Indian Journal of Geo Marine Sciences
Vol. 49 (04), April 2020, pp. 543-547

Catch rate and stock status of blue shark in the Pacific Ocean inferred from fishery-independent data

W W Li[a,b], R Kindong[*,b,c,d,e,†] , F Wu[b,c,d,e], S Q Tian[b,c,d,e] & X J Dai[b,c,d,e,$]

[a]Laboratory of Marine Biology and Ecology, Third Institute of Oceanography, Ministry of Natural Resources, Xiamen, Fujian – 361 005, China

[b]College of Marine and Sciences, Shanghai Ocean University, Shanghai – 201 306, China

[c]National Engineering Research Center for Oceanic Fisheries, Shanghai – 201 306, China

[d]Scientific Observation and Experimental Station, Oceanic Fisheries Resources, and Environment, Ministry of Agriculture, Shanghai – 201 306, China

[e]Collaborative Innovation Center for Distant Water Fisheries, Shanghai Ocean University, Shanghai – 201 306, China

[E-mail: [†]kindong_richard@yahoo.com; [$]xjdai@shou.edu.cn]

Received 01 October 2018; revised 25 October 2018

Among pelagic sharks, the Blue shark, *Prionace glauca* (*Carcharhiniformes, Carcharhinidae*) is known to be the most abundant. Although, blue shark is relatively productive, concerns have been raised related to the decline in population of these apex fish predators; and this decline can affect the marine ecology. This paper presents catch per unit effort (CPUE) data of blue sharks obtained from observers' on-board Chinese pelagic longline fishing vessels from 2009–2014 in the Pacific Ocean. All the blue shark species were incidentally captured (without shark hook). Nominal CPUE ranged from 0 individual per 1000 hooks to 5.21 individuals per 1000 hooks; the highest annual average nominal CPUE recorded in this study was 0.89 individual per 1000 hooks in 2011 while, 0.58 was the lowest recorded in 2010. Our results equally indicates that, blue shark population was so close to MSY level showing that fishing mortality rate might surpass MSY level in the future, since decrease in catches were observed. Therefore, additional management measures should be implemented in the Pacific Ocean in order to achieve a healthy stock status of this species.

[Keywords: Blue shark (*Prionace glauca*), Catch rate, Pacific Ocean, Stock status]

Introduction

Blue shark *Prionace glauca*, found in temperate and tropical waters in the world is the main byproduct in many commercial fisheries including longline and gillnetfisheries[1]. Shark byproducts in commercial fisheries, particularly, in longline fishing vessels have increasingly been a worrying issue amid marine scientists due to their significance in marine ecosystems[2]. Additionally, captures of blue sharks are very common, since they're the highly incidentallycaught shark species in longline commercial fisheries in the world. The official data-poor, reporting the scale of catch and mortality, and production can be estimated as 6.5–11 million individuals per year[3-5]. Their growth is a major concern regarding the overfishing potential of sharks in the current levels of exploitation; different RFMOs (Regional Fishery Management Organizations) have incited numerous efforts to evaluate the status of shark stocks.

The fin trade among many other activities is a main threat to the population of shark species. Records from the shark fin market shows that, blue sharks, are the dominant shark species with the highest exploited fins in shark fin trade market[6]. This is attributed to the fact that, blue sharks are widely distributed throughout the oceanic waters worldwide. Also, trade record analysis presently reports that, blue sharks in the world may be facing exploitation at levels closer to or above maximum sustainable yield[3]. As far as prior studies are concerned, declines in catch-per-unit-effort (CPUE) of greater than 60 % was estimated for blue sharks in the Northwest Atlantic Ocean over the past 15 years[8]; and the abundance of blue sharks in the Central Pacific Ocean decreased in 1990s, assessed to be only 13 % of its abundance in 1950s[9]. All above studies reported that the stocks of blue sharks in these regions were vulnerable. Stock assessment for blue shark carried out in the North Pacific Ocean indicated that this species population appeared to be declining[10]. The biology of blue shark is well documented in the South Atlantic[11], North-west Atlantic[12], North-east Atlantic[13], Indian[14],

southeastern Pacific[15], and North Pacific Oceans[16]. However, there were relatively few descriptions of the blue shark in the Western and Central Pacific Ocean (WCPO).

