ISC/16/SHARKWG-1/21

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

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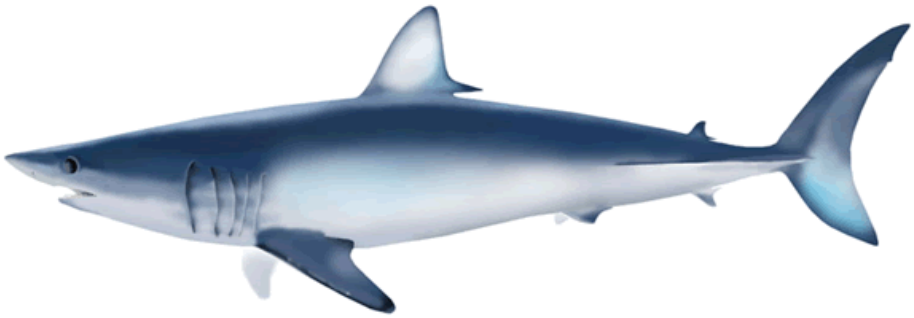

[1]Working document submitted to the ISC Shark Working Group Workshop, 14-21 November 2016,
Haeundae Grand Hotel, Busan, South Korea

Abstract

The size and spatial distribution of the blue shark, *Prionace glauca*, were described based on 3942 specimens, that were collected by scientific observers on-board Taiwanese large-scale tuna longline fleets in the North Pacific between June 2004 and December 2014. Size segregation was found, and the mean size of blue sharks in the tropical and subtropical area (0-30 °N) was significantly smaller than those in the temperate area (north of 30 °N). No significant sex segregation was found. Males predominated in the size range of 210-290 cm TL in the temperate area and in the range of 230-310 cm TL in the tropical and subtropical area.

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 numbers of this species have 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), and Hsu et al. (2011, 2012) 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.

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Materials and Methods

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 (48°40´W-27°42´E, 0°-41°13´N) between June 2004 and December 2014 (Fig. 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. The fork length was measured in a natural form. The equation FL = -1.222 + 0.829 TL was used to convert the FL to total length (TL). Based on the definition of ISC Shark Working Group, two areas (the tropical and subtropical area, 0-30°N, and the temperate area, south of 30°N) were stratified. The fishing vessels mainly targeted the bigeye tuna in the tropical and subtropical area and albacore tuna in the temperate area, respectively. Four seasons (seasons 1-4) were defined as January to March, April to June, July to September, and October to December, respectively.

Size and sex ratio data analysis

The mean sizes of specimens were compared between areas and sexes and among seasons using t-tests and analysis of variance (ANOVA) on the assumption of a normal distribution because of the large sample size. The annual variation of the mean catch-at-size was examined by ANOVA. 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.

Results and Discussion

Size range of specimens

A total of 3942 blue shark specimens, including 2189 males, and 1753 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 2582 specimens in the tropical and subtropical area ranged from 32 to 354 cm TL and 138 to 375 cm TL for males and females, respectively (Fig. 2). The sizes of the 1360 specimens in the and temperate area ranged from 69 to 406 cm TL and 44 to 406 cm TL for males and

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females, respectively (Fig. 3).

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

The mean size of the blue sharks in the tropical and subtropical area (248 cm TL) was significantly smaller than that in the temperate area (261 cm TL). The mean size of males was significantly larger than that of females in the tropical and subtropical area in every season. In the temperate area, the mean size of females was significantly smaller than that of males in seasons 2 and 4, but no significant difference was found for the other seasons. ANOVA revealed seasonal variations in the mean size in both areas. The mean sizes for both sexes of blue sharks increased from season 1 and peaked in season 3 in both areas (Fig. 1). There was a slight decreasing trend for the mean catch-at-size from 2004 to 2014 in the tropical and subtropical area, but such a trend was not found in the temperate area. The sex ratios were significantly less than 0.5 in both areas for every season (0.27-0.49), except season 1 (0.56) in the tropical and subtropical area. The sex ratios also varied with the specimen sizes and ranged from 0.25 to 0.67 and 0.15-0.62 in the tropical and subtropical and temperate areas, respectively. No significant sex segregation was found. Males predominated in the size range of 210-290 cm TL in temperate area and in the range of 230-310 cm TL in the tropical and subtropical area.

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. Our findings in this study were contradict to Nakano's results. This may be due to the smaller size of this study and the Taiwanese longline fleets' practice of discarding undersize fish.

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 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

