Blue shark (*Prionace glauca*) bycatch in tuna longline fishery in Sri Lanka

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Growing conservation concerns have emerged for sharks due to their high vulnerability to the tuna longline fishery. The Blue shark (*Prionace glauca*) is often identified as a bycatch species associated with the tuna longline fishery in Sri Lanka. However, there is a lack of species-specific data on blue shark landings in Sri Lanka. Consequently, this study aims to assess key aspects of the fishery and reproductive features, including bycatch composition, Catch-per-Unit-Effort (CPUE), the effects of bait and hook type, length distribution, sex ratio, and spatial distribution of blue sharks based on data collected from port sampling, logbooks, and the observer programme from 2020 to 2023. A total of 218 male (102-310 cm TL) and 209 female (113–298 cm TL) blue sharks were examined. The results showed that blue sharks (43%) were the second most dominant species, following the Silky shark (33.1%) and the Shortfin Mako shark (8.3%). The highest nominal CPUE was 0.16 in 2023, with variations related to fishing operations. J hooks contributed to the highest CPUE (1.8 indi/1000 hooks), while squid and "other" bait types were the most common baits, influencing blue sharks entangled in longlines. The length frequency distribution was normal. The sex ratio among the samples was approximately 1:1. Maturity stages were analysed solely for male sharks based on clasper length and calcification, with mature males having clasper lengths greater than 12 cm. The highest percentage of sexually mature male sharks was recorded in March and September-October each year.

Keywords: Blue sharks, bycatch, Sri Lanka, length distribution, Nominal CPUE

1. Introduction

The blue shark (Prionace glauca) belongs to the family Carcharhinidae, is a highly migratory species, spending most of its lifetime in high-sea areas and exhibiting a circumpolar distribution. Its distribution and migratory patterns depend on water temperature, food availability, and reproductive conditions (Nakano & Stevens,2008; Zhu & Richard, 2023), and they are usually caught at the depths of 75-445m while larger individuals (>180cm FL) are more common in deeper waters (>300m). Although they are highly abundant, fast-growing, and the most fecund shark species compared to other pelagic sharks, their populations have declined due to frequent interactions with longlines targeting tuna, swordfish and purse seines. This is driven by increasing fishing pressure in various oceanic regions, owing to their commercial value, particularly for shark fins (Mejuto, 1985). This leads to substantial by-catch a sometimes-exceeding target catches in volumes (Sulaiman et al., 2018; Jordaan et al., 2020).

It has become challenging to assess the population status due to inconsistent and a lack of species-specific data on blue sharks (Jordaan, 2018; Smale, 2008). Research indicates that the Western Indian Ocean is heavily impacted by high levels of longline fishing activities. Therefore, effective management measures must be implemented (Rochman et al., 2021). However, blue sharks are still classified as Near Threatened and show a decreasing population trend. In the Indian Ocean region, the blue shark stock was estimated as not overfished and not subject to overfishing in 2021. Additionally, circle hooks result in less at-vessel mortality compared to J-shaped hooks (Godin et al., 2012). The sustainability of blue shark populations in this area raises concerns, necessitating a closer examination of their life history, distribution patterns, and the impacts of fishing practices.

Sri Lanka is one of the dominant countries in the Northern Indian Ocean, engaging in a tuna fishery using multi-day longline vessels that target Yellowfin and Bigeye tuna throughout the year. According to the NPOA Shark 2018-2022, sharks constitute a significant portion of the non-directed catches of these multi-day longline vessels. The blue shark is the predominant species recorded between 2014 and 2017, representing 45.5% of longline shark landings (NPOA-2018-2022). Despite this, national-level statistics on species-specific information regarding blue shark interactions with tuna longline fleets, as well as data on size composition and spatio-temporal patterns, remain to be addressed. This study has been designed to examine the species-specific

fisheries and biological data on blue shark landings in major fishery harbours in Sri Lanka from 2020 to 2023.

Methodology

This study used data collected monthly basis from selected six (6) fishing harbours in Sri Lanka during the 2020 to 2023 period. (Figure 1).