In this paper, based on data obtained from the Chinese Longline Fishery Observer Program mainly targeting tuna species in the Pacific Ocean from 2009 to 2014, we had as objective to firstly, describe the biology of blue shark caught by Chinese longliners; secondly, to analyze the reproductive characteristics of the blue shark; thirdly, to analyze the monthly and annual nominal CPUEs, and finally to examine the stock condition of blue shark in the Pacific Ocean.

Materials and Methods

Survey description

All the data analyzed in this paper were collected based on Chinese Longline Fishery Observer Program mainly targeting tuna species in the Pacific Ocean (including Western, Central and Eastern Pacific Ocean) from 2009 to 2014 (Fig. 1). Altogether, 2340 sets were observed during a period of 6 years. All trained scientific observers were in charge of collecting biological data for tunas, bycatches, and fishing information on board longliners. Data provided by the Commission of Western and Central Pacific Ocean (WCPFC) was used for the analyses of the stock condition of blue shark in the Pacific Ocean.

Biological data collection

Round body weight (RW) and Liver weight (LW) were measured to the nearest kilogram (kg). Additionally, the following morphological measurements were made over the curve of the body to the nearest centimeter (cm): Total length (snout to a perpendicular line from the tip of the upper caudal fin in a normal position; TL), Fork length (snout to the deepest point of fork tail; FL), and Clasper length (CL). Gonad weight was measured to the nearest gram (g). Selected specimens were dissected to observe internal organs. Following Lucifora[17], male sharks were regarded mature when claspers were calcified and freely rotated forward. In addition to pregnant ones, females with puffy oviducal glands, widened uteri all along their length, and oocytes having yolk were also regardedmature[17].

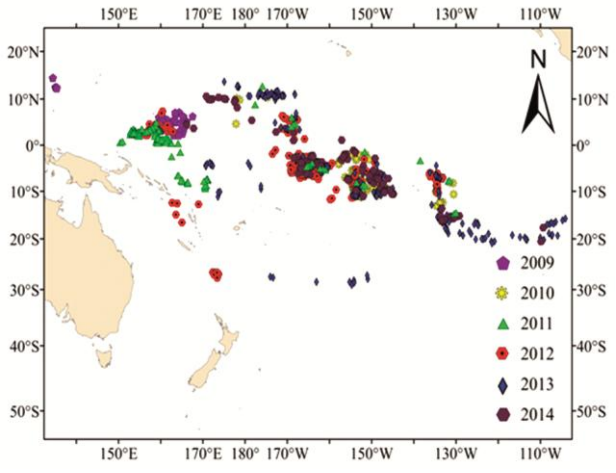

Fig. 1 — Observers distributed in the Pacific Ocean from 2009 to 2014

Data analysis

All length and weight relationships were estimated using Microsoft Excel Worksheet 2016 Version; as well as various monthly and annual nominal CPUEs, and the production of blue sharks in the WCPO from 1994 to 2014. Chi-squared tests of sex ratio of females and males were conducted using SPSS Statistics software version 17.0.

Results

Biological characteristics

Length, round weight and liver weight

Where fairly large numbers of Total length (TL), Fork length (FL), Round weight (RW) and Liver weight (LW) from different seasons were recorded, but small sizes of blue sharks were caught during the survey period in the Pacific Ocean from 2009 to 2014, the relationship between FL and RW was described as $RW = 7 \times 10^{-7} FL^{3.3029}$ ($R^2 = 0.848$) (Fig. 2). More relationships between the TL, FL, RW and LW were also analyzed (Figs. 2a - d). Although, the correlation

