Size and sex structure of blue sharks in the North Pacific Ocean†

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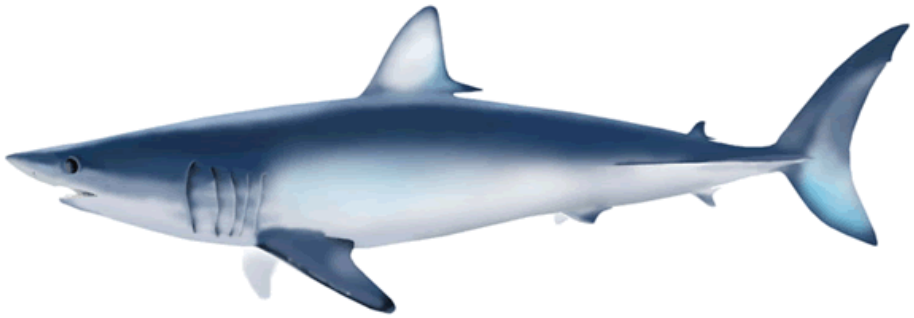

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Abstract

An updated stock assessment for blue sharks (*Prionace glauca*) in the North Pacific Ocean (NPO) is being developed by the ISC Shark Working Group (SHARKWG). The SHARKWG requested that spatially explicit size and sex data be submitted to aid in understanding of fleet dynamics and stock structure. This analysis focuses on the spatial dynamics of blue shark by size and sex, both overall for understanding stock structure and by fleet for understanding fleet dynamics and gear selectivity. Overall, the smallest mean size of females and males (< 145 cm PCL) is found in the northwestern Pacific Ocean (NWPO) and the northeastern Pacific Ocean (NEPO), while sexually mature females and males are found throughout the remaining distribution. Relatively larger sample sizes (>100 observations per 5 x 5 degree block) are found in the north central Pacific Ocean (NCPO) and NWPO, while relatively lower sample sizes (<20 observations per block) are found mostly below 15°N latitude, and above 30°N latitude in the CPO. Immature females and males are found in the NEPO (≤ 100 cm) and NWPO (≤ 145 cm) during all four quarters, and mature females and males are found in the NCPO during all four quarters. The largest (≥200cm) females and males were observed in the tropical NWPO during the 3rd quarter. This working paper and the data used within it are included in another working paper for the meeting to understand gear selectivity and propose an approach to fleet aggregations. Overall, the sample size of data available for this study is substantial with 669,388 observations, although some fisheries were sampled much more than others.

Introduction

An updated stock assessment for blue sharks (*Prionace glauca*) in the North Pacific Ocean (NPO) is being developed by the ISC Shark WG. The previous assessment (ISC, 2014) included development of a length-structured model in Stock Synthesis (SS3), but some uncertainties about the size data, fleet definitions the size selectivity of different fleets were unresolved from that assessment and were identified as priorities for ongoing development in the pending assessment.

The SHARKWG requested that spatially explicit size and sex data be submitted to aid in understanding of fleet dynamics and stock structure. This analysis focuses on the spatial dynamics of blue sharks by size and sex, both overall for understanding stock structure and by fleet for understanding fleet dynamics and gear selectivity.

Materials and Methods

Spatially explicit size and sex data were available from 20 different fisheries from Japan, USA, Taiwan, Mexico, China, and Korea. Set-specific locations (exact longitude and latitude) were available for US, Taiwan, Mexico, China and Korea fleets, and from Japanese fisheries at 1x1°, 5x5°, or 20x10° (lon x lat) resolution.

Many of these fisheries and their biological sampling programs have been described previously for the ISC blue shark and/or mako shark stock assessments. The following references provide information about previously described fisheries: USA - Hawaii deep and shallow set longline (Sippel et al., 2014; Walsh and Teo, 2013, 2012); drift gillnet (DGN) fishery (Teo et al., 2012): Japan - Kinkai shallow fishery (Hiraoka et al., 2011); JRTV/JRVS/JRVD (Ohshimo et al., 2014; Yokawa, 2012a); driftnet (Yokawa, 2012b);

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small longline (Kimoto et al., 2012): Mexico – observers aboard shallowset longliners from Ensenada and San Carlos (Castillo-Geniz et al., 2014); Taiwan large vessel longline (Tsai and Liu, 2014); Korea – longline observers (Kim et al., 2016). A description of Chinese fisheries and methods of collecting biological samples from them has not yet been provided, but will hopefully be forthcoming in the future.

Lengths were measured from different fisheries in either pre-caudal length (PCL), total length (TL), fork length (FL), dorsal length (DL) or alternate length (AL), where dorsal and alternate length are different terms used for the same standard measurement of the length between the origin or the first dorsal fin to the origin of the second dorsal fin. The ISC Shark working group previously adopted PCL as the standard blue shark measurement for which other measurements should be converted to. The following conversion equations were used;

PCL = (TL x 0.748) + 1.063 --- R^2=0.94, size range = 98-243 cm PCL, n=497 (source, ISC SHARKWG Report – April 2013)

PCL = (DL or AL x 2.56) + 9.971 ---- R^2=0.971, size range = 10.92-88 cm DL, n=862, (source, Japanese data September 2016)

TL = (FL x 1.189) + 3.192 --- R^2=0.986, size range 45-273 cm FL, n=11384 (source, US DGN observer data – updated July 2016)

Length at 50% maturity is assumed to be 193 cm TL (145 cm PCL) for both sexes based on a review of life history information previously conducted by the ISC Shark WG (Table 3, ISC SHARKWG, 2013).

Data are summarized in 5x5^o spatial grids because this resolution captured the majority of the data and provided mostly adequate sample sizes (> 10 observations per grid) for calculating mean size. Exploration of summaries at 2x2^o resolution resulted in smaller sample sizes in data poorer areas (mostly in the eastern tropical Pacific and south Pacific). However, data provided at 20x10^o resolution are excluded from finer scale summaries and are provided separately in the Appendix.

The spatial extent of fisheries was estimated by calculating the 80% spatial density kernel (also known as the Utilization Distribution) of all data provided at 5x5^o resolution or better (but excluding 20x10^o resolution).

Results

The spatial extent of the data used herein is shown by fishery in Figure 1. Sample sizes by year for each fishery are provided in Table 1.

Overall, a roughly equal percentage (~50%) of the two sexes is found in the central Pacific Ocean (CPO, Figure 2). This pattern is broadly apparent in Q1, Q2, and Q4, but in Q3 the CPO is dominated mostly by males and a roughly equal percentage of females and males is found in the northwest Pacific Ocean (NWPO, Figure 3.).

Overall, the smallest mean size of female and males (<145 cm PCL) is found in the NWPO and the eastern Pacific Ocean, while sexually mature females and males are found throughout the remaining distribution (CPO, Figure 4.). Relatively larger sample sizes (>100 observations per strata by sex) are

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found in the CPO, the NEPO and NWPO, while relatively lower sample sizes (<20 observations) are found mostly in the southernmost strata and in the northern CPO. By quarter, immature females and males are found in the northern EPO (≤100 cm) and NWPO (≤145 cm) during all four quarters, and mature females and males are found in the CPO during all four quarters (Figure 5). The largest (≥200 cm) females and males were observed in the tropical WPO during the 3rd quarter.

Distribution by size and sex is further broken down by each fishery for which data were submitted. For the sake of brevity because there are 20 different fisheries, these results are included in the Appendix. Within the Appendix, results from Japanese kinaki shallow and research and training vessel (JRTV) fisheries, Taiwan large longline, and USA Hawaii deep-set longline are provided first because abundance indices for these fisheries were considered in the base case and sensitivity runs for the 2014 assessment. Those abundance indices are most likely to be considered again for inclusion in the pending assessment (2017) by the ISC SHARKWG. Following those main fisheries, results from other fisheries are also provided.

Discussion

The roughly equal female/male proportions of blue sharks in the CPO in Q1, Q2, and Q4 combined with the mean size of both sexes in the region being at or above the 50% maturity could be consistent with the mating grounds. The presence of very large females and males (≥200cm) in the tropical WPO and northern CPO, particularly during Q3, is difficult to interpret but it could perhaps be a foraging ground. The persistent observations (all four quarters) of smallest individuals in the northern WPO and EPO is consistent with parturition and nursery areas. The mean size in these areas is smaller in the EPO (~100 cm) than in the northern WPO (~145 cm), suggesting females may give birth and then move out of the EPO, but in the northern WPO the larger mean size and the skew toward a higher proportion of males suggests that subadult and adult males may utilize the nursery areas as well. This is mostly consistent with the hypothesis of mating, parturition, and movement proposed by Nakano (Nakano, 1994), but with a much larger dataset. However, Nakano proposed that segregation of adults from pupping grounds occurs to minimize predation, where this working paper proposes that some mixing of adults on NWPO pupping grounds may occur. This working paper presents largely exploratory analysis, and a more comprehensive model based analysis should help answer this question.

An objective of this study is to contribute information to understanding of fishing fleet dynamics and selectivity for defining fisheries, and aggregating data when possible for the ongoing development of an SS3 assessment model. Carvalho and Sippel (2016) propose fleet definitions/aggregations based on selectivity patterns using this same dataset (although with slightly different Japanese fleet definitions based on an updated data submission from Japan).

Overall, the sample size of data available for this study is substantial with 669,388 observations, although some fisheries were sampled much more than others. Fleet aggregation, if the working group decides to proceed in that manner, will result in pooling of size data, and thus the sample sizes for some of the relatively smaller fisheries could be combined. Once these decisions are made the SHARKWG, calculation of effective sample sizes for data weighting within the assessment model will be possible (Francis, 2014, 2011).

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Tables

Table 1. Number of blue shark size observations by fishery and year (Female, Male, and Unknown combined).

	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016
China - LL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	158	169	342	515	611	348	3	0
Hawaii - DSLL	0	0	0	0	321	278	579	318	402	256	541	365	235	121	125	125	31	26	7	8	24	18	10	0	28	0	0
Hawaii - SSLL	0	0	0	0	167	290	984	1806	843	448	176	14	0	0	11	94	34	27	128	47	145	16	25	2	8	0	0
Japan - Driftnet	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1575	7268	3699	4623	2099	36
Japan - JRVD	0	0	0	0	0	36	33	80	0	58	1	0	14	0	42	0	29	0	45	9	114	30	17	0	93	55	0
Japan - JRVS	0	0	0	0	0	0	0	0	0	3	42	22	167	163	335	271	98	49	325	63	182	16	244	265	415	194	0
Japan - JTRV	0	0	17948	23641	21444	16150	16307	18489	12364	4555	9103	10271	9842	11008	8728	5947	4917	1906	775	16	22	292	46	65	90	45	0
Japan - Kinkai shallow longline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1045	15188	14488	8500	82621	63880	65216	57667	7514
Japan - Kinkai_shallow_longline_sn	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	3966	19500	16499	9427	1531	0
Japan - Observer deep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	9	12	0	9	129	1119	923	0
Japan - Observer shallow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1376	0	0	8391	12785	0
Japan - Small LL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1050	506	361	395	31
Japan - Small LL deep	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	102	158	0	0	0
Japan - Small LL shallow	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	140	243	177	0	0
Korea-longline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	121	20	434	22	0	0	0	0	4	12	0	3
México-Ensenada SSLL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	2475	8104	4356	1799	2623	645	1090	724	7	0	0
México-San Carlos SSLL	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	1216	353	0	0	0	0	273	0	0	0
Taiwan - large longline	0	0	0	0	0	0	0	0	0	0	0	0	0	0	47	196	479	412	852	136	285	695	448	800	369	0	0
US-JuvySurvey	0	0	0	115	13	149	456	486	6	3	974	224	69	96	514	121	298	224	270	138	245	314	238	73	105	15	0
USA-DGN	231	148	890	694	590	1315	775	1573	1667	1471	863	322	355	253	172	66	49	320	211	57	22	35	67	96	32	0	0

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Figures

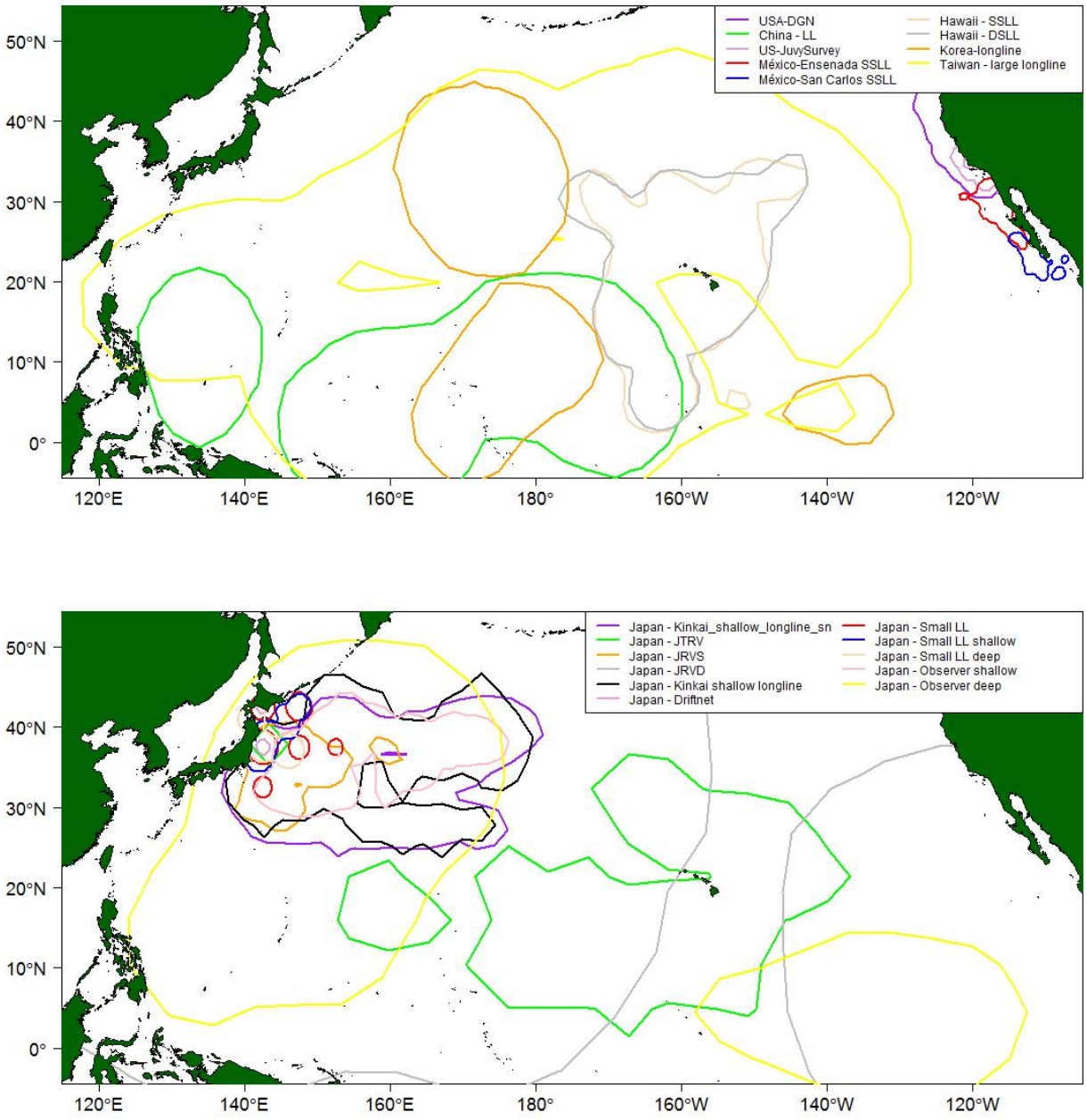

Figure 1. Spatial extent (95% density kernel of utilization distribution all fisheries except 80% required to estimate distribution for US-Juvy Survey) of fisheries providing blue shark size and sex data used for this study (excluding the subset of Japanese data provided at 20x10^{o} resolution). Top panel is non-Japanese fisheries (USA, China, Korea, Taiwan, Mexico) and bottom panel is Japanese fisheries.

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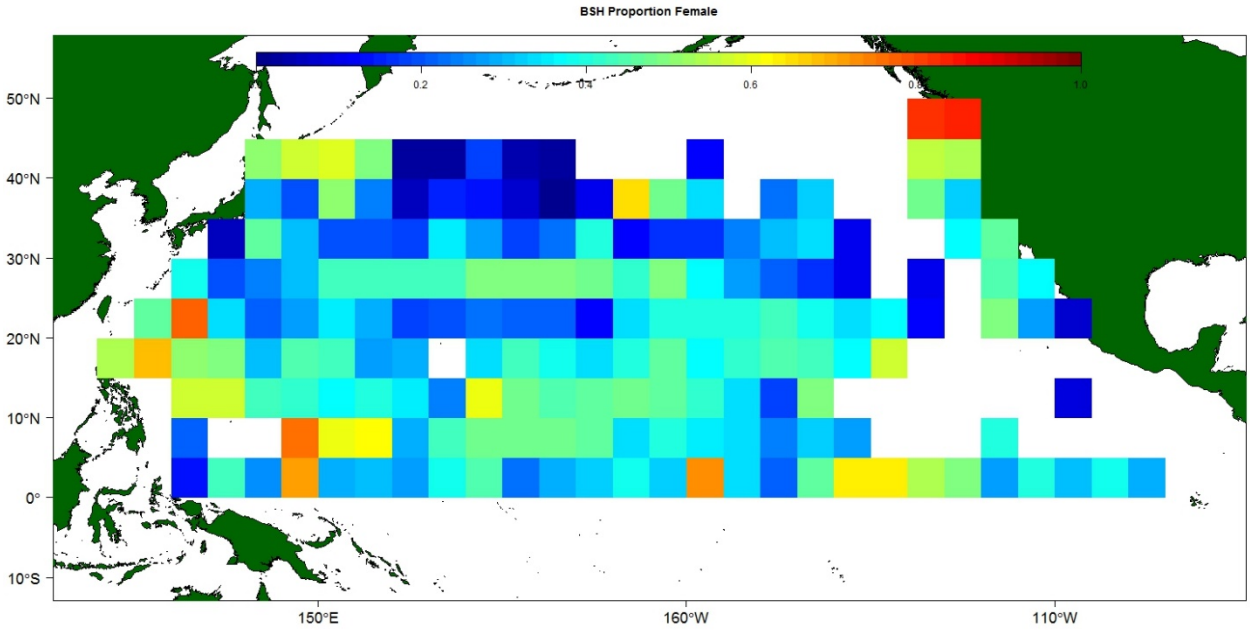

Figure 2. Proportion of female blue sharks from all fisheries, excluding data provided at 20x10^{o} resolution.