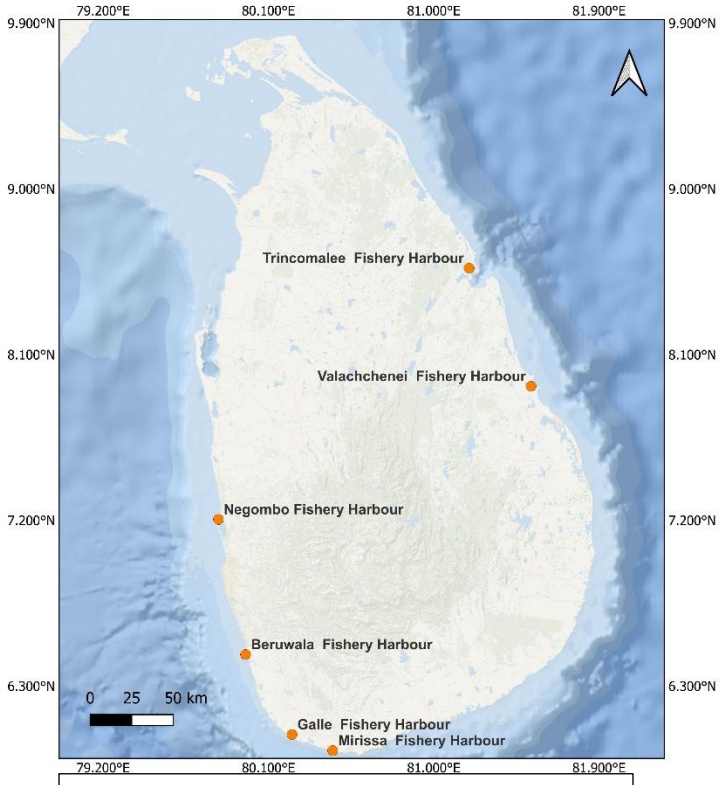

Figure 1: Map of the Selected Fisheries Harbours for Sampling in Sri Lanka

During the survey fisheries related catch and effort data were collected and it included type of vessel, boat registration number, gear used, gear specifications (number of hooks, hook type and size) bait type, trip duration. Moreover, shark species were identified up to possible taxonomic level using standard guides. Total length, fork length, sex, clasper length and maturity were measured in each blue shark landed. Logbook data relevant to each sampled boats were obtained from the Department of Fisheries and Aquatic Resources in order to verify more information on fishing operations and shark by-catch. Blue shark landing related data from observer program which had been conducted during the study period was also used for the analysis.

Data Analysis

Species composition for total shark by-catch landings was estimated as the number of individuals in each species relative to the total number of sharks landed during the survey period. Catch rate of the blue shark was estimated as the total number of individuals per 1000 hooks. Summary statistics were calculated including the frequency of use of different bait types and hook types, and the proportion of blue shark retained. Normality and homogeneity of variance were checked by

using the Shapiro-Wilk normality test and the Leven's test for catch rates, bait types and hook types. The Generalized Linear Model (GLM) was used to model the relationship between catch rates and hook type, and bait types.

Catch Per Unit Effort (CPUE) for blue sharks was calculated to each boat as the number of blue sharks per 1000 hooks per fishing trip. Average CPUE values were plotted against the month for four years to see the seasonal fluctuations. Total length was used to analyse the length-frequency distribution. Average length values were plotted for both male and female blue sharks together and separately see the variations monthly variations. All the analysis were done using R Studio software.

Results

During the survey period 821 sharks were recorded as the by-catch landing of tuna longline fishery and 609 were included to this study. Eight species of sharks were recorded during the study period as bycatch of tuna longlines in Sri Lanka (Table 1). The blue shark was the most common species (43%), followed by the silky shark, shortfin Mako shark (8%), and the tiger shark (3.2%).

Table 1: List of shark species recorded during the survey and their percentage composition compare to total shark landings.

Scientific name	Common Name	Percentage composition (%)
Prionace glauca	Blue shark	43
Carcharhinus falciformis	Silky shark	33.2
Isurus paucus	Shortfin Mako shark	8.1
Isurus oxyrinchus	Longfin Mako shark	8
Sphyrna lewini	Scalloped Hammerhead shark	3.2
Galeocerdo cuvier	Tiger shark	3
Carcharhinus leucas	Bull shark	1.1
Sphyrna zygaena	Smooth Hammerhead shark	0.4

During the study four different types of hooks were identified and those were J 36, J 26, O 83 and O17. Highest average catch rate of sharks was recorded by the J 26 (0.0889ind/1000hooks) hook type.

