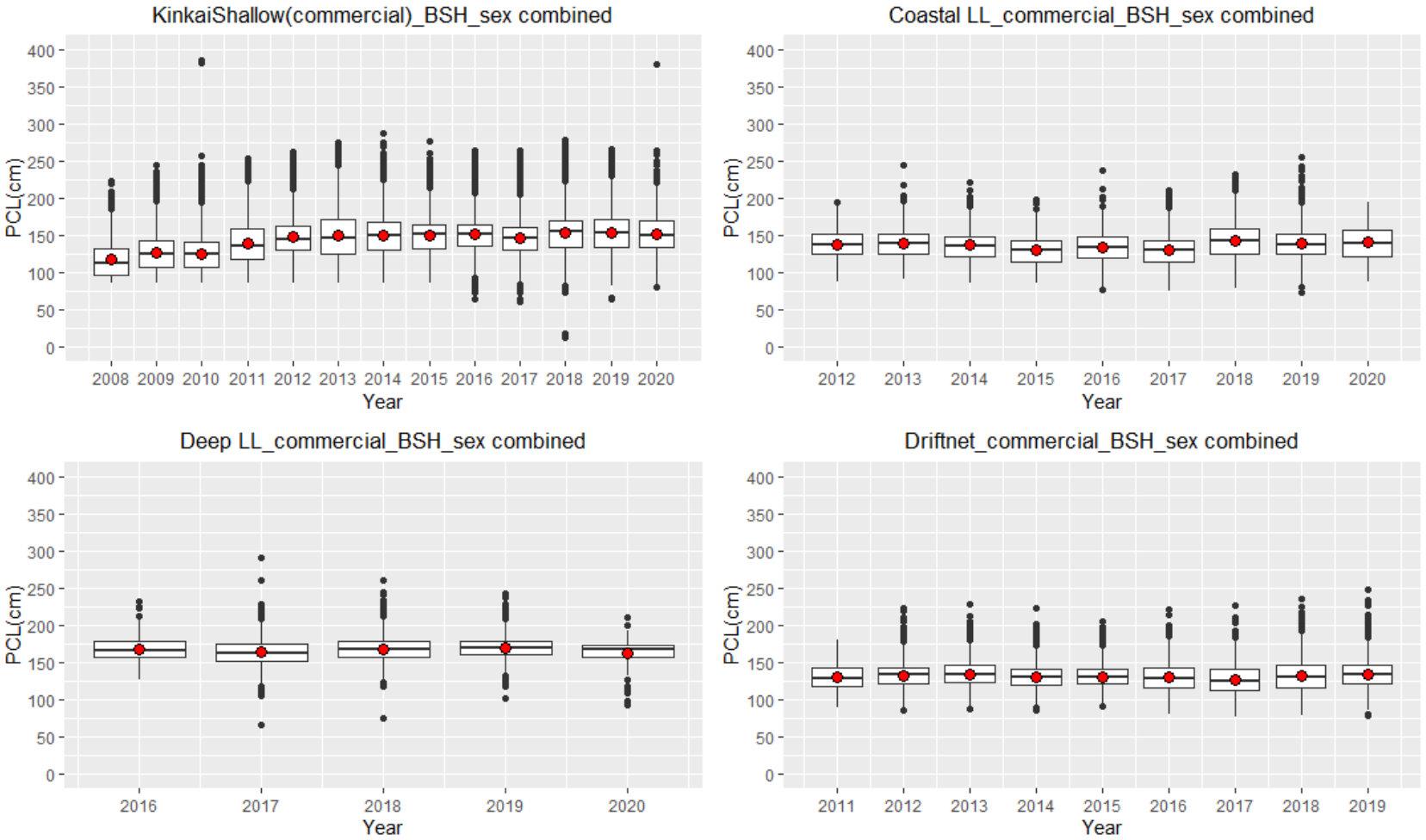

Figure 2. Box plot of blue shark lengths by year for Kinkai-shallow (2008–2020; top left), coastal longline (2012-2020, top right), deep-set (2016-2020; bottom left) and driftnet (bottom right) showing the median (solid black line), mean (red circle) and quartiles (closed box). The whiskers show 1.5 times the interquartile range from the box and points indicate data outside of that range.