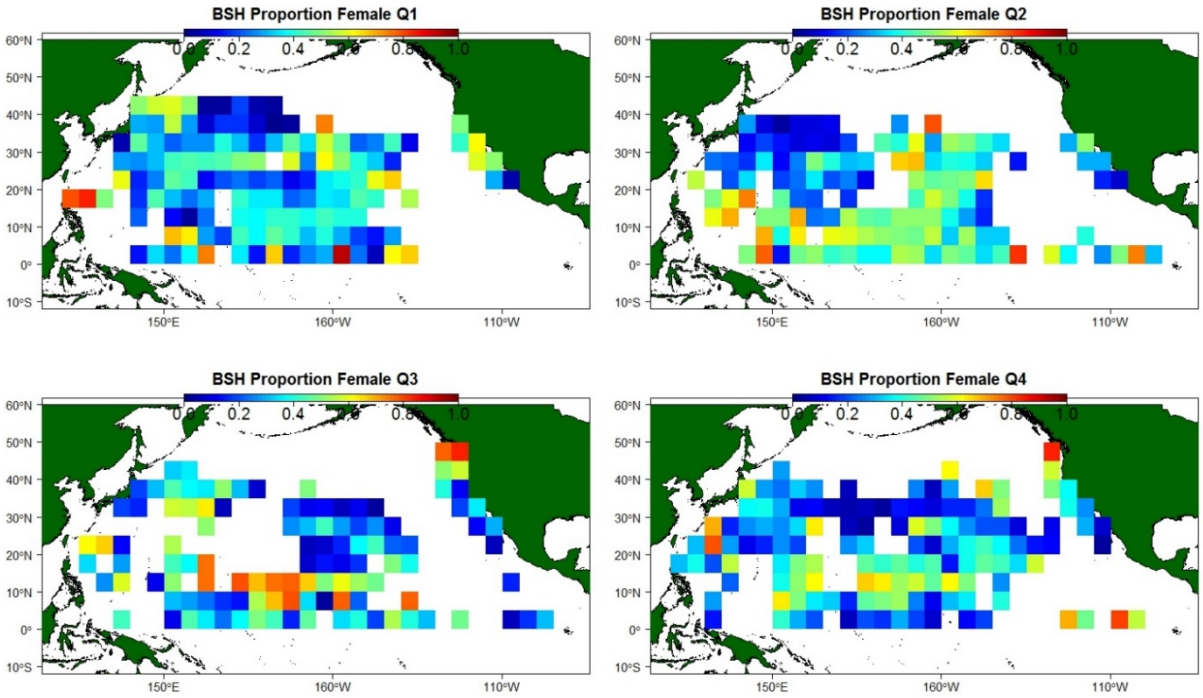

Figure 3. Blue shark quarterly female proportion from all fisheries, excluding data provided at 20x10^{o} resolution.

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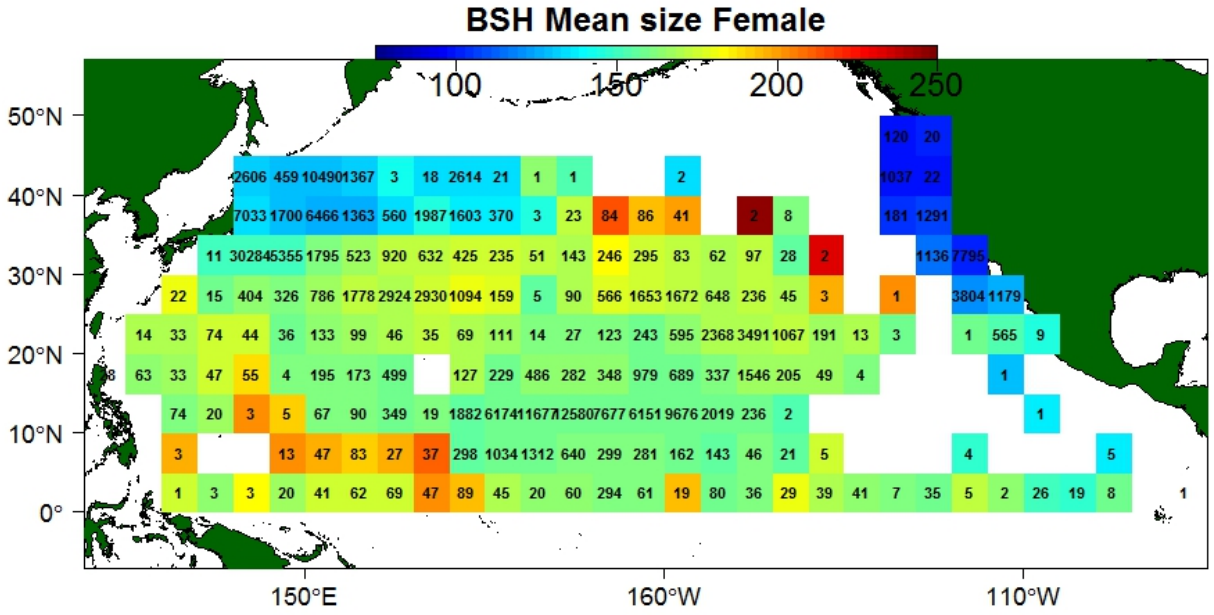

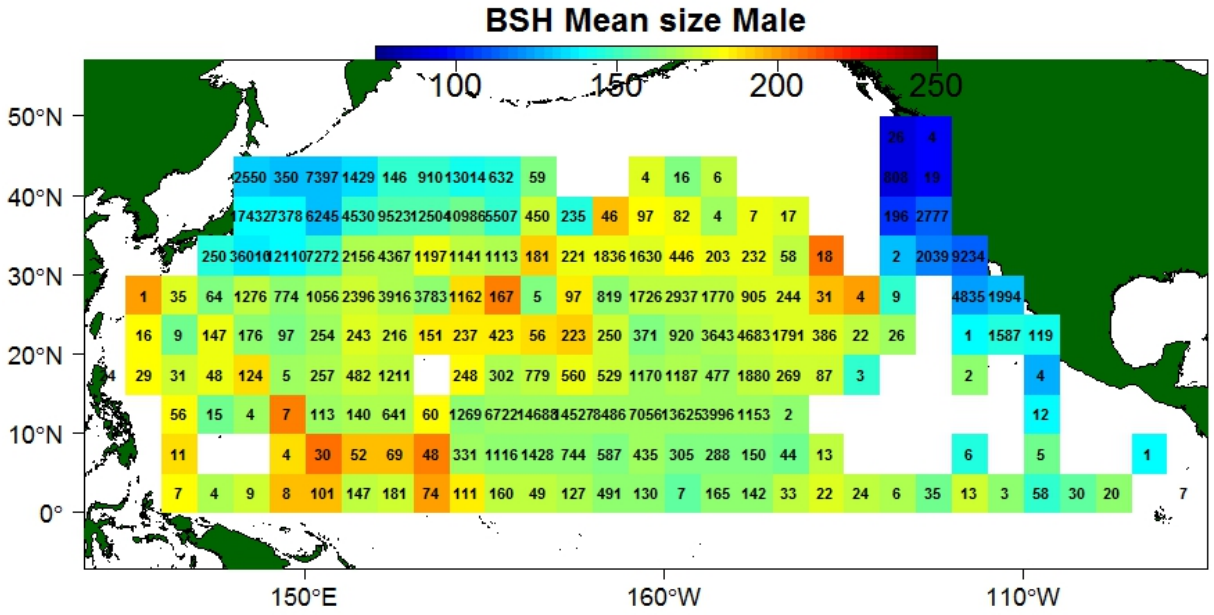

Figure 4. Blue mean shark size (cm PCL) of female (top) and male (bottom) from all fisheries, excluding data provided at 20x10^{o} resolution, with sample size in each pixel.

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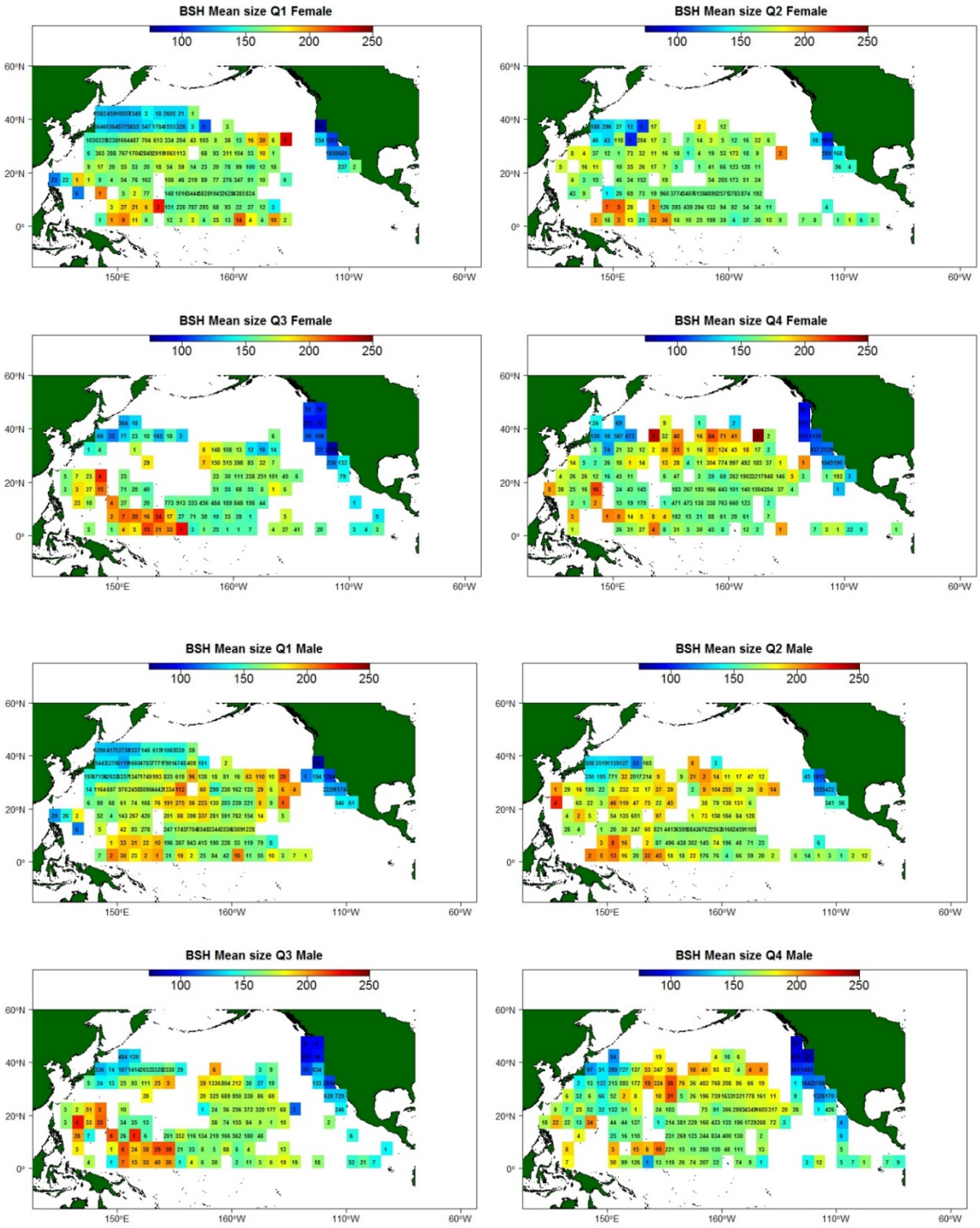

Figure 5. Blue shark quarterly mean size (cm PCL) of female (top 4 panels) and male (bottom 4 panels) from all fisheries, excluding data provided at 20x10^{o} resolution.

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Appendix: ISC/16/SHARKWG-1/14 - Size and sex structure of blue sharks in the North Pacific Ocean†

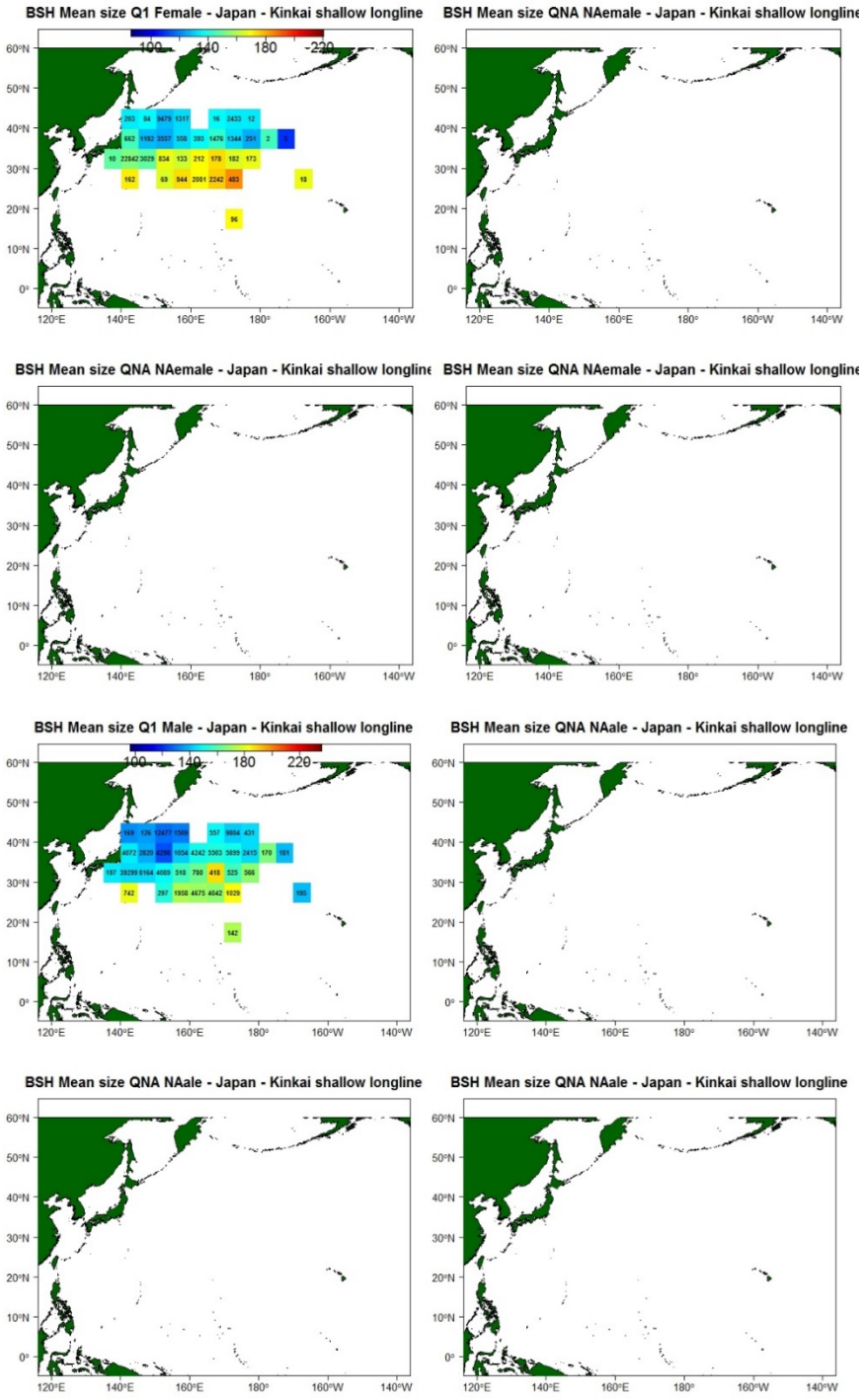

Figure A1. Mean size of female (top panel) and male (bottom panel) blue shark from the Japanese Kinkai shallow longline fishery by quarter.

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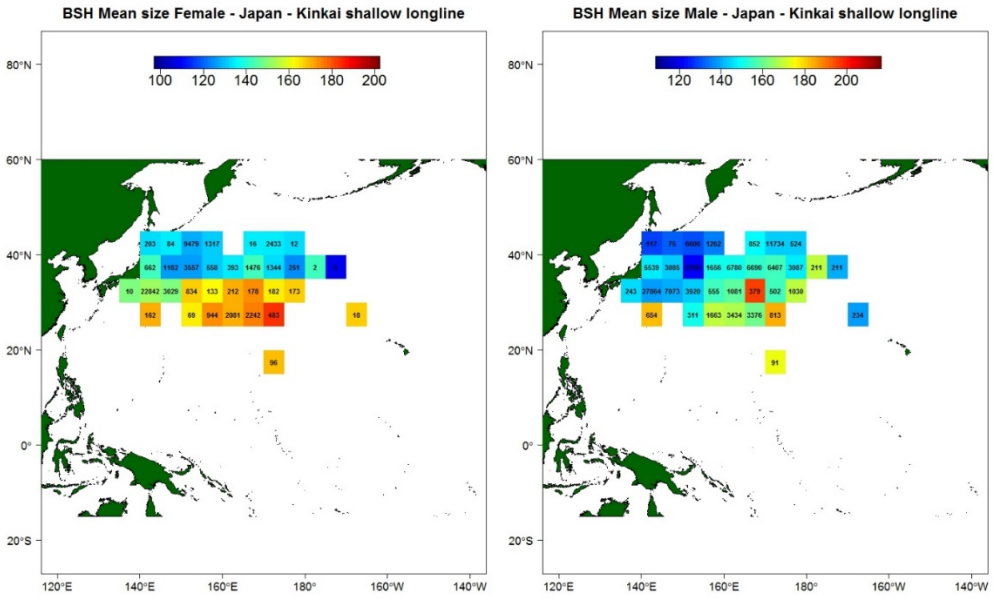

Figure A2. Mean size of female and male blue shark from the Japanese Kinkai shallow longline fishery.

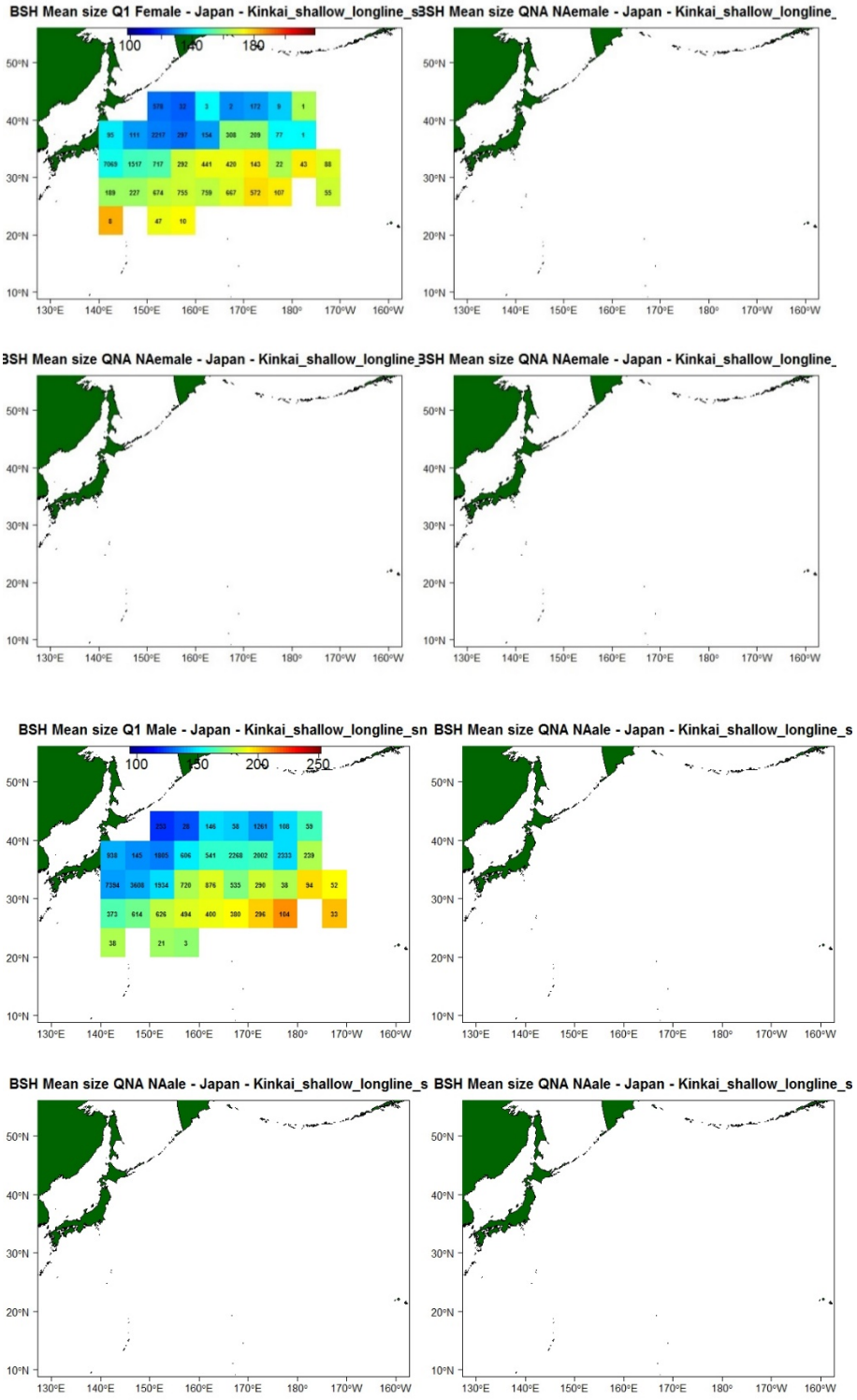

Figure A3. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Japanese Kinkai shallow longline_sn (skippers notes) fishery by quarter.