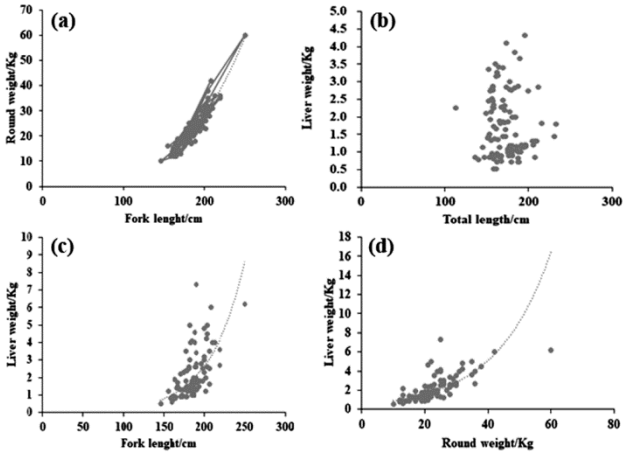

Fig. 2 —The relationship between a) Fork length and Round weight; b) Total length and Liver weight; c) Fork length and Liver weight; and d) Round weight and Liver weight.

of the Fork length and Liver weight; Round weight and Liver weight could be calculated as LW = 0.022 x $e^{0.0239FL}$ (R^2 = 0.45) and LW = 0.4867 x $e^{0.0587RW}$ (R^2 = 0.5756) separately, their correlation coefficients (R^2) obtained were relatively low.

Reproductive characteristics

Sex ratio

Random samples of 1952 individuals (823 females and 1129 males) showed that the sex ratio for female and male blue sharks caught was 1:1.37. The chi-squared test proved that the sex ratio was considerably different from 1:1 ($P < 0.05$). A total of 88 pregnant individuals were detected showing that the sex ratio for females and males was 1:0.96. The Chi-squared test, however, showed anon-significant difference from 1:1 ($P > 0.05$).

Clasper length

A total of 150 right outer clasper lengths (CL) of Male blue sharks were measured during the period when observers were on-board the tuna longline vessels in 2014; the range of clasper lengths measured was between 7 and 32 cm, with an average of 21.79 cm. The association between clasper length and Fork length of male blue sharks could be described as a binomial expression model: CL = -0.0013FL^2+ 0.7031FL-65.318 (Fig. 3a), (R^2 = 0.7237, n = 150). All claspers of the 150 males were elongated and fully calcified, which indicated that these males were mature and that their minimum length at maturity may be less than 142 cm (FL). On the other hand, data obtained during the period from 2009-2013, showed thatthe relationship between clasper length and Total length converged to a range of values instead of regressing (Fig. 3b).

Length and gonad weight

Data of 60 females (FL, RW, and Ovary weight) and 97 males (FL, RW, and Testis weight) were used to analyze the relationship between length and gonad weight. Relationships of Fork length and Ovary weight, Round weight and Ovary weight, Fork length and Testis weight, Round weight and Testis weight are shown in Figures 4(a-d). All these 4 relationships did not presentnormal regressions.

Catch rate

Nominal CPUE (Catch per Unit of Effort) is an important index of stock assessment and fishery management which reflects the fishery abundance. It was described as individuals per 1000 hooks. A total of 2350 sets in different seasons were collected and analyzed monthly and annually from 2009 to 2014. From January to July, the nominal CPUE showed a decreasing trend, but from July to December, the nominal CPUE increased (Fig. 5a). From 2009 to 2014, nominal CPUEs recorded stable fluctuations that were between 0.58 individuals per 1000 hooks and 0.89 individuals per 1000 hooks (Fig. 5b).