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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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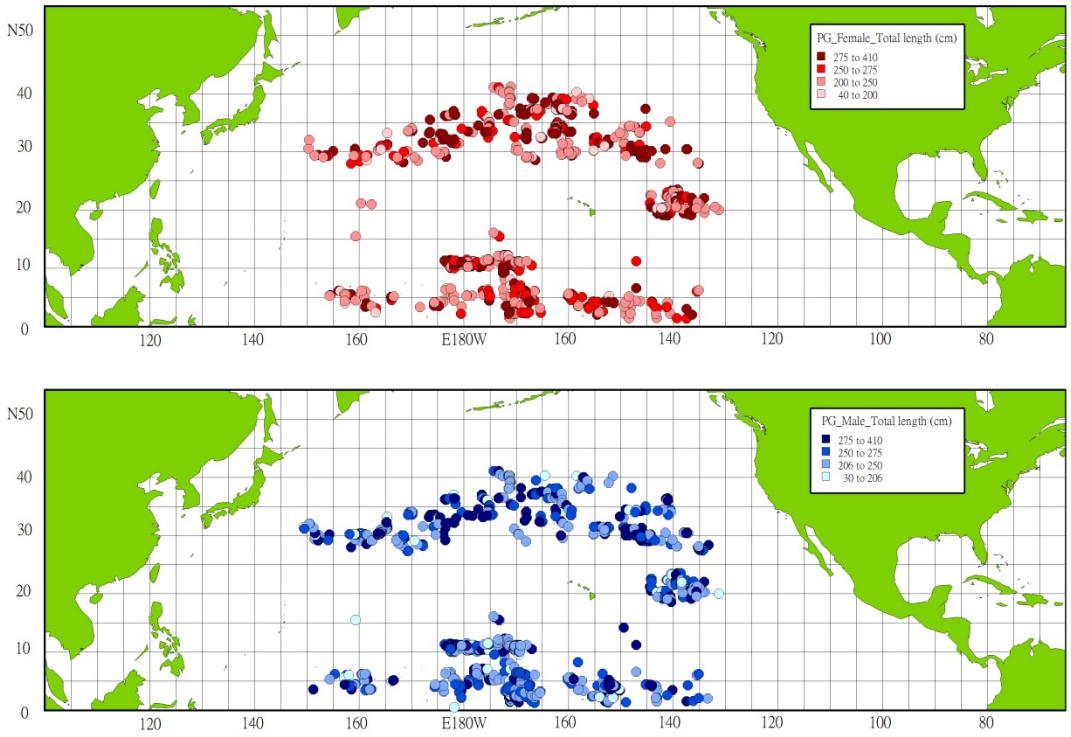

Fig. 1. Sampling location and size (TL, cm) by sex of the blue shark (*Prionace glauca*) recorded by observers for this study in North Pacific.

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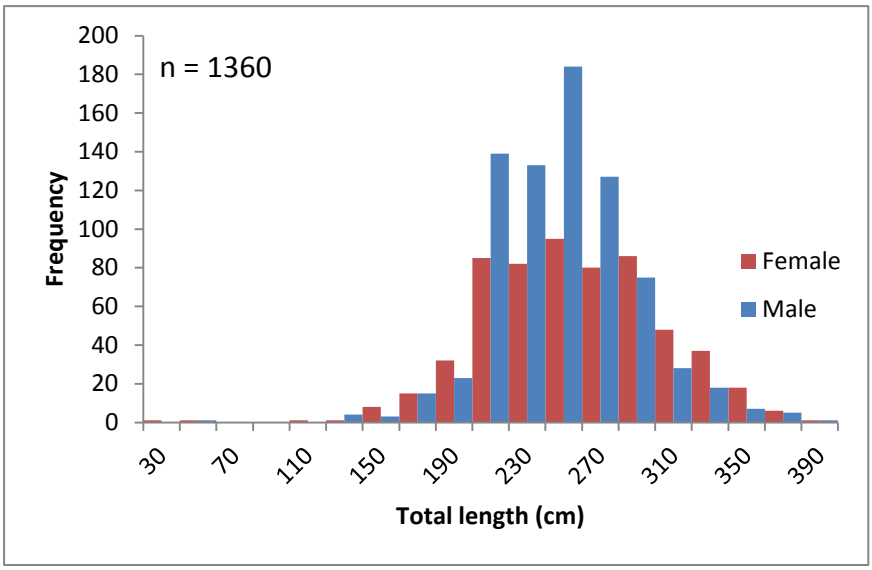

Fig. 2. The total length-frequency distribution of blue sharks caught by Taiwanese LTLL in the temperate area (>30 N) of North Pacific from 2004-2014.

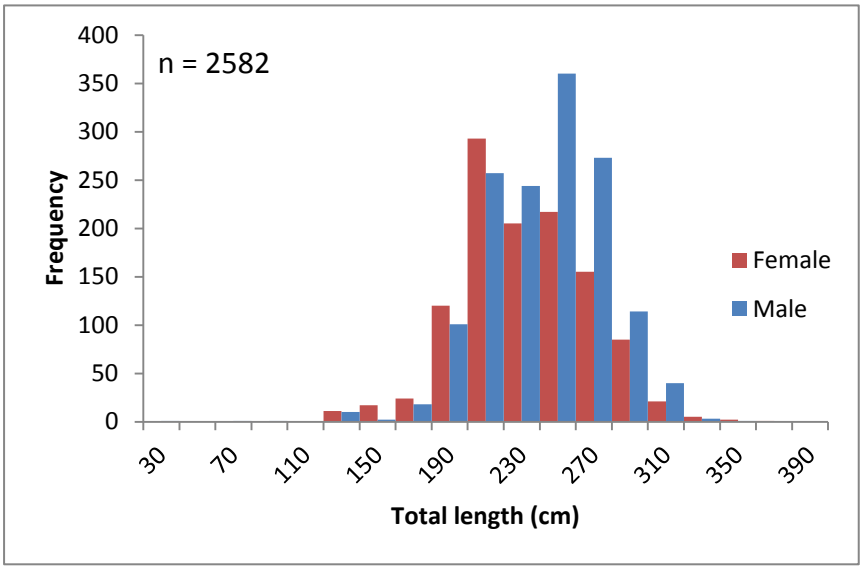

Fig. 3. The total length-frequency distribution of blue sharks caught by Taiwanese LTLL in the tropical and subtropical area (<30 N) of North Pacific from 2004-2014.

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