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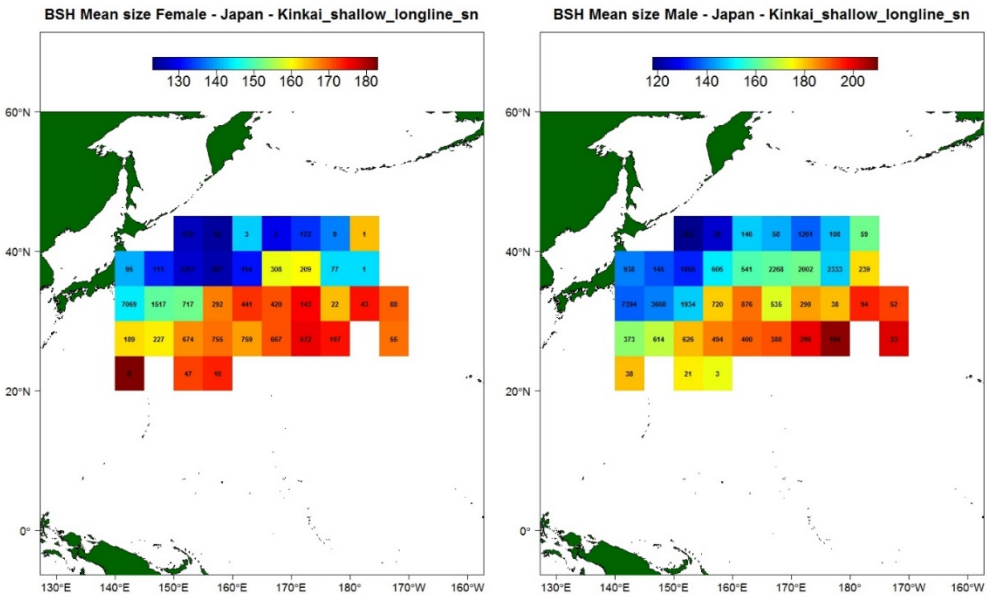

Figure A4. Mean size of female and male blue shark from the Japanese Kinkai shallow longline_sn (skippers notes) fishery.

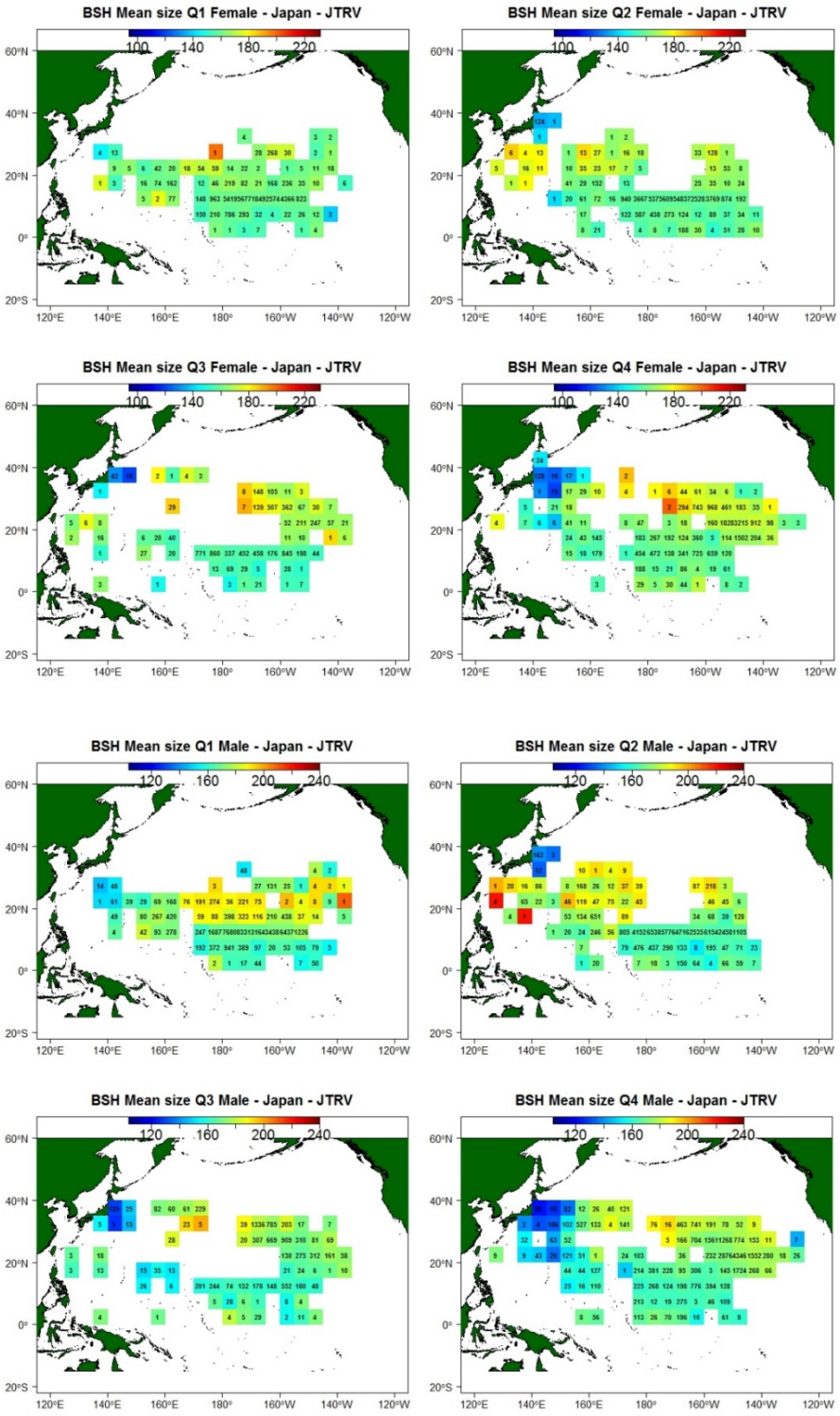

Figure A5. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Japanese research and training vessel (JRTV) fishery by quarter.

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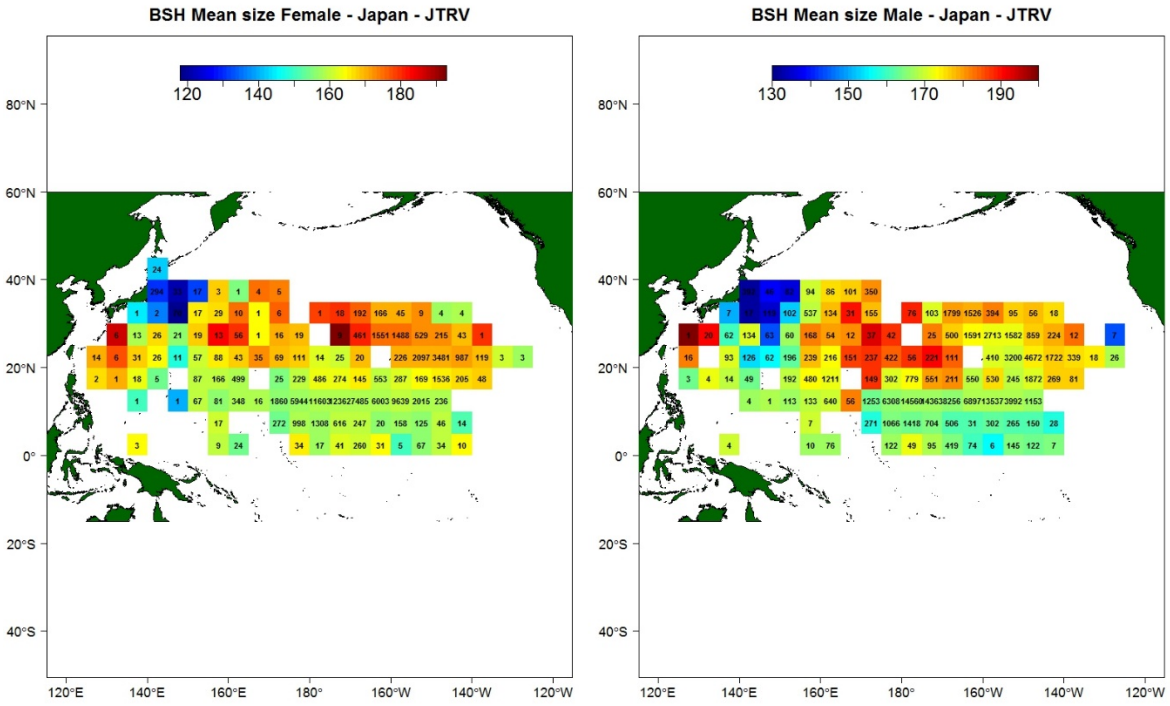

Figure A6. Mean size of female and male blue shark from the Japanese research and training vessel fishery.

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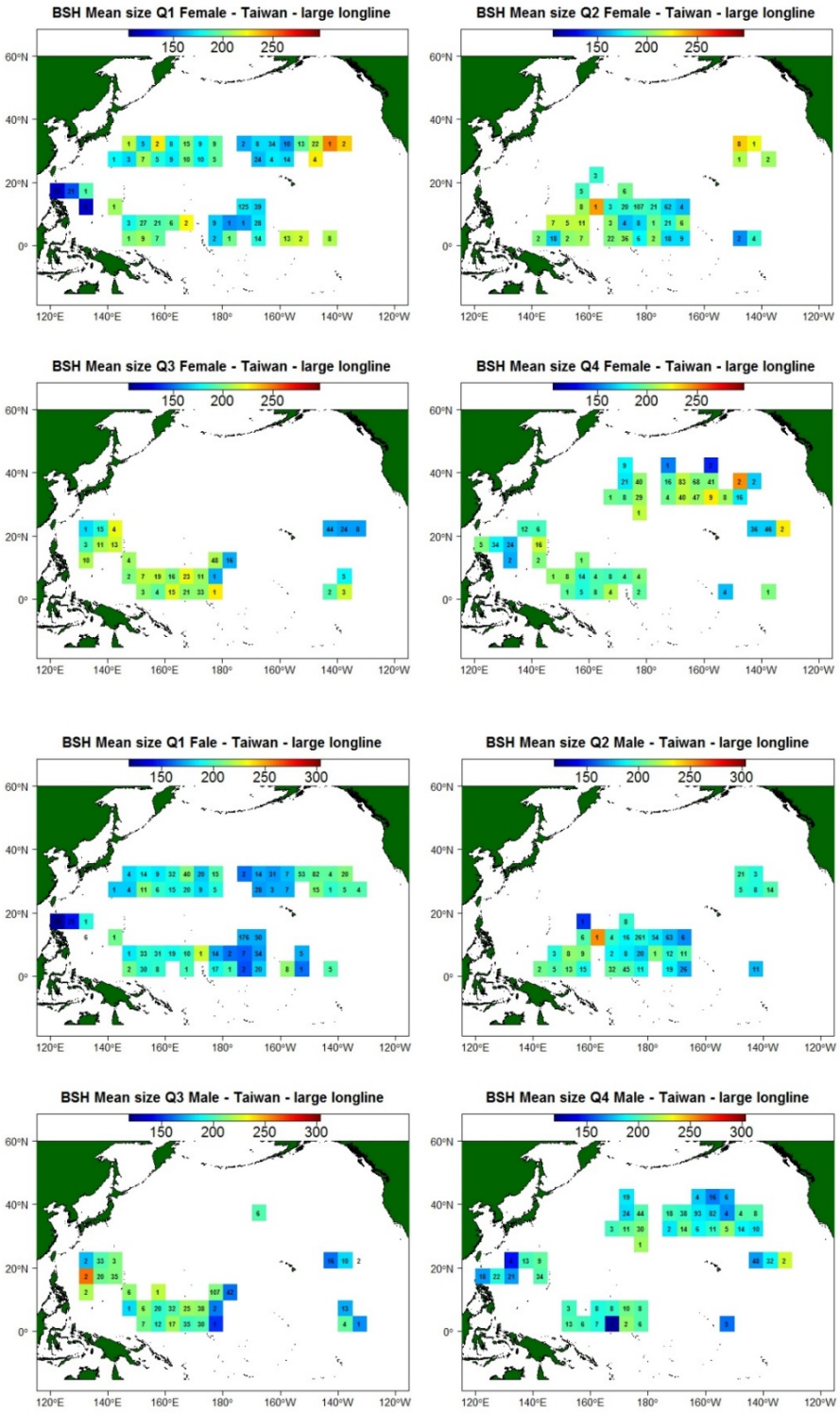

Figure A7. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from Taiwan large vessel longline fishery by quarter.

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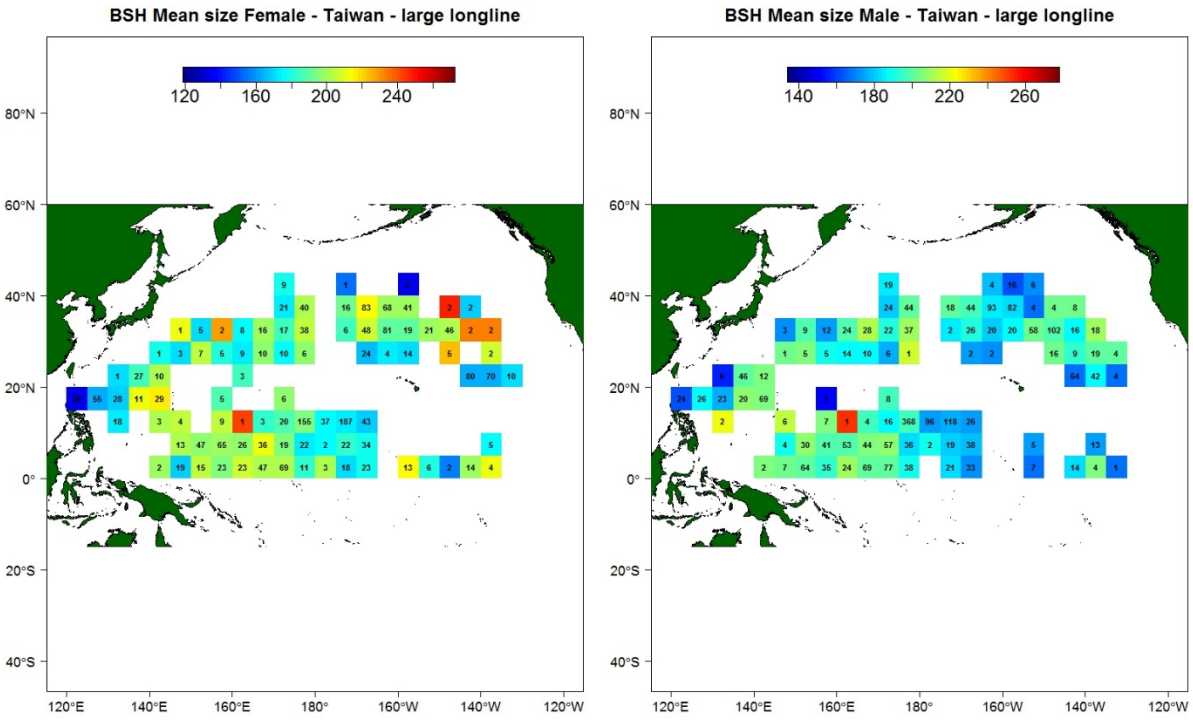

Figure A8. Mean size of female and male blue shark from the Taiwan large vessel longline fishery.

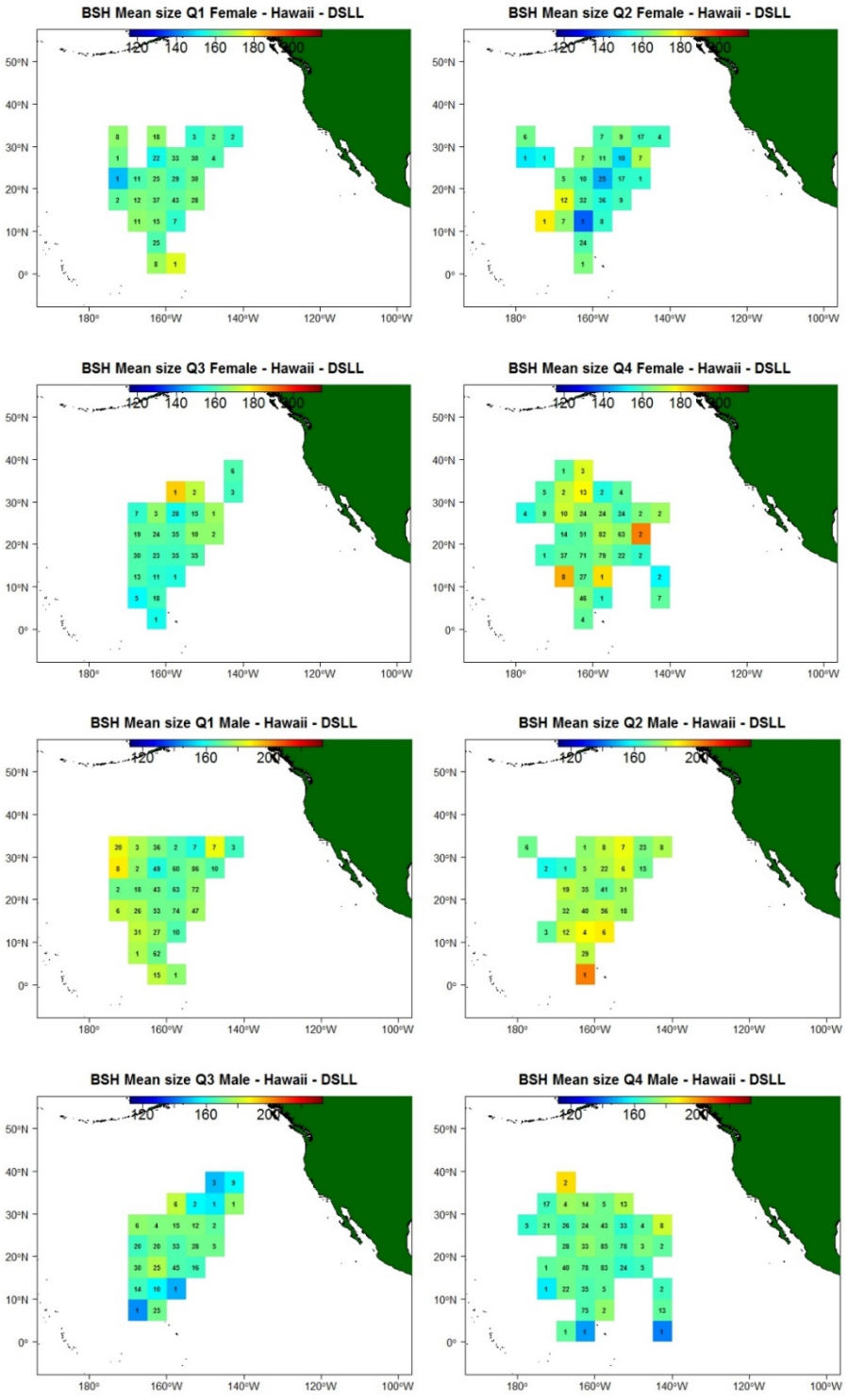

Figure A9. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Hawaii deepset longline fishery by quarter.

