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Size and spatial distribution of the blue shark, *Prionace glauca*, caught by the Taiwanese large-scale longline fishery in the North Pacific Ocean[1]

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Abstract

The size and spatial distribution of the blue shark, *Prionace glauca*, were described based on 5,897 specimens, that were collected by scientific observers on-board the Taiwanese large-scale tuna longline vessels in the North Pacific between June 2004 and December 2020. Size segregation was found, and the mean size of blue sharks in area B (0-25°N) was significantly smaller than that in area A (north of 25°N). No significant sex segregation was found. Males predominated in the size range of 170-280 cm and 170-200 cm TL in area A and B, respectively.

1. Introduction

The blue shark, *Prionace glauca* (Linnaeus, 1758), is the top shark bycatch species for the Taiwanese longline fishery in the three oceans (Joung et al. 2005; Huang and Liu 2010; Tsai et al. 2015). The stock status of the blue shark has become an issue of great concern for regional fisheries management organizations (RFMOs) such as the Western and Central Pacific Fisheries Commission (WCPFC), the International Commission for the Conservation of Atlantic Tunas (ICCAT), and the Indian Ocean Tuna Commission (IOTC) because large amount of this species has been caught by various fisheries.

The reproductive biology of the blue sharks in the North Pacific Ocean has been well described. These include the studies by Pratt (1979), Cailliet and Bedford (1993), Nakano (1994), Blanoco-Parra et al. (2008), and Joung et al. (2011). The growth parameters of blue sharks in the North Atlantic also have been well documented. Nakano (1994), Nakano and Seki (2002), Blanoco-Parra et al. (2008), Hsu et al. (2011, 2012) and Fujunami et al. (2019) documented the age and growth of the blue sharks in the North Pacific. All of these studies were based on the vertebral band pair counts and the VBGF parameters.

The size and distribution pattern are important information for stock assessment using stock synthesis model. Although Nakano (1994) proposed a migratory route for blue sharks by life stages in the North Pacific, the information on distribution patter of blue shark by size, sex, and season is still limited. In this study, the distribution pattern of the blue sharks in the North Pacific Ocean were described from the sampling records of scientific observers on-board the Taiwanese large-scale longline fishing vessels in this region.

2. Materials and Methods

2.1 Specimen collection and preparation

The observer program for Taiwanese large-scale tuna longline (LTLL) fishery started from 2004. All the observers have been trained on identification of tuna and tuna like species and by-catch species such as sharks, sea birds, and sea turtles. The blue shark specimens caught by the Taiwanese LTLL vessels in the North Pacific Ocean (145°E to 130°W, 0°N to 45°N) between June 2004 and December 2020 (Figure 1) were opportunistically collected by the on-board scientific observers. The fishing date, location, weight (in kg), and fork length (FL in cm) of the specimens were recorded, and the sex of each specimen was identified. Based on the suggestion of the ISC shark working group in 2012, the North Pacific Ocean was stratified as 2 areas namely, area A (north of 25ºN) and area B (0ºN-25ºN). The fishing vessels mainly targeted the bigeye tuna in the tropical and subtropical area (area B) and albacore tuna in the temperate area (area A), respectively. Four seasons (seasons 1-4) were defined as January to March, April to June, July to September, and October to December, respectively.

2.2 Size and sex ratio data analysis

The mean sizes of specimens were compared between areas and sexes and among seasons using t-tests or analysis of variance (ANOVA) on the assumption of a normal distribution because of the large sample size. The GLM was used to examine the factors of sex, season, area, and their interactions on the mean catch-at-size. The sex ratio was expressed as the number of females/the number of both sexes combined. Sex ratios were compared between areas and among seasons with a Chi-square test. A significance level of 0.05 was used in all statistical tests.

3. Results and Discussion

3.1 Size range of specimens

A total of 5,897 blue shark specimens, including 3,340 males, and 2,457 females were caught by the Taiwanese LTLL vessels in the North Pacific Ocean and collected by the on-board scientific observers. The sizes of the 3,309 specimens in the area A ranged from 56 to 335 cm FL and 94 to 335 cm FL for males and females, respectively (Table 1). The sizes of the 2,588 specimens in the area B ranged from 73 to 277 cm FL and 113 to 285 cm FL for males and females, respectively (Table 1).