Stock condition

According to the data provided by the WCPFC from 1994 – 2013, catch of blue shark increased from 1994 to 2000, it reached to apeakof 42340 MT in 2000; but from 2000 – 2013, the catch of blue shark decreased (Fig. 6). The catch of blue shark in 2009

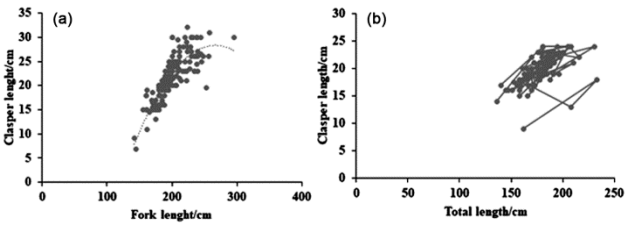

Fig. 3 — The relationship between a) Fork length and Clasper length; and b) Total length and Clasper length from 2009 - 2013

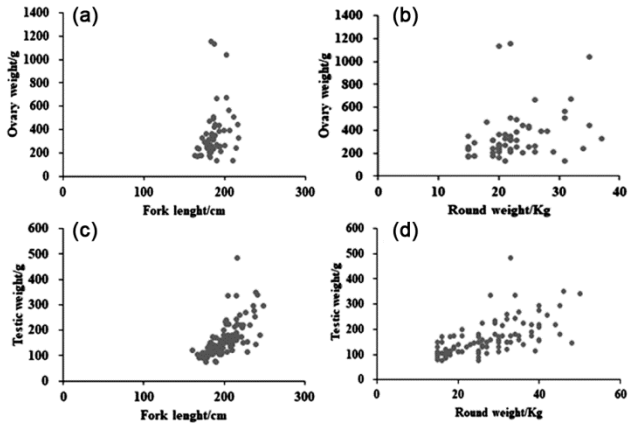

Fig. 4 — The relationship between a) Fork length and Ovary weight; b) Round weight and Ovary weight; c) Fork length and Testis weight; and d) Round weight and Testis weight

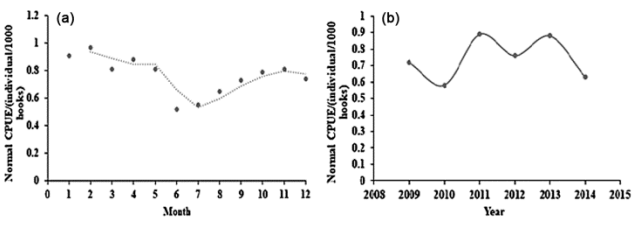

Fig. 5 — Normal CPUE distribution a) for different months; and b) from 2009 to 2014

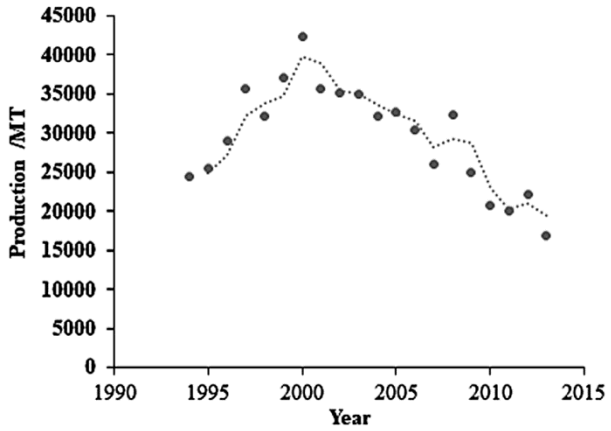

Fig. 6 — The production of blue shark varying between years in the Western and Central Pacific Ocean

was at the same level as that of 1994. The amount of blue shark caught in 2013 was 7/10th as it was in 1994. At present, the production of blue shark in the WCPO is relatively low.

Discussion

Information regarding the length composition, sex ratio, distribution and relative abundance of blue sharks in Western and Central Pacific Ocean is still rare. Many blue shark studies have been conducted in the northwestern, northeastern and north Atlantic but few in the Western and Central Pacific Ocean; though, the stock status of this species remains unclear in the region due to the complexity of its population structure and highly migratory behavior. This study provides complementary data that will contribute to understand and characterize the stock configuration of this species in the region.