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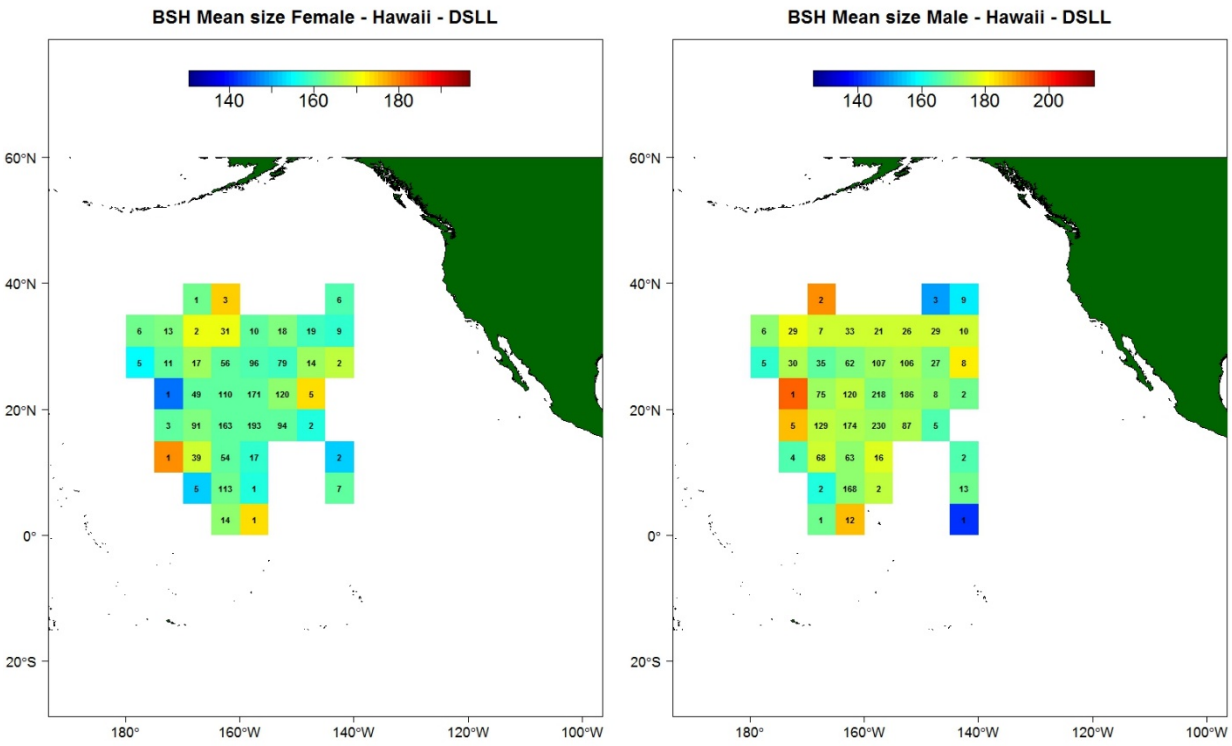

Figure A10. Mean size of female and male blue shark from the Hawaii deepset longline fishery.

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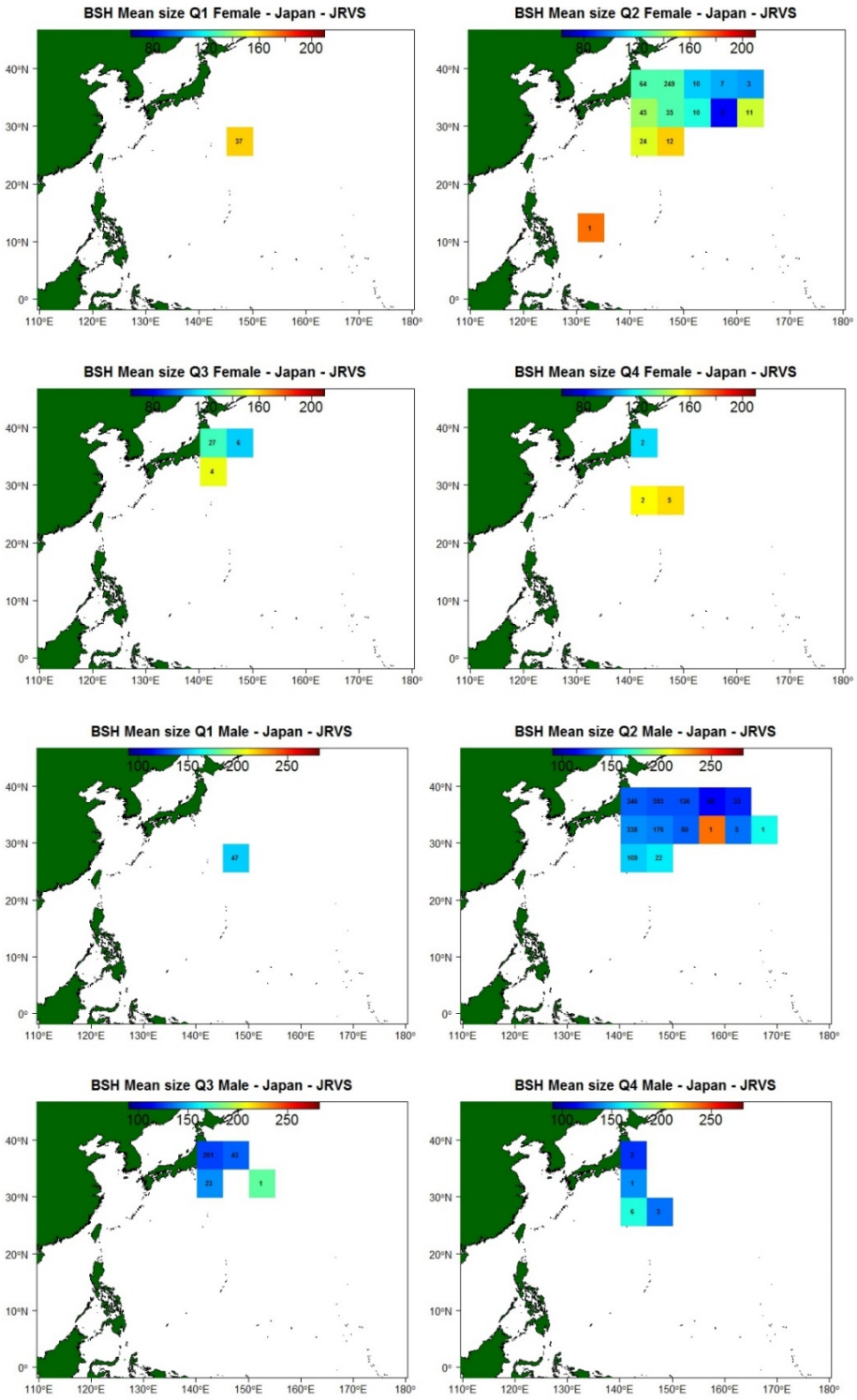

Figure A11. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Japan research vessel – shallow (JRVS) fishery by quarter.

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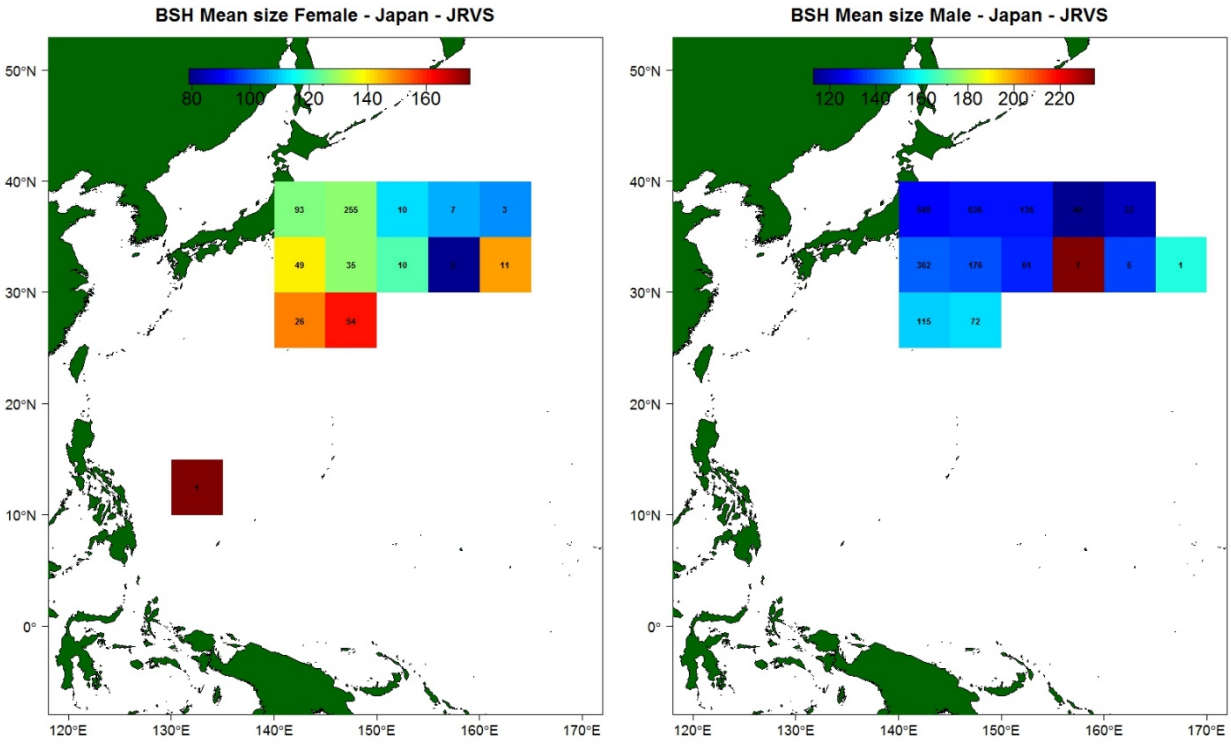

Figure A12. Mean size of female and male blue shark from the Japan research vessel – shallow (JRVS) fishery.

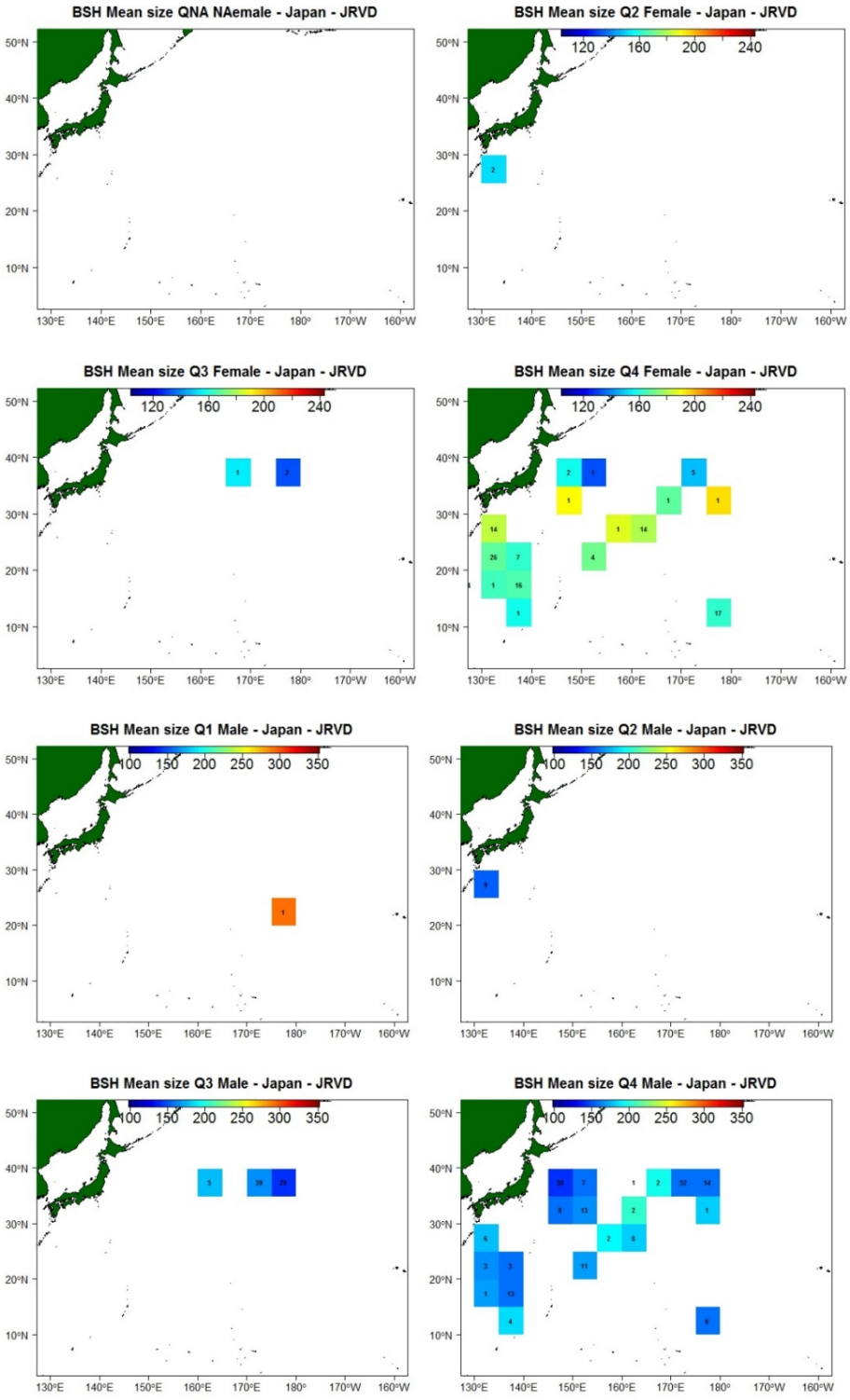

Figure A13. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Japan research vessel – deep (JRVD) fishery by quarter.

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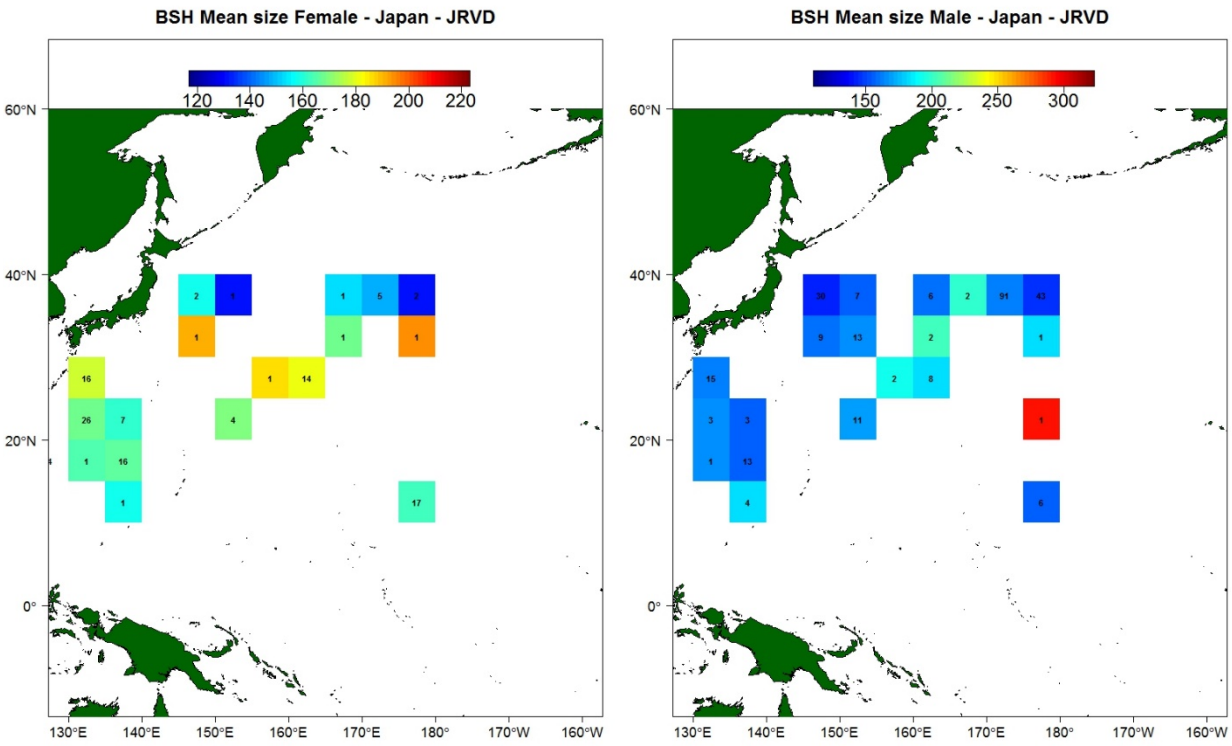

Figure A14. Mean size of female and male blue shark from the Japan research vessel – deep (JRVD) fishery.