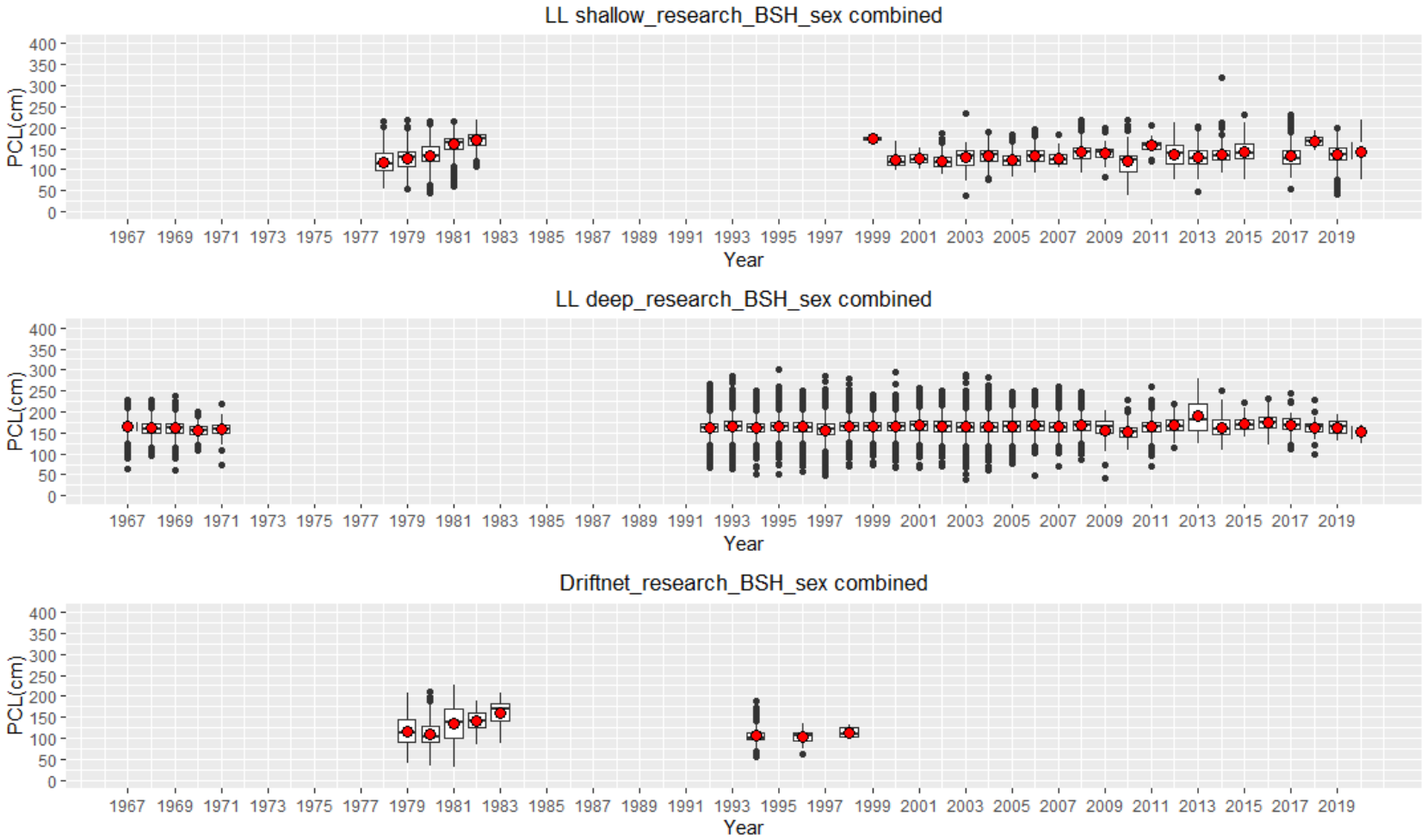

Figure 3. Box plot of blue shark lengths by year for shallow-set research (1978–2020; top), deep-set longline research (1967-2020, middle), and driftnet research (bottom) showing the median (solid black line), mean (red circle) and quartiles (closed box). The whiskers show 1.5 times the interquartile range from the box and points indicate data outside of that range.