3.2 Spatial and seasonal variation in distribution, size, and sex ratio

The mean size of the blue sharks in area B (Female: 188 cm FL; Male: 196 cm FL) was significantly smaller than that in area A (Female: 210 cm FL; Male: 220 cm FL)(Figure 2). The mean size of males was significantly larger than that of females in area B in seasons 1 and 3 ($P<0.05$)(Table 1). In area A, the mean size of females was significantly smaller than that of males in seasons 1, 2 and 4 ($P<0.05$), but no significant difference was found for seasons 3 (Table 1). GLM indicated that sex, season, area, sex-area, and season-area interactions have significant effects on the mean catch-at-size (Table 2). There was a slight decreasing trend for the mean catch-at-size from 2007 to 2018 in area B, but such a trend was not found in area A (Figure 3).

The sex ratios were significantly less than 0.5 in area A for every season (0.19-0.37)($P<0.05$), except for season 3. The sex ratios were only significantly less than 0.5 in area B in season 4 (0.43)($P<0.05$). The sex ratios also varied with the specimen sizes and ranged from 0.35 to 0.80 and 0.17-0.60 in the area A and area B, respectively (Figure 4). No significant sex segregation was found.

Males predominated in the size range of 170-200 cm TL in the area A and in the range of 170-280 cm TL in the area B. Nakano (2004) found that the juvenile and subadult blue sharks occurred in higher latitude in the North Pacific and adults were often found in the tropical waters. Different findings obtained in this study may be due to the limited sample size in seasons 2 and 3 of area A in this study and different gear configurations between the two fleets. However, further study is needed to clarify this point.

Because only a few small blue sharks (< 60 cm FL) were recorded in this study, the parturition area could not be identified. The lack of small blue sharks may be due to the gear selectivity and the Taiwanese longline fleets' practice of discarding undersize fish. Two types of Taiwanese large-scale longline fishing fleets operate in the North Pacific. The fleet targeting tropical tunas such as bigeye or yellowfin tuna operates in the tropical waters and uses a deep set of 15 or more hooks per basket. Those vessels targeting albacore operate in the temperate waters and use a shallow set of < 12 hooks per basket. Another possibility is that the fishing areas did not include the coastal and high-latitude waters, which might be the nursery grounds of blue shark.

Sex segregation of subadult blue sharks in the North Pacific has been documented (Nakano 1994). However, sex segregation between areas was not observed in this study because males were overwhelming in both areas and all seasons except season 1 in the equatorial and tropical area. Fitzpatrick (2012) concluded that the blue shark has a high incidence of polyandry (80%) based on the microsatellite DNA analyses of litters, suggesting that one adult female may mate with several adult males. Both females and males can mate several times during the mating season. However, no information is available on the mating times for both sexes. Hazin et al. (1994) found that many adult males lacked sperm packs and were sexually resting in the tropical western South Atlantic. Thus, the sex ratio of adult blue sharks may be biased toward males in the mating season. Our finding of a low sex ratio (0.35) of large blue sharks (> 218 cm FL) in season 1 in the subtropical and temperate area implied the occurrence of mating. However, more information is needed to verify this finding.

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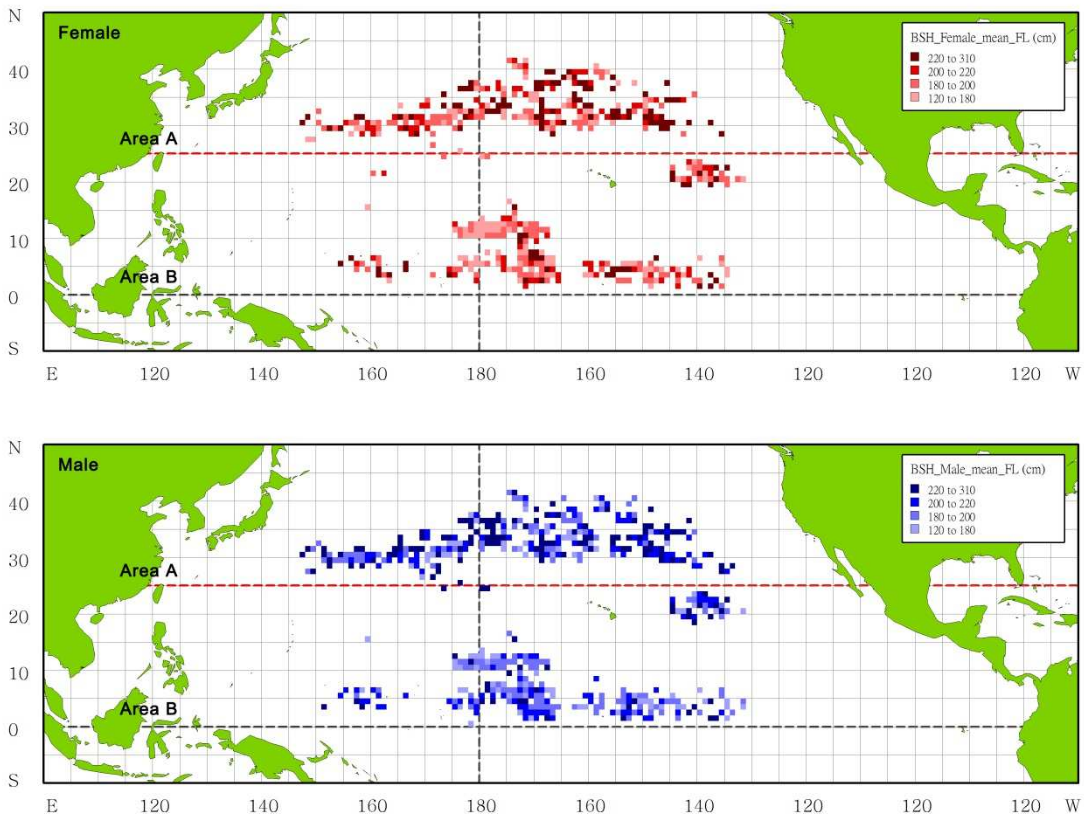