The biology of blue shark

The length–weight relationship is an important parameter in assessing fish stocks. The fitted function for Fork length and Round weight was $RW = 7 \times 10^{-7} FL^{3.3029}$ ($R^2 = 0.848$). In the distance-water longliner, blue sharks Round weight can be converted to dress weight[18] which would effectively improve the data-poor situation of blue sharks for a better stock assessment. The liver weight of pregnant blue sharks was lighter than non-pregnant blue sharks at the same total length, for the reason that the mother blue shark absorbs nutrients to the fetus through the placenta from the liver[19]. So, the relationship between length or round weight with Liver weight proving to be a random relationship for small sizes of blue sharks wasn't caught during the period when the observers were onboard vessels.

Reproductive biology

The sex ratio of female to male blue sharks caught from 2009 to 2014 wassignificantly different from 1:1; during the observers program, many male blue sharks were caught than female individuals in the Pacific Ocean. The result was consistent to that of Porsmoguer[20] who conducted an experimental study showing thathooks equipped with magnets can increase catches of blue sharks in longline fisheries, the most abundant being the male specimens. Our study also supported that the sex ratio of pups at birth amounted to 1:1, as reported by Mejuto and García-Cortés[21], but the difference of sex ratio between individuals caught by longliner and individuals of pups in gravid females was not easy to explain, may be the females became weaker after reproduction and more vulnerable, leading to the decrease in their population. In addition, Hazin[11] reported that females appear to be distributed somehow closer to the surface than males in some tropical zones, considering this study, male blue sharks will be higher than females in fishing operated zones targeting tuna species. The gonad weights related to the level of gonad development were not identified in the samples collected. However, this study showed that minimum length at maturity was less than 142 cm (FL). Clasper length growth being directly proportional to the Fork length but when the clasper length develops large enough, it showed slight shrink with increase in Fork length.

Blue shark stock condition in the Pacific Ocean

Currently, the production of blue shark in the Pacific Ocean is in a decreasing trend according to the statistics provided by the WCPFC. Specifically, the number of blue sharks caught in 2013 in the WCPO was only the 7/10th of what was caught in 1999. Moreover, Rice[10] showed that blue sharks in the North Pacific Ocean are still not overfished; but it indicates that the population is at least close to MSY level and that fishing mortality may approach the MSY level in near future, as shown by the decrease in catch analyzed in this study. Anyway, the stable fluctuation of nominal CPUE supported that the blue shark in the Pacific Ocean is still at a healthy level but might possibly decline in the nearest future. However, the nominal CPUE observed from 2009 to 2014 showed seasonal variations indicating high nominal CPUEs from November to April, and from May to October. Time series observation data had some influences on yearly CPUE standardization which

affected the results of the stock assessment. In addition, small sizes of average total lengths were observed (214.16 cm TL in 2013, and 212.36 cm in 2014) during present study. Smaller total lengths in blue shark observed in present study as compared to studies of blue sharks elsewhere confirmed that, the stock condition of blue shark in the Pacific Ocean is not healthy enough and may probably decline in near future if it stays in this current exploitation level.

Acknowledgements

We would like to thank all observers who collected data for this study. We are thankful to the College of Marine Sciences, Shanghai Ocean University for supporting this study. This work was supported by a project sponsored by the National Key Research and Development Program of China (2018YFC0507205).

Conflict of Interest

On behalf of all authors, the corresponding author states that there is no conflict of interest.

Author Contribution

WL: Conceptualization; RK and WL: Formal analysis; ST and XD: Funding acquisition; FW and WL: Investigation; FW, ST and XD: Resources; WL and RK: Software; XD: Supervision; WL and FW: wrote the original draft; RK, ST and XD: did review & edited the MS before final submission.

References

1 Nakano H & Stevens J D, The biology and ecology of the blue shark, *Prionace glauca*. Sharks of the open ocean: *Biology, fisheries and conservation*, (2008) pp. 140-151.

2 Stevens J D, Bradford R W & West G J, Satellite tagging of blue sharks (*Prionace glauca*) and other pelagic sharks off eastern Australia: depth behavior, temperature experience and movements, *Mar Biol*, 157 (2010) 575-591.