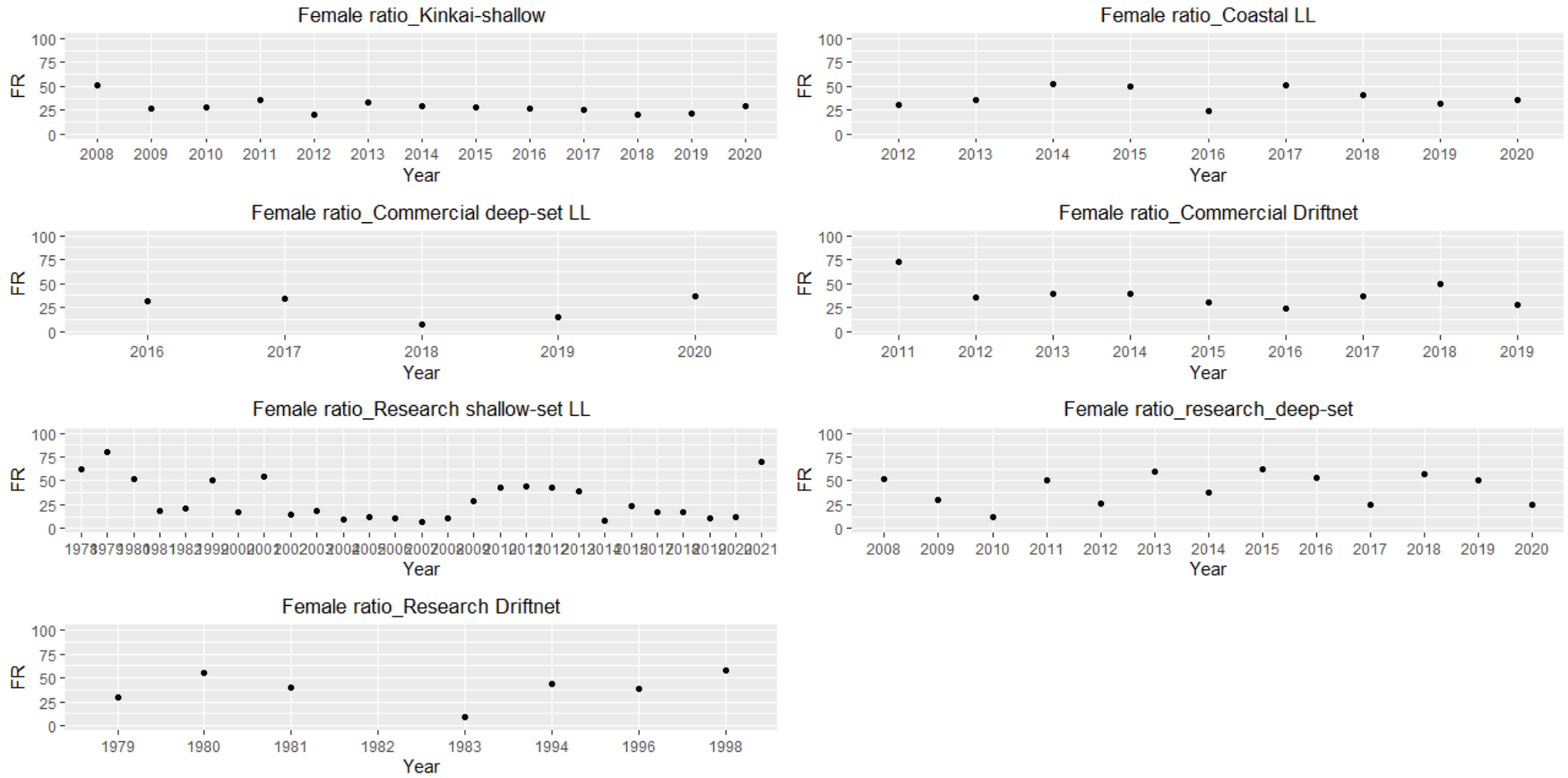

Figure 4. Annual sex ratio by each fishery type. Y-axis indicate the percentage (%) of f