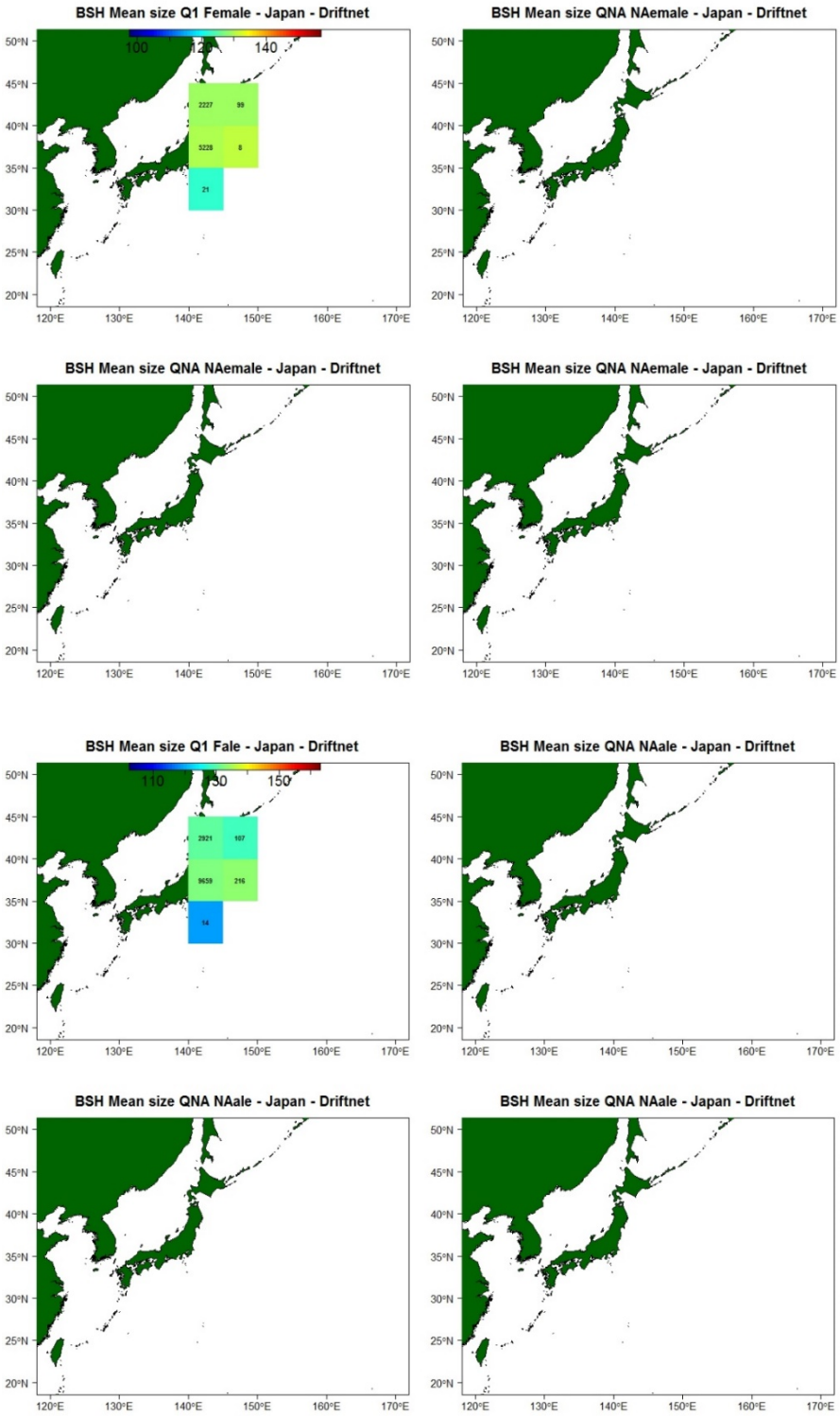

Figure A15. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Japan driftnet fishery by quarter.

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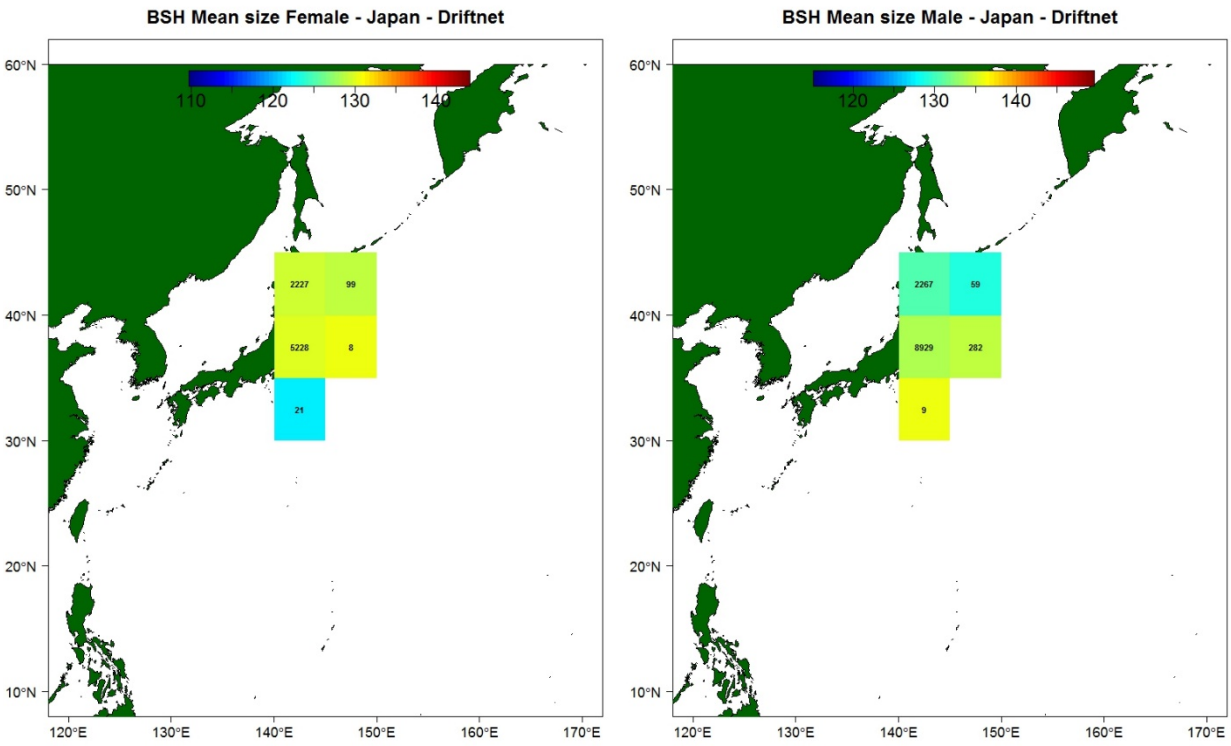

Figure A16. Mean size of female and male blue shark from the Japan driftnet fishery.

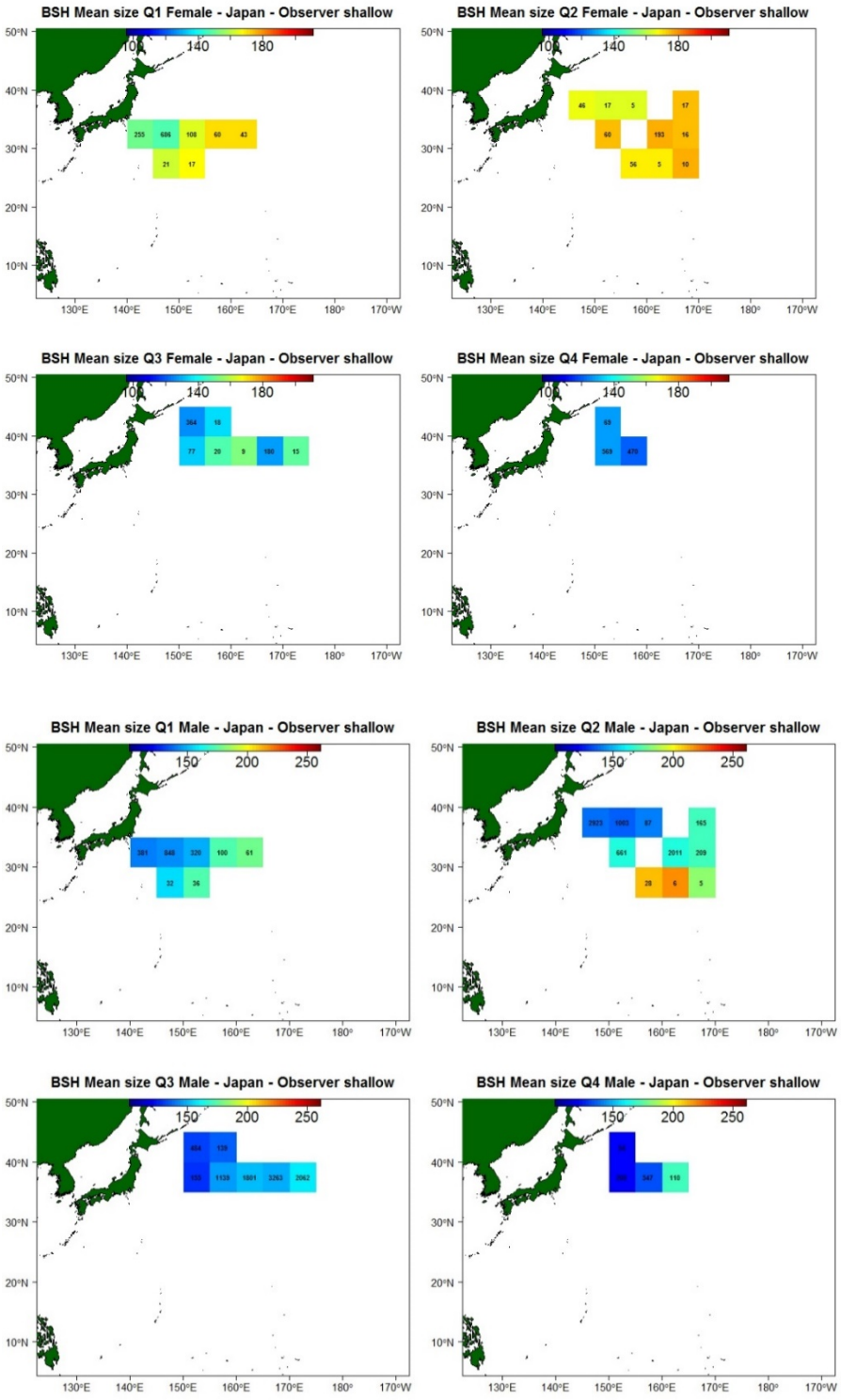

Figure A17. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Japan observer shallowset longline fishery by quarter.

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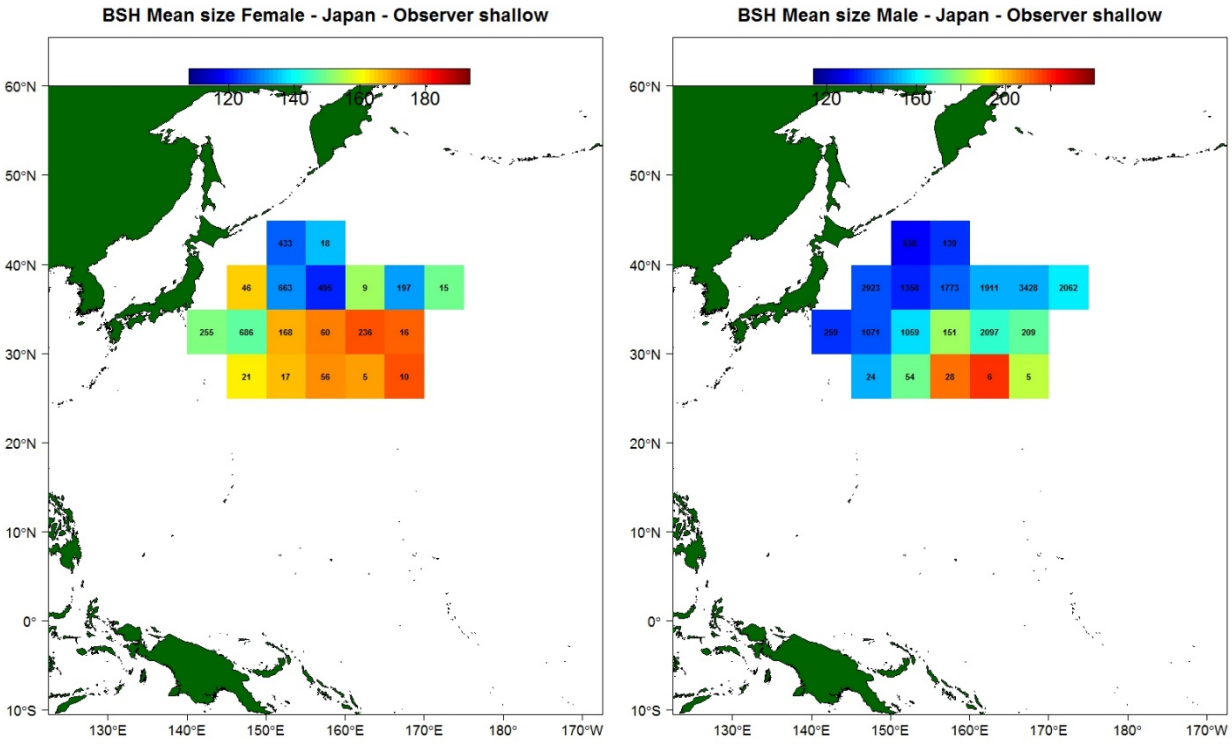

Figure A18. Mean size of female and male blue shark from the Japan observer shallowset longline fishery.

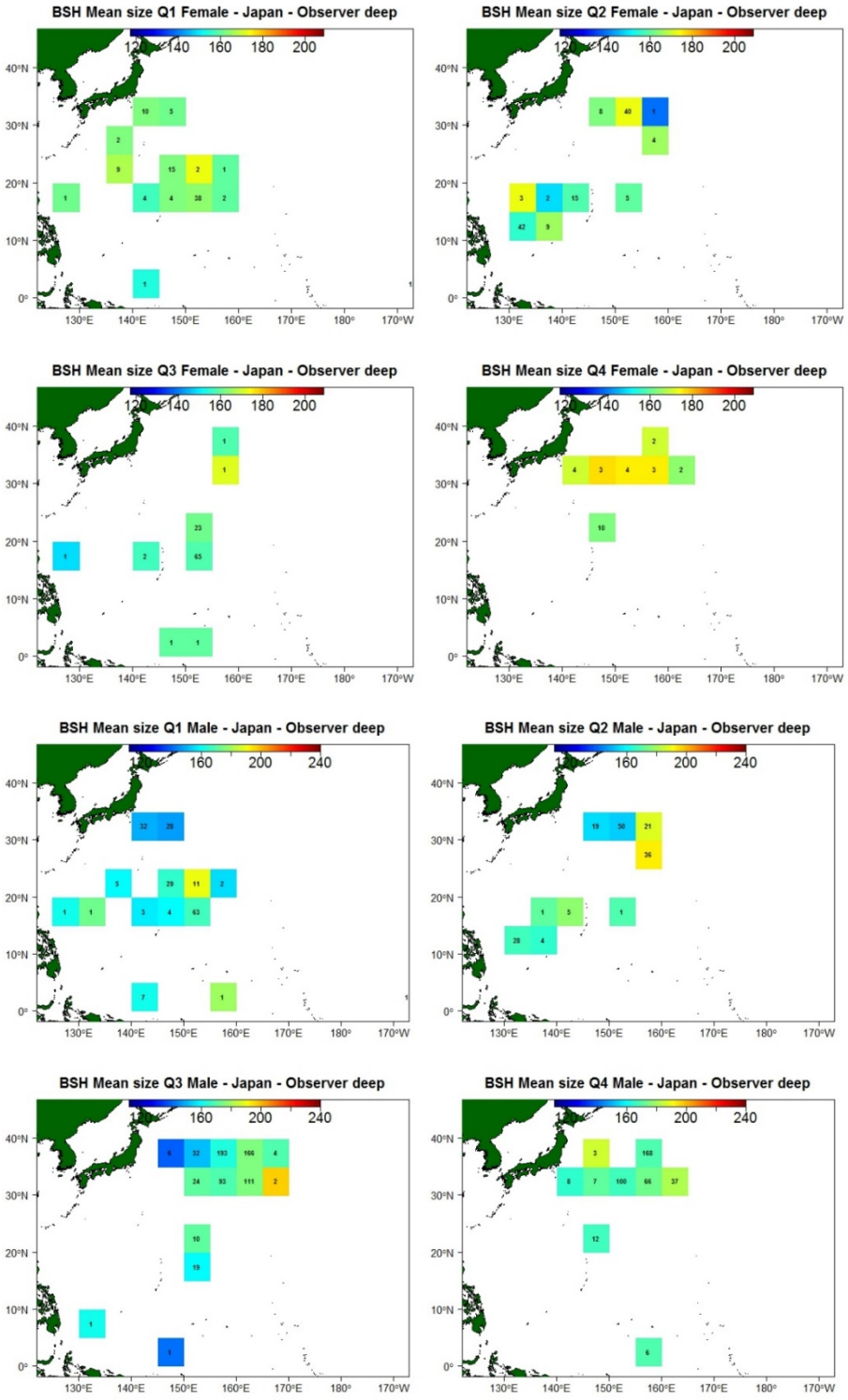

Figure A19. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Japan observer deepset longline fishery by quarter.

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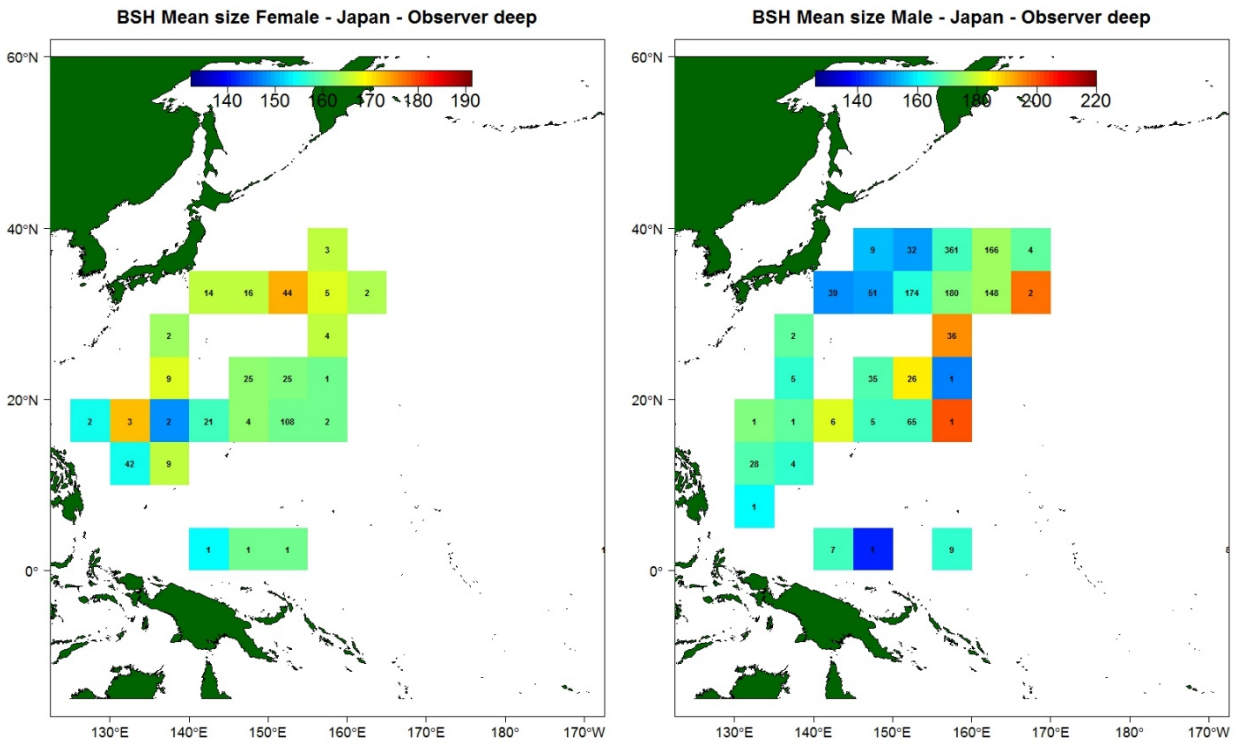

Figure A20. Mean size of female and male blue shark from the Japan observer deepset longline fishery.