Figure 1. Sampling location and mean size (FL, cm) of the blue shark (*Prionace glauca*) recorded by observers onboard the Taiwanese large-scale longline fishing vessels in the North Pacific.

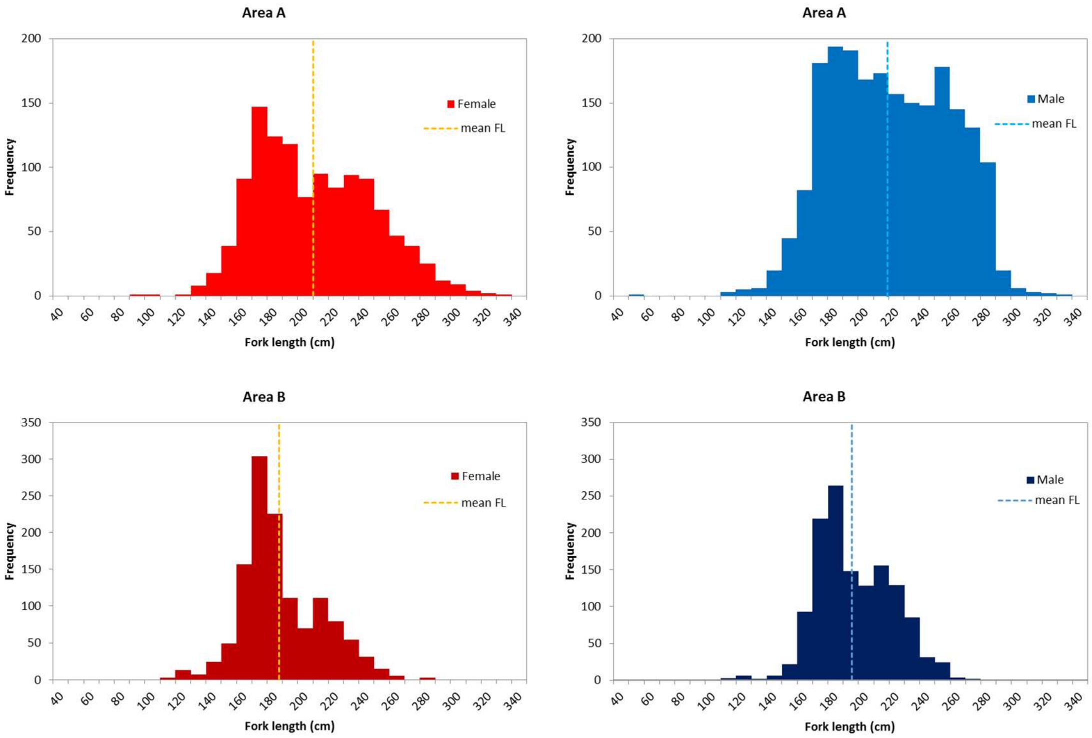
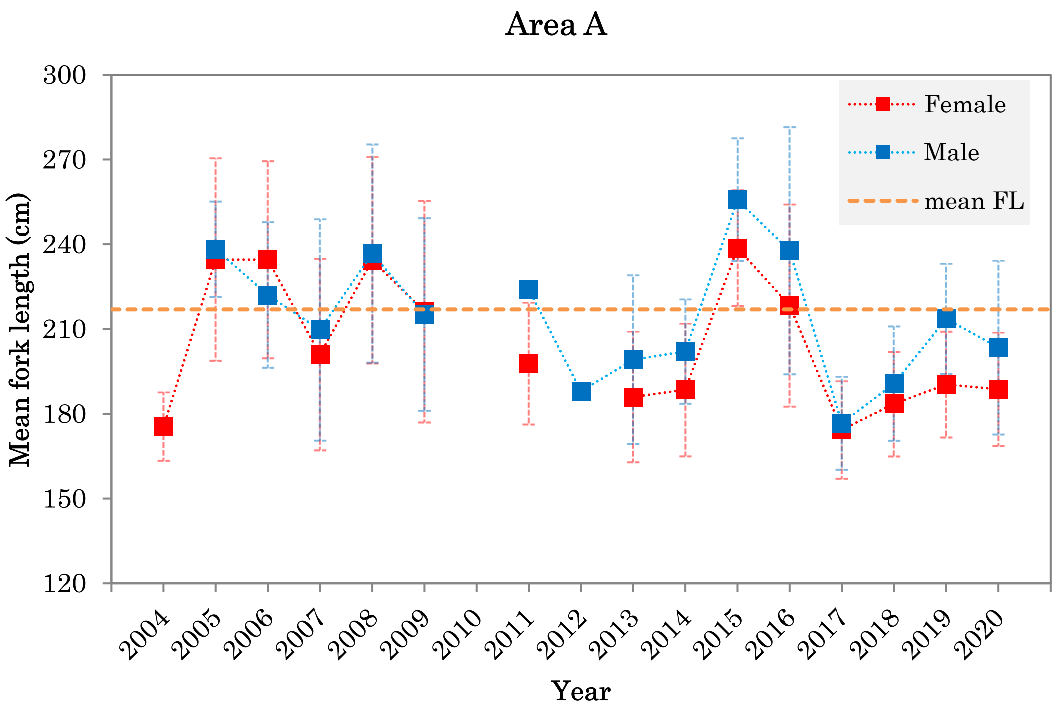