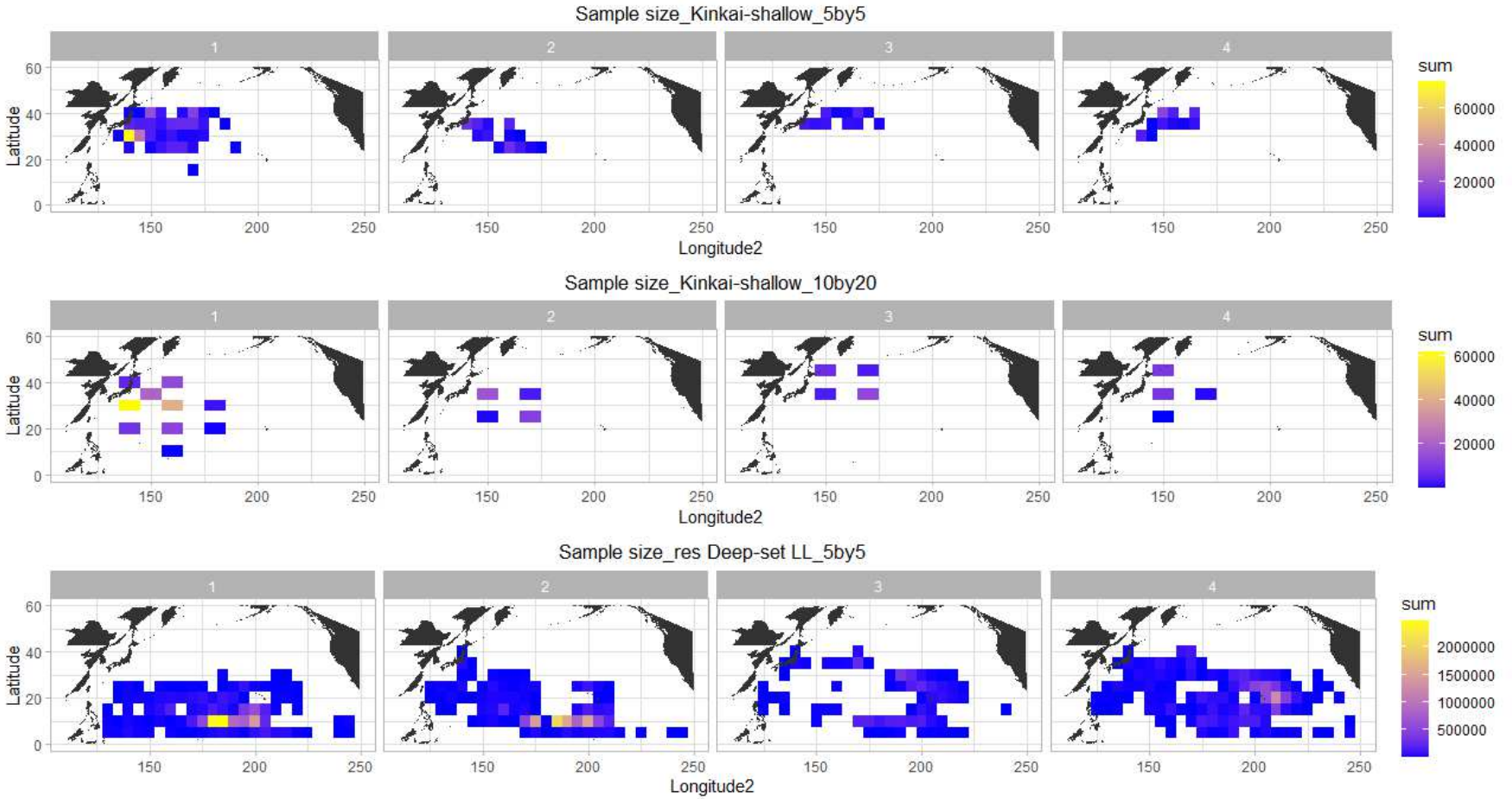

Figure 5. Seasonal distribution of size data of blue shark for Kinkai-shallow (5 by 5 and 10 by 20 degrees grid) and research deep-set LL (5 by 5 degrees grid). Upper panel indicates number of size data calculated using data with spatial resolution of 1 by 1 and 5 by5. Middle and bottom panel indicate number of size data calculated using Kinkai-shallow with resolution of 10 by 20 degree and research deep-set longline data with resolution of 1 by 1 degree, respectively.