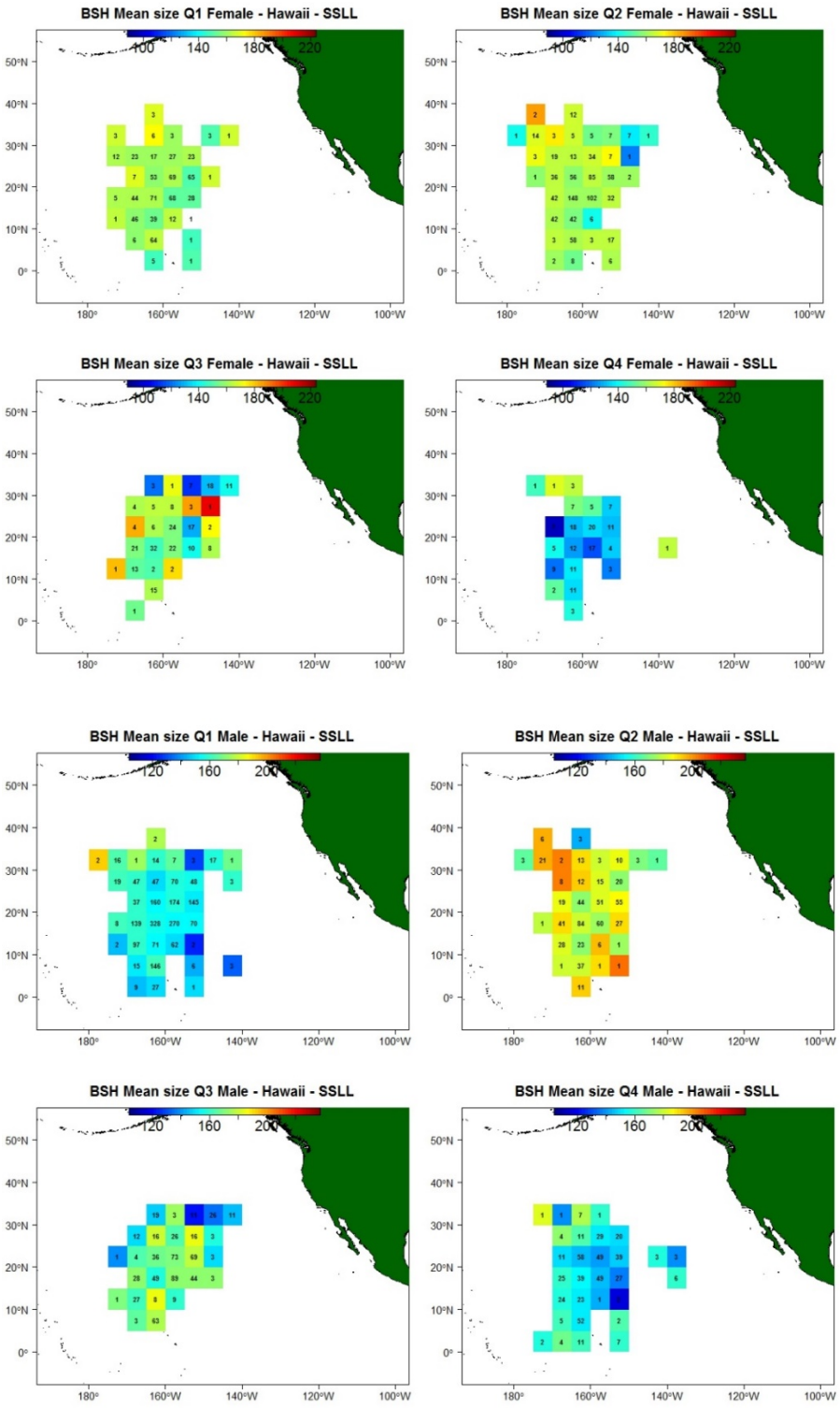

Figure A21. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Hawaii shallowset longline fishery by quarter.

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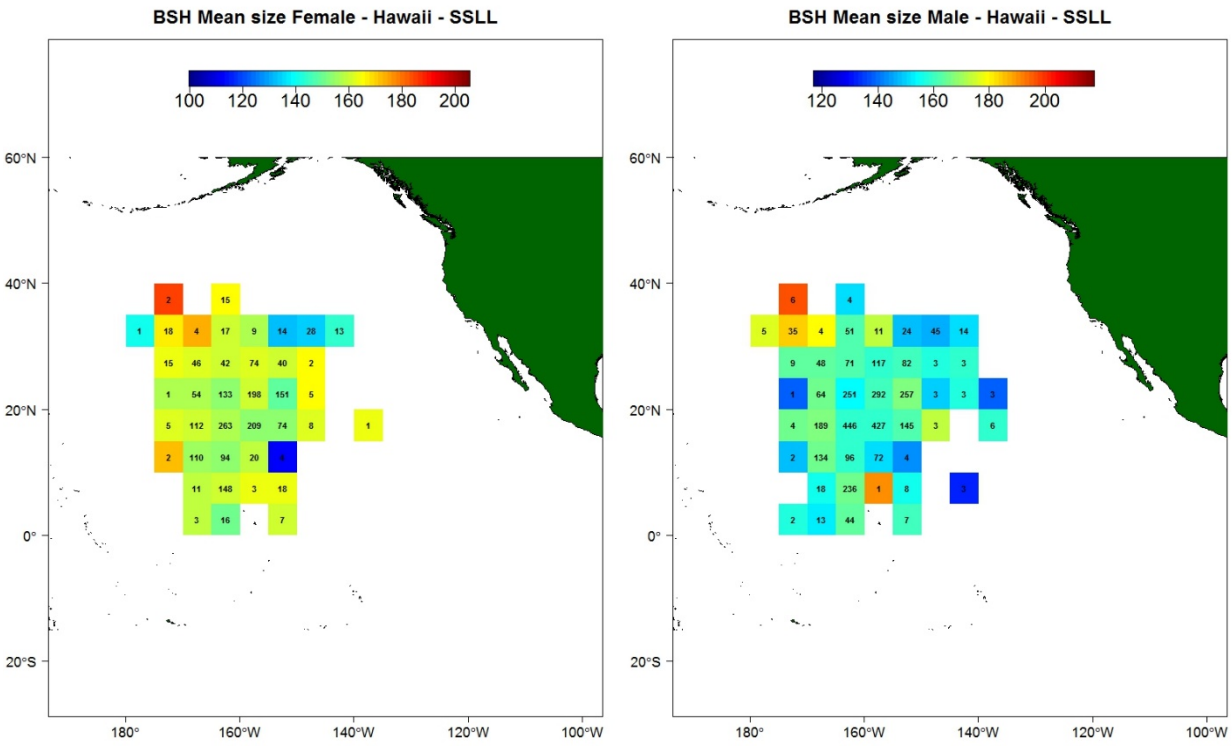

Figure A22. Mean size of female and male blue shark from the Hawaii shallowset longline fishery.

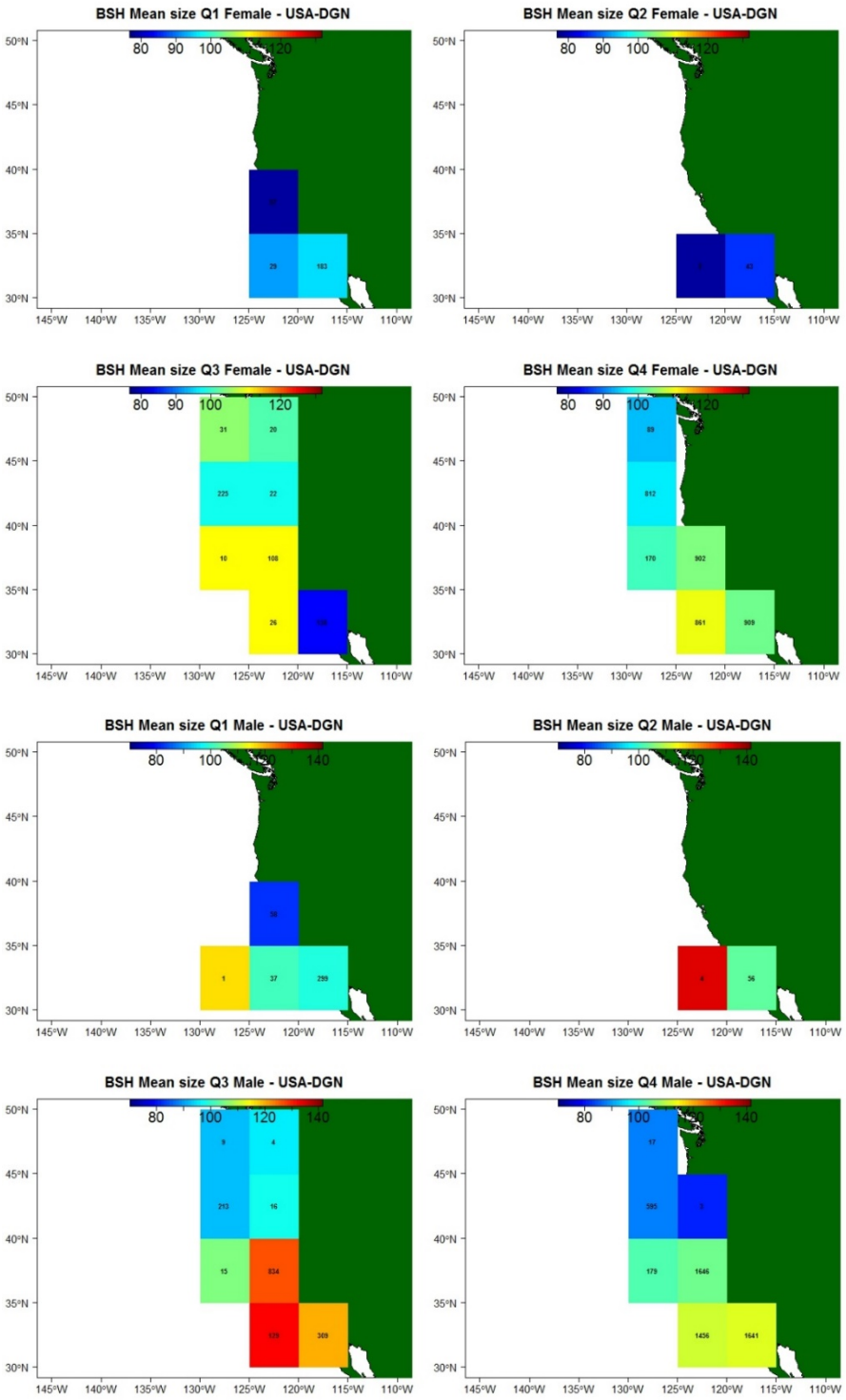

Figure A23. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the US west coast drift gillnet fishery by quarter.

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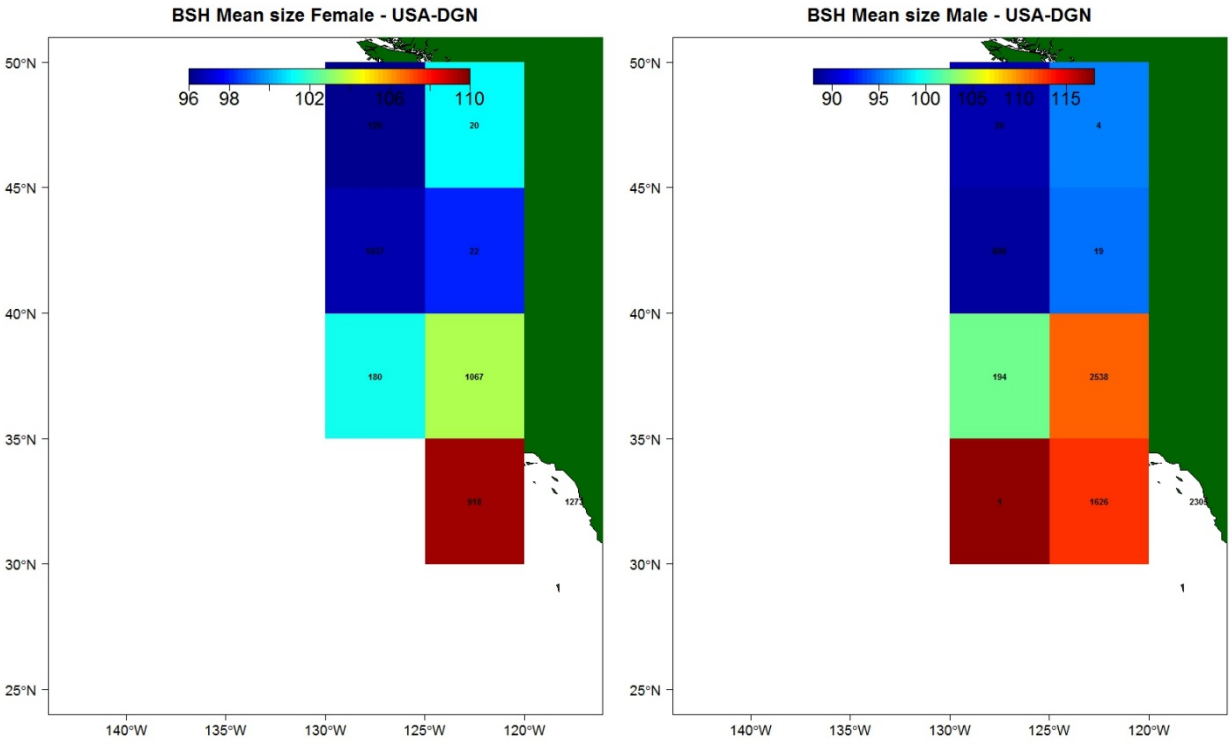

Figure A24. Mean size of female and male blue shark from the US west coast drift gillnet fishery.

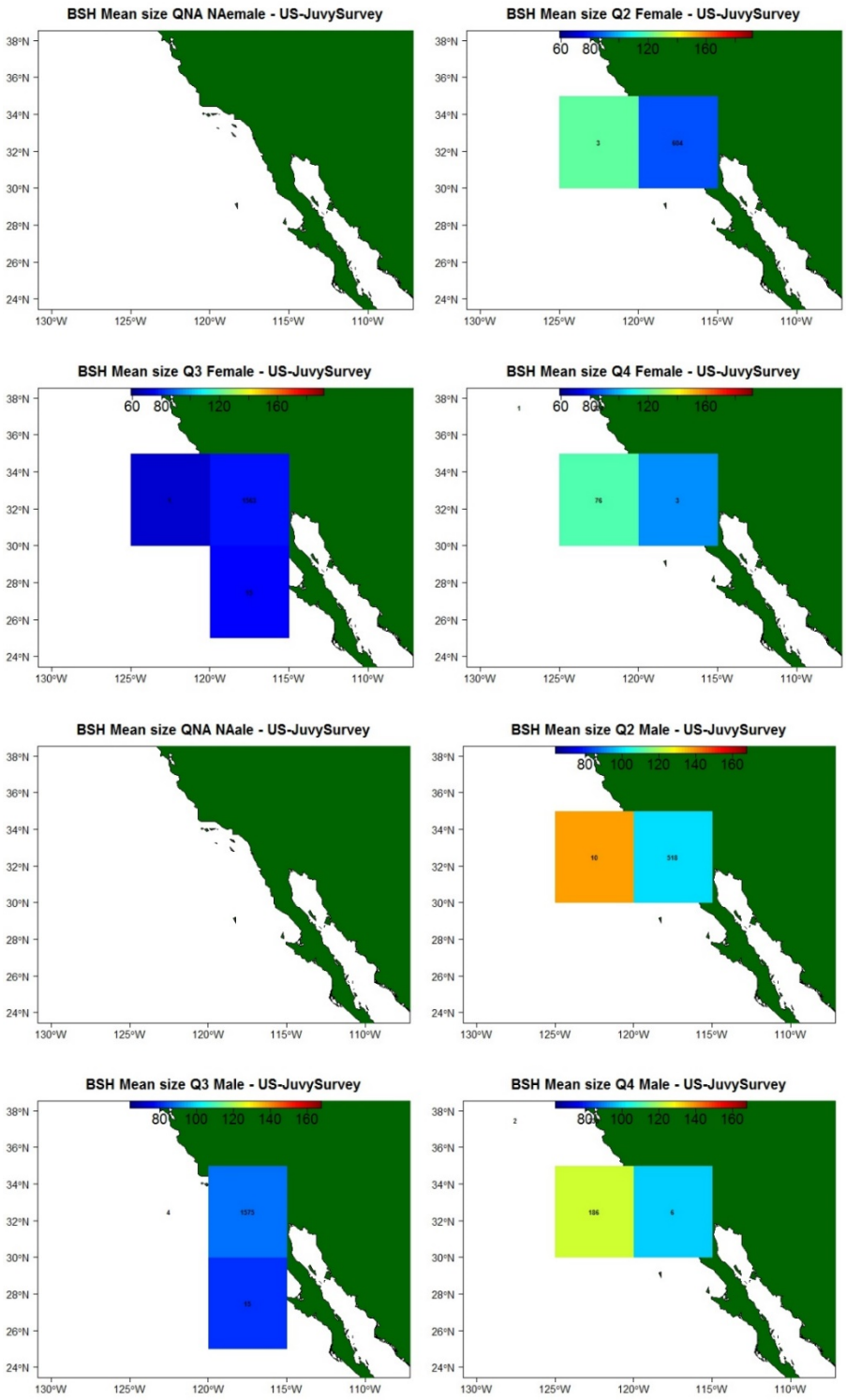

Figure A25. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the US west coast juvenile shark survey by quarter.

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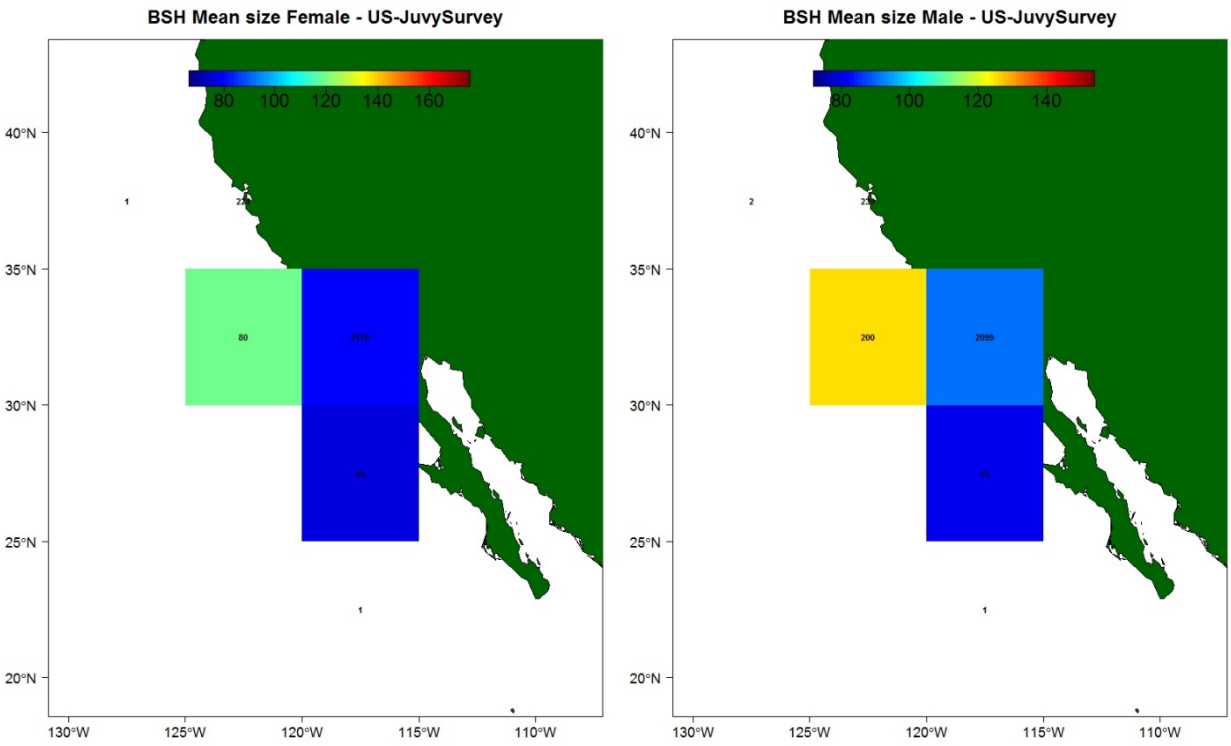

Figure A26. Mean size of female and male blue shark from the US west coast juvenile shark survey.