Figure 2. Length-frequency distribution of the blue shark in the North Pacific caught by the Taiwanese large-scale longline fishery.



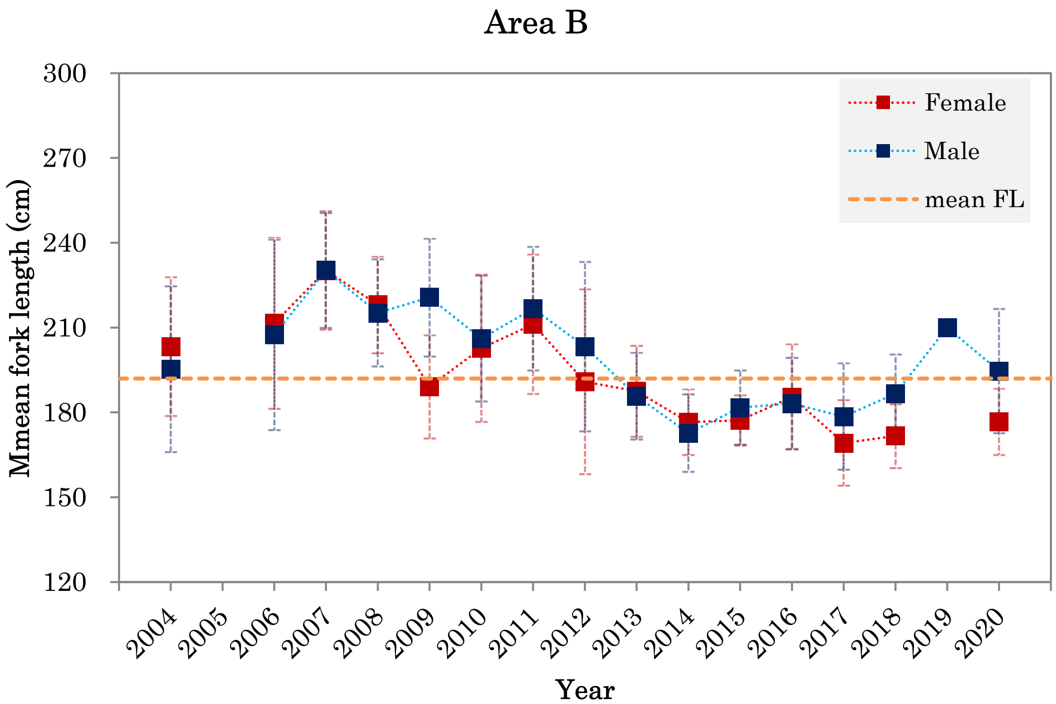


Figure 3. Mean fork length of the blue shark by area recorded by observers onboard the Taiwanese large-scale longline fishing vessels in the North Pacific from 2004 to 2020.