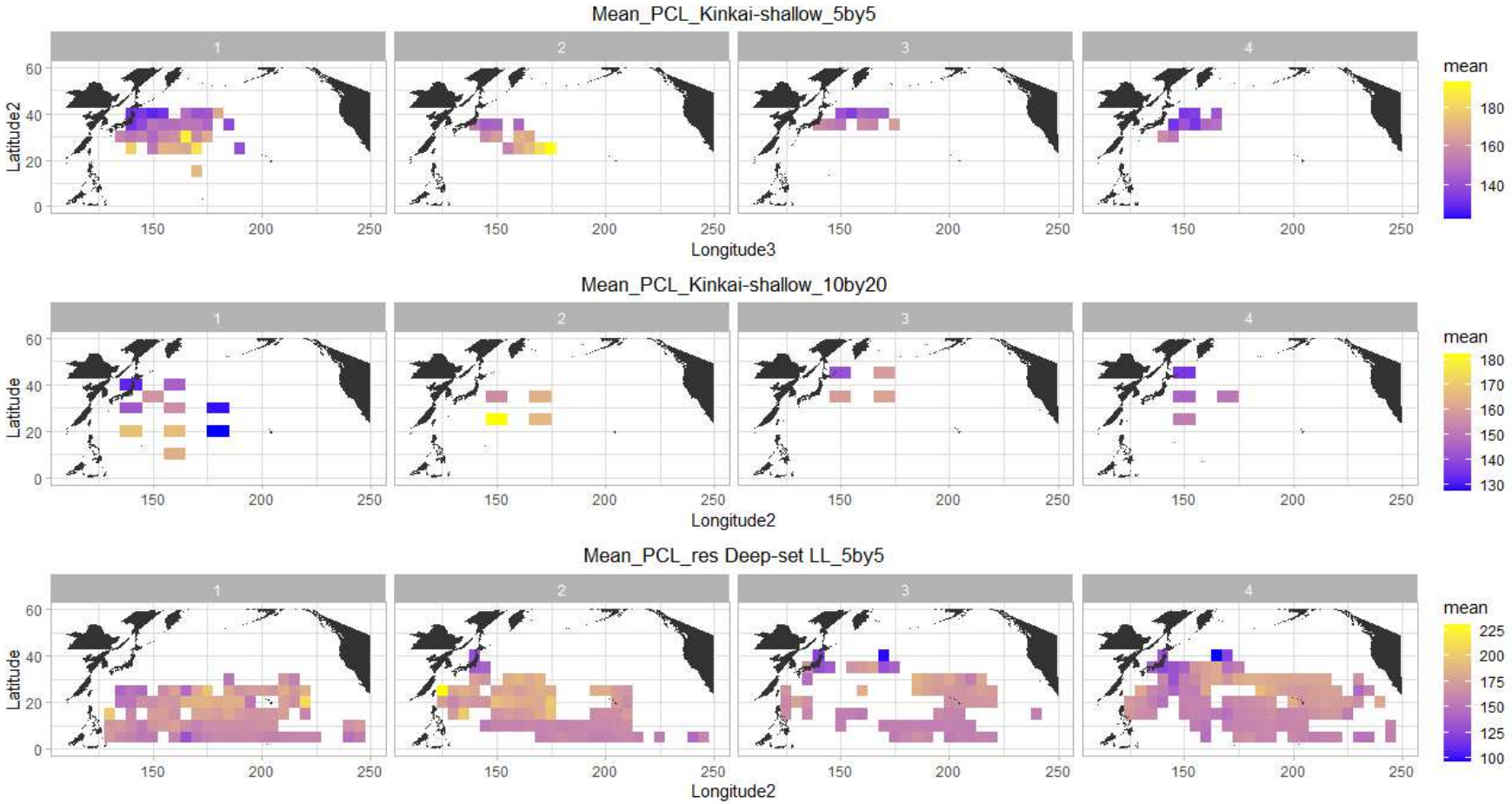

Figure 6. Seasonal distribution of mean PCL of blue shark for Kinkai-shallow (5 by 5 and 10 by 20 degrees grid) and research deep-set LL (5 by 5 degrees grid). Upper panel indicates mean PCL calculated using data with spatial resolution of 5 by 5 degree and 1 by 1. Middle and bottom panel indicate mean PCL calculated using Kinkai-shallow data with resolution of 10 by 20 degree and research deep-set longline data with resolution of 1 by 1 degree, respectively.