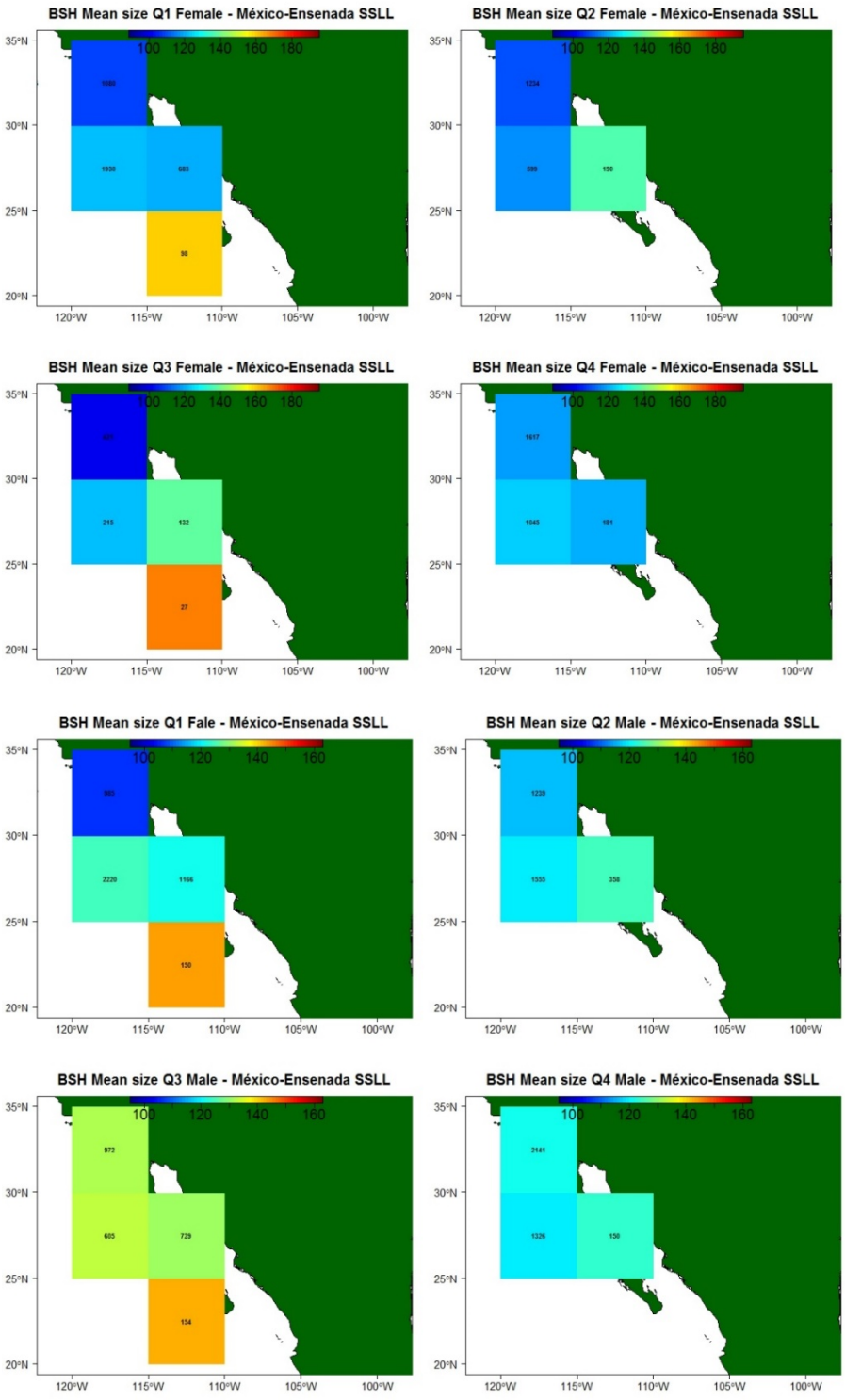

Figure A27. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Mexico-Ensenada shallowset longline fishery by quarter.

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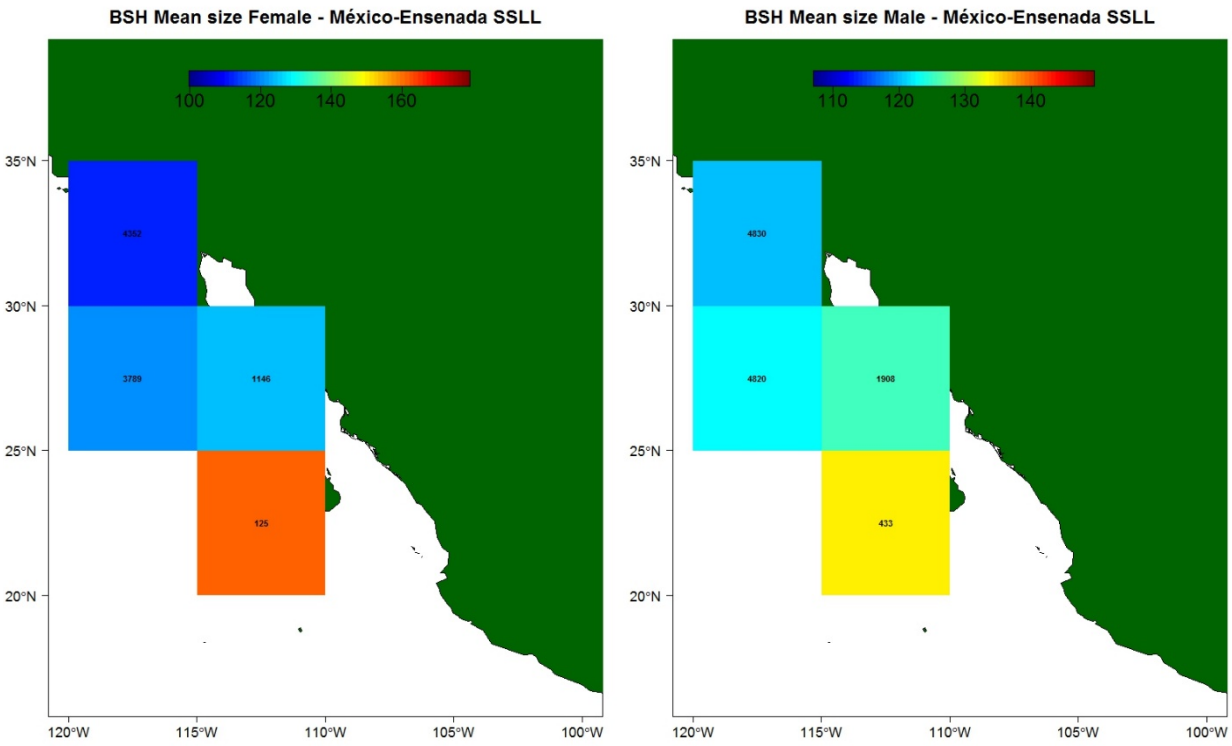

Figure A28. Mean size of female and male blue shark from the Mexico-Ensenada shallowset longline fishery.

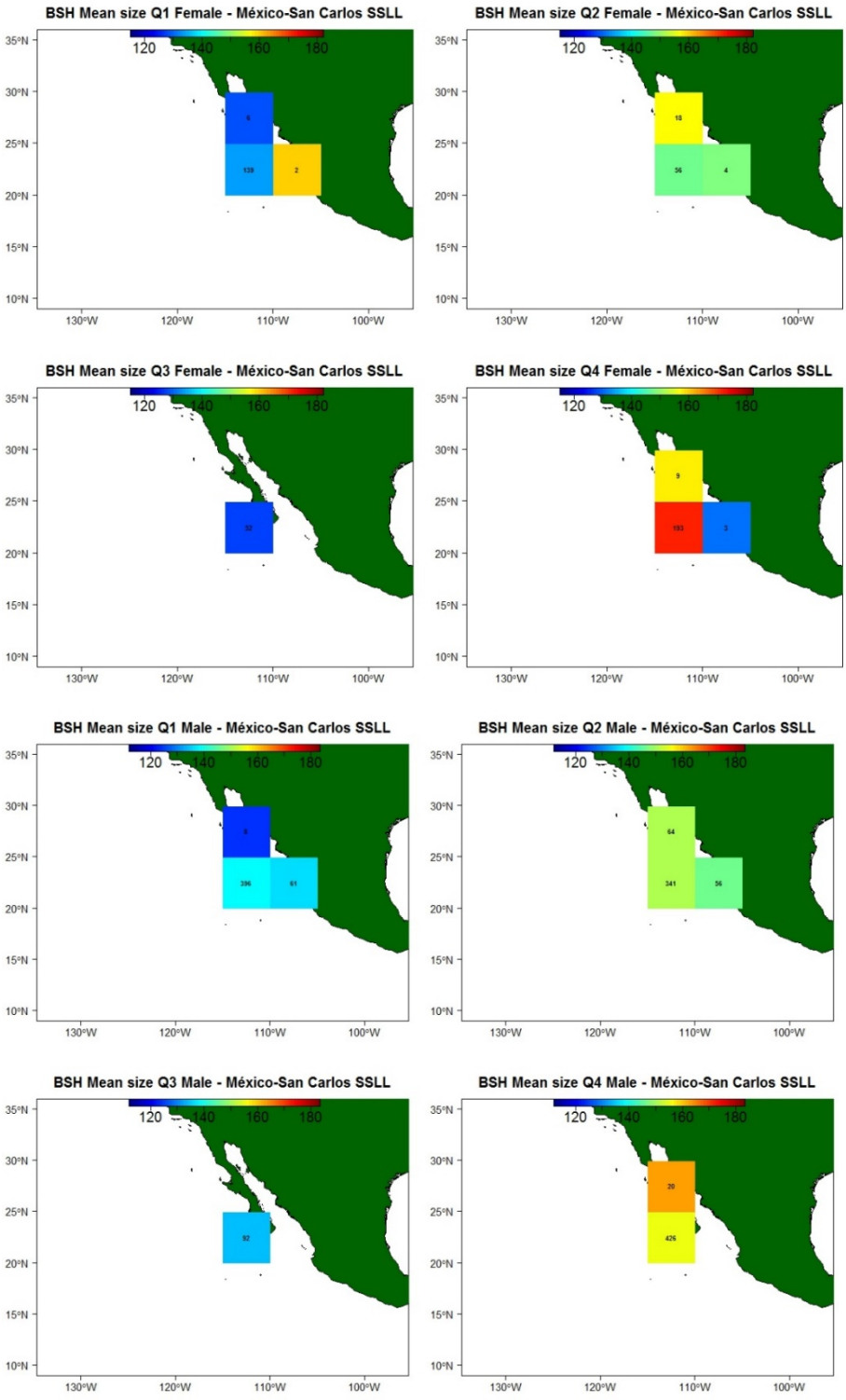

Figure A29. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from the Mexico-San Carlos shallowset longline fishery by quarter.

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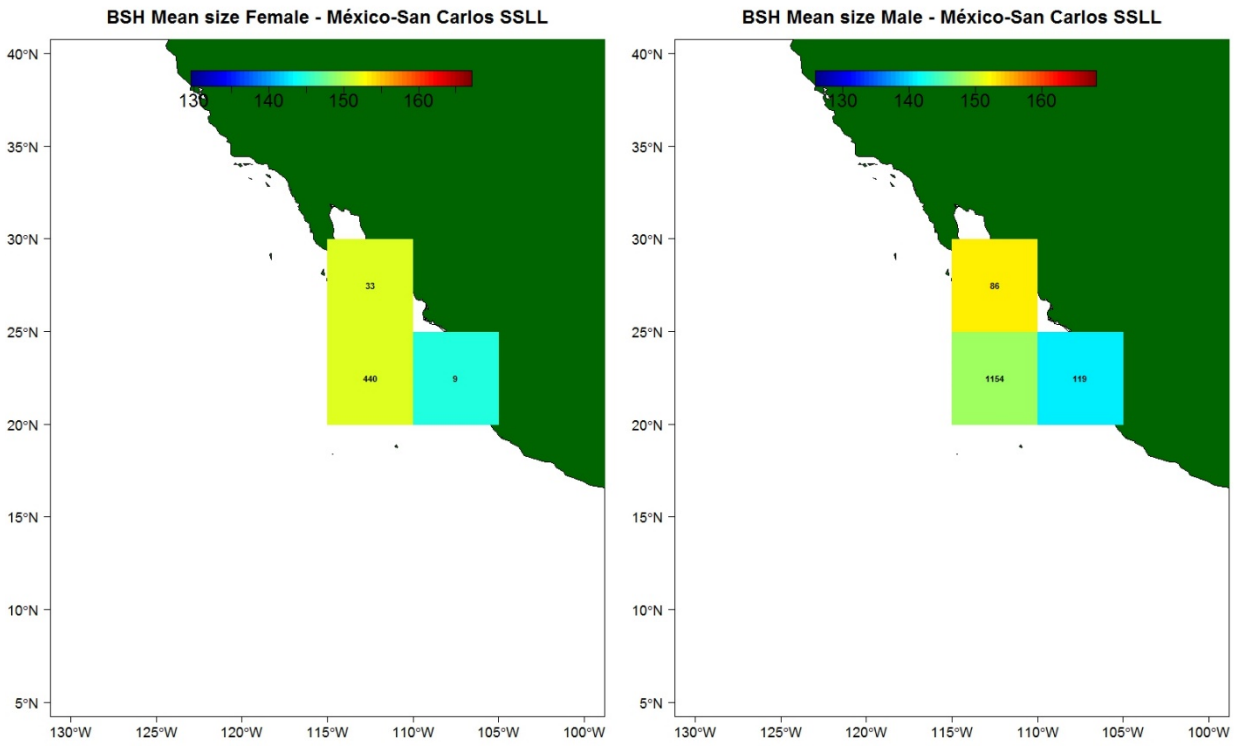

Figure A30. Mean size of female and male blue shark from the Mexico-San Carlos shallowset longline fishery.

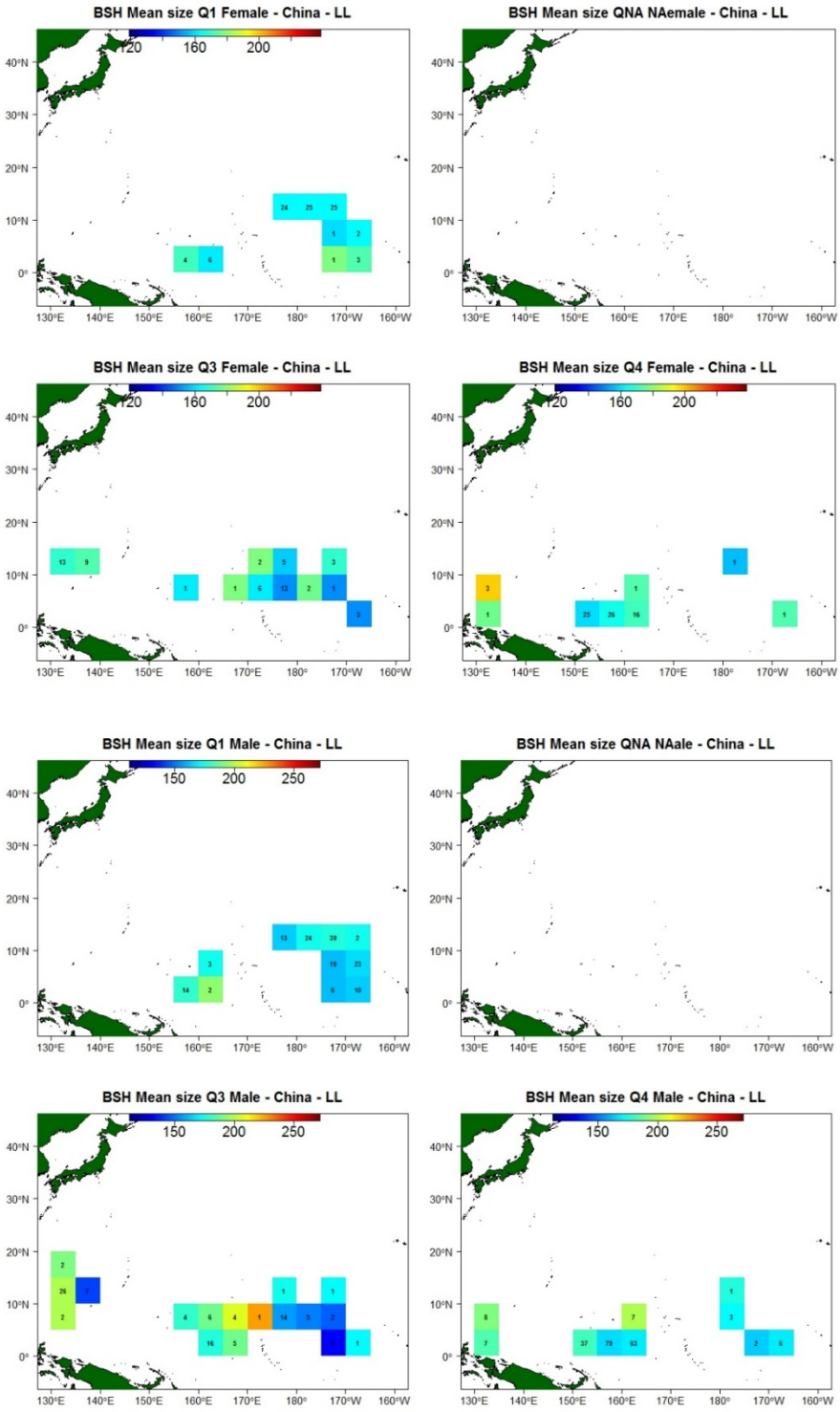

Figure A31. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from China's longline fishery by quarter.