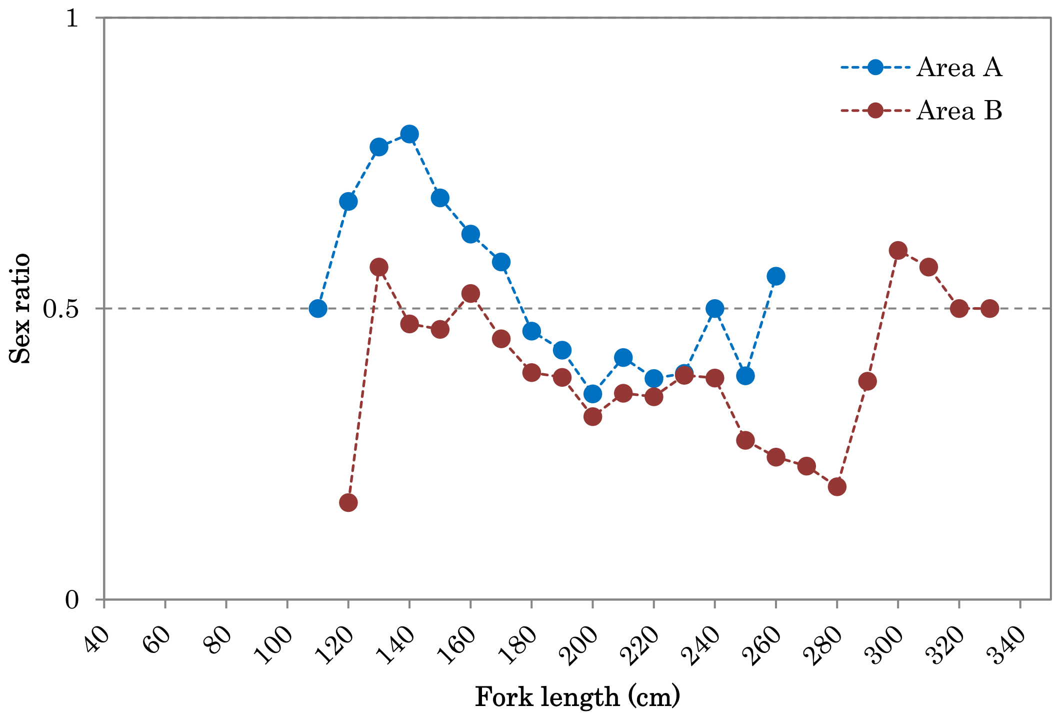


Figure 4. The sex ratio by size of the blue shark caught by the Taiwanese large-scale longline fishery in the North Pacific.

Table 1. The size range and mean length of the blue shark by area and season based on the Taiwanese large-scale longline observer's data.

Area	Season	Female			Male			Total		
		n	mean FL (cm)	range of FL (cm)	n	mean FL (cm)	range of FL (cm)	n	mean FL (cm)	range of FL (cm)
Area A	1	652	202	94-316	1,109	213	112-335	1,761	209	94-335
	2	12	250	186-285	51	218	170-292	63	224	170-292
	3	-	-	-	3	222	193-250	3	222	193-250
	4	531	219	120-335	951	229	56-320	1,482	226	56-335
	Sum	1,195	210	94-335	2,114	220	56-335	3,309	217	56-335
Area B	1	255	194	121-285	276	198	142-277	531	196	121-285
	2	625	184	124-260	604	195	108-267	1,229	189	108-267
	3	243	189	113-280	259	197	73-260	502	193	73-280
	4	139	197	116-260	187	198	119-267	326	197	116-267
	Sum	1,262	188	113-285	1,326	196	73-277	2,588	192	73-285
	Total	2,457	199	94-335	3,440	211	56-335	5,897	206	56-335

Table 2. The ANOVA table of GLM of the relation between mean catch-at-size and sex, season, area and their interactions

	Df	Deviance	Resid. Df	Resid. Dev	F	Pr(>F)	
NULL			5896	7509099			
Sex	1	213937	5895	7295162	200.6999	< 2.2e-16	***
Season	3	694827	5892	6600335	217.2788	< 2.2e-16	***
Area	1	271799	5891	6328536	254.9816	< 2.2e-16	***
Sex:Season	3	693	5888	6327844	0.2166	0.88493	
Sex:Area	1	6974	5887	6320870	6.5424	0.01056	*
Season:Area	3	48800	5884	6272070	15.2602	6.87E-10	***