3 Clarke S C, Mc Allister M K, Milner-Gulland E J, Kirkwood G P, Michielsens C G J, *et al.*, Global estimates of shark catches using trade records from commercial markets, *Ecol Letters*, 9 (2006) 1115-1126.

4 José I C, Christa M W & Rebecca L B, A Preliminary Evaluation of the Status of Shark Species, *Food & Agric Org*, 1999.

5 Ramon B, Overview of World Elasmobranch Fisheries, *Food & Agric Org*, 1994.

6 Clarke S C, Magnussen J E, Abercrombie D L, Mc Allister M K & Shivji M S, Identification of shark species composition and proportion in the Hong Kong shark fin market based on molecular genetics and trade records, *Conserv Biol*, 20 (2006) 201-211.

7 Nakano H & Seki M P, Synopsis of biological data on the blue shark, *Prionace glauca* Linnaeus, *Bul Fish Res Agen*, 6 (2003) 18-55.

8 Baum J K, Myers R A, Kehler D G, Boris W, Shelton J H, *et al.*, Collapse and conservation of shark populations in the NWAtlant, *Sci*, 299 (2003) 389-392.

9 Ward P & Myers R A, A method for inferring the depth distribution of catchability for pelagic fishes and correcting for variations in the depth of pelagic longline fishing gear, *Can J Fish Aquat Sci*, 62 (2005) 1130–1142.

10 Rice J, Harley S & Kai M, Stock assessment of blue shark in the North Pacific Ocean using Stock Synthesis, *WCPFC*-SC9-2013/SA-WP-02.

11 Hazin F, Lessa R & Chammas M, First observations on stomach contents of the blue shark, *Prionace glauca*, from Southwestern Equatorial Atlantic, *Rev Brasil Biol*, 54 (1994) 195-198.

12 Pratt H L, Reproduction in the blue shark, *Prionace glauca*, *Fish Bul*, 77 (1979) 445-470.

13 Henderson A C, Flannery K & Dunne J, Observations on the biology and ecology of the blue shark in the North-east Atlantic, *J Fish Biol*, 58 (2001) 1347-1358.

14 Gubanov Y E P & Grigor'yev V M, Observations on the distribution and biology of the blue shark, *Prionace glauca*, (Carcharhinidae) of the Indian Ocean, *J Ichthy* 15 (1975) 37–43.

15 Zhu J, Dai X, Xu L, Chen X & Chen Y, Reproductive biology of female blue shark *Prionace glauca* in the southeastern Pacific Ocean. *Environ Biol Fish*, 91 (2011) 95-102.

16 Nakano H, Age, reproduction, and migration of blue shark in the North Pacific Ocean, *Bul Nat Res Instit Far Seas Fish Enyosuikenho*, 31 (1994) 141-256.

17 Lucifora L O, Menni R C & Escalante A H, Reproduction and seasonal occurrence of the copper shark, *Carcharhinus brachyurus*, from north Patagonia, Argentina, *ICES J Mar Sci*, 62 (2005) 107-115.

18 Semba Y, Okamoto H, Shiozaki K & Fujinami Y, Processed form of blue shark (*Prionace glauca*) caught by Japanese longline fisheries with the estimation of conversion factor from processed weight to round weight, *Scientific Committee Eleventh Regular Session, Pohnpei*, Federated States of Micronesia, 2015.

19 Dai X, Research on the Biology and Ecology of Several Pelagic Sharks in the Eastern Pacific Ocean [D], *East China Normal University*, 2004.

20 Porsmoguer S B, Bănaru D, Boudouresque C F, Ivan D, & Christophe A, Hooks equipped with magnets can increase catches of blue shark (*Prionace glauca*) by longline fishery, *Fish Res*, 172 (2015) 345-351.

21 Mejuto J & García-Cortés B, Reproductive and distribution parameters of the blue shark, *Prionace glauca*, on the basis of on-board observations at sea in the Atlantic, Indian and Pacific Oceans, Col. Vol. *Sci Pap ICCAT*, 58 (2005) 951-973.