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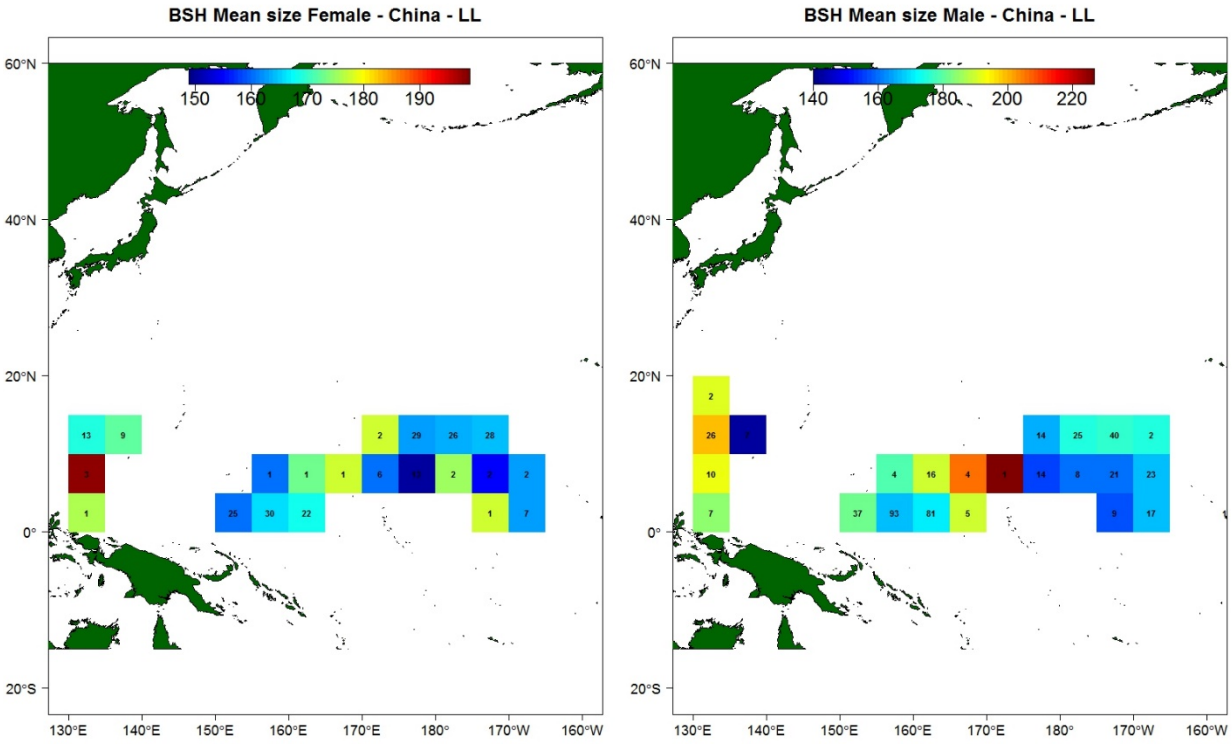

Figure A32. Mean size of female and male blue shark from China's longline fishery.

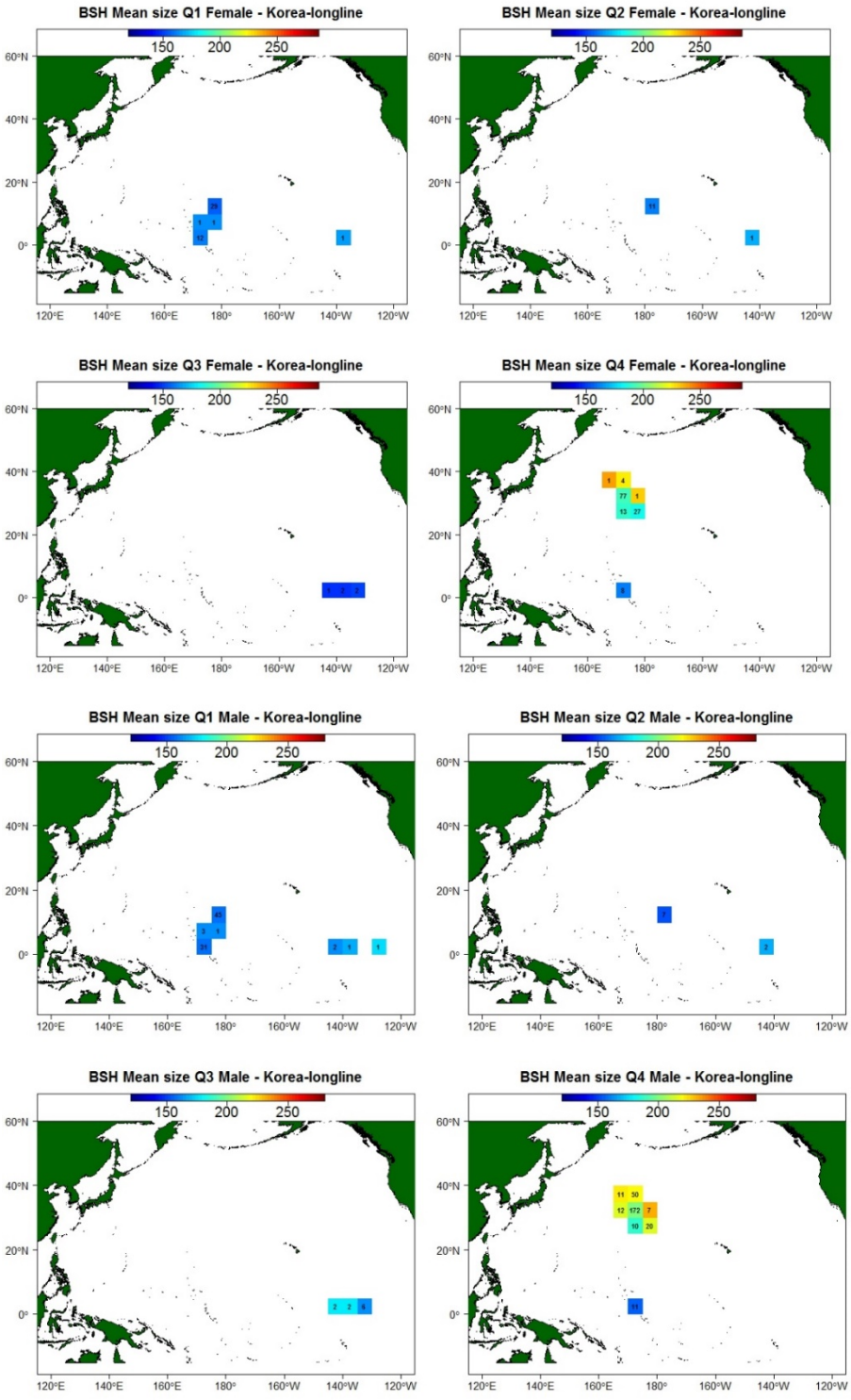

Figure A33. Mean size of female blue (top panel) and male (bottom panel) blue sharks shark from Korea's longline fishery by quarter.

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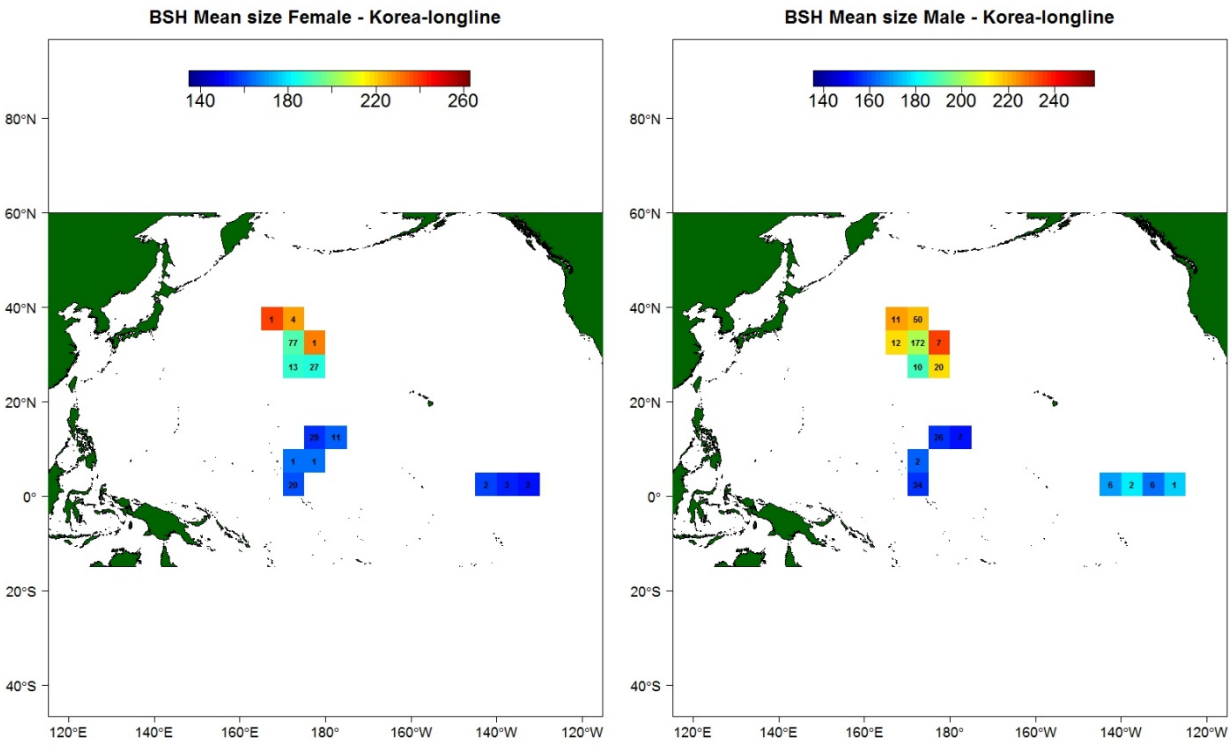

Figure A34. Mean size of female and male blue shark from Korea's longline fishery.

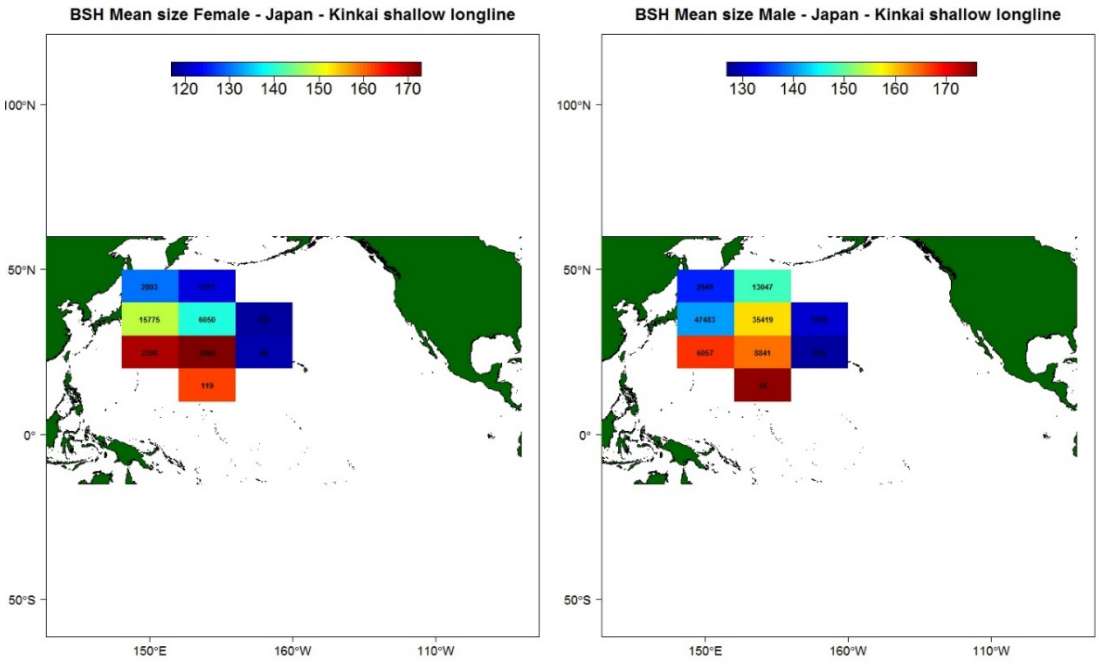

Figure A35. Mean size of female and male blue shark from Japan kinaki shallow longline fishery, from data provided at 20x10^{o} resolution (this excludes the data used in the 5x5^{o} summaries).

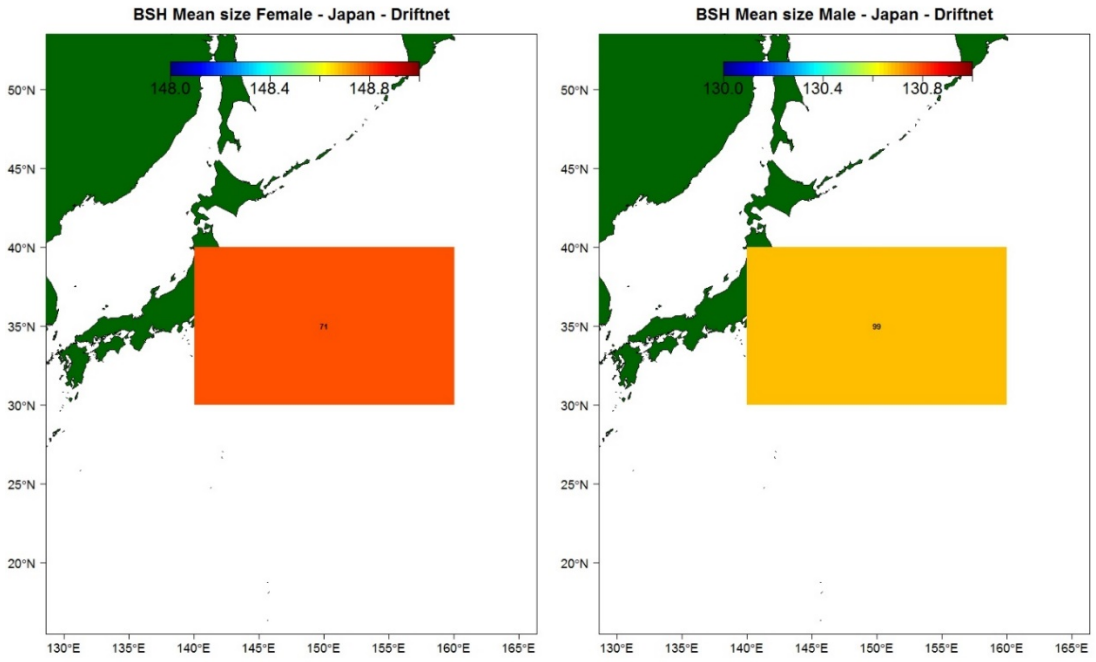

Figure A36. Mean size of female and male blue shark from Japan driftnet fishery, from data provided at 20x10^{o} resolution (this excludes the data used in the 5x5^{o} summaries).

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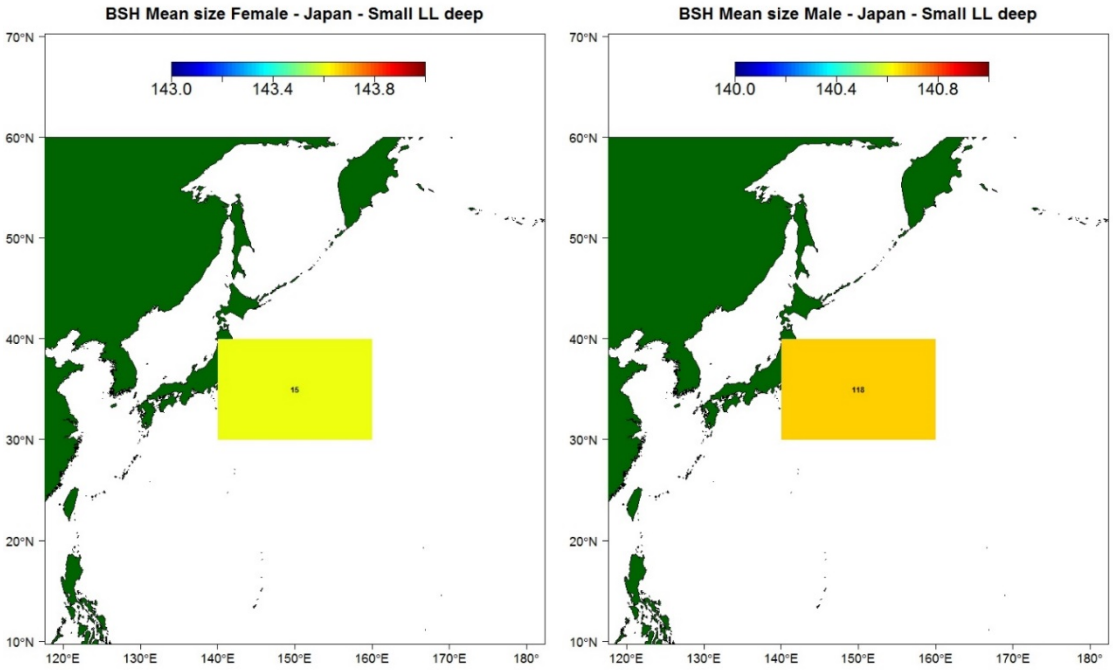

Figure A37. Mean size of female and male blue shark from Japan small vessel longline deepset fishery, from data provided at 20x10^{o} resolution (this excludes the data used in the 5x5^{o} summaries).

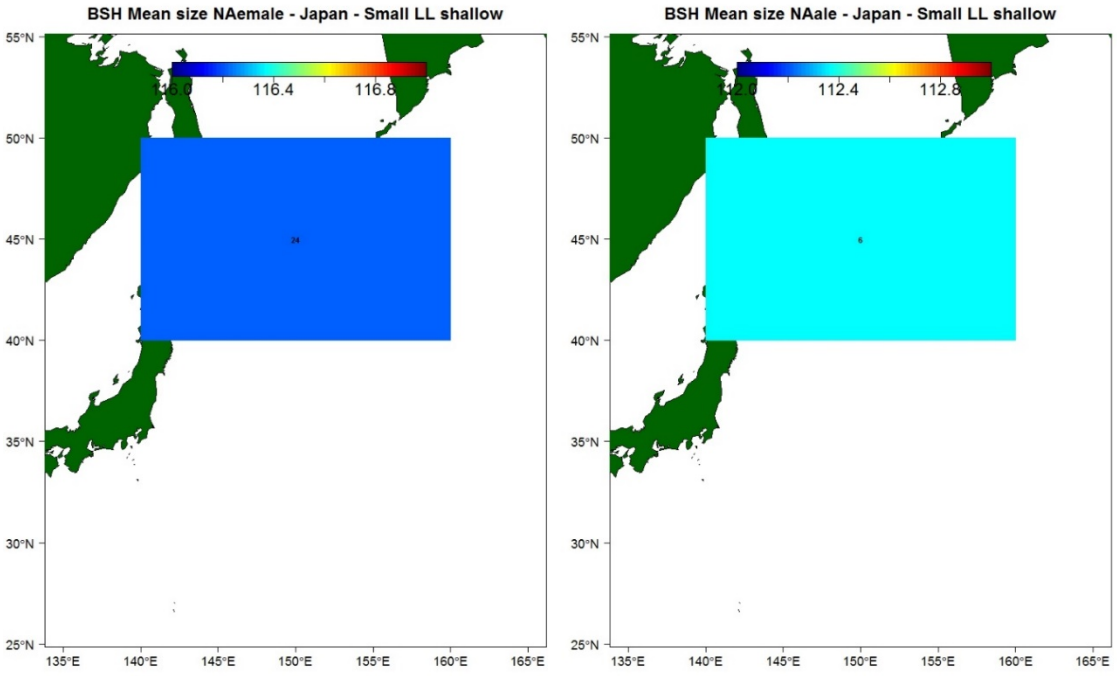

Figure A38. Mean size of female and male blue shark from Japan small vessel longline shallowset fishery, from data provided at 20x10^{o} resolution (this excludes the data used in the 5x5^{o} summaries).

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