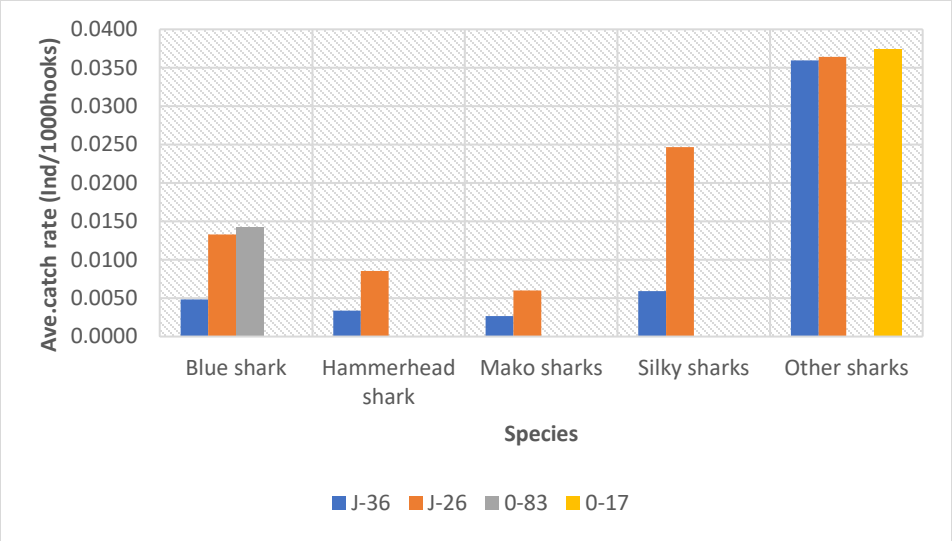

Figure 2: Average catch rates of sharks with different hook types (2020-2023)

Circle shape 83 size hook types has given the highest average catch rate of Blue sharks (42%) followed by J shaped 26 type (39%). J shaped 36 hook type contributed in less percentage for the blue shark catch rate compare to all the other shark species. Blue shark was the only shark species showed significant value in average catch rate when using the circle shape hook type.

Four major categories of bait types were recorded during the study as squids, flying fish (family Exocoetidae), Milk fish (*Chanos chanos*) and others which include scads and artificial baits.

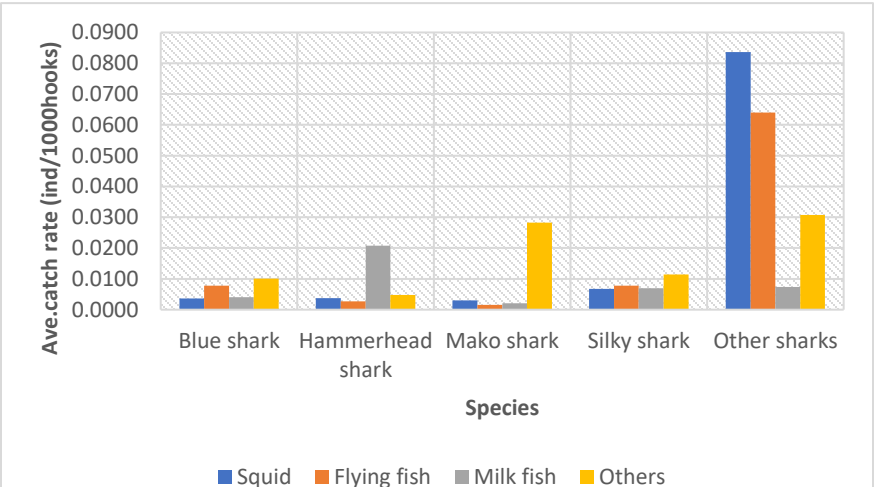

Figure 3: Average catch rates of sharks based on different bait types used (2020-2023)

The highest average catch rate of sharks (0.0836 ind/1000hooks) was recorded by the squid bait followed by the flying fish (0.0640ind/1000hooks). Blue shark average catch rate (*Prionace glauca*) (0.0101 ind/1000hooks) was higher when using "other" bait type which may include scads and artificial baits. Milk fish bait type has given the lowest catch rate compared to other shark species entangled.

The Shapiro–Wilk normality test confirmed that blue shark catch rates were not normally distributed ($W = 0.81$, $p < 0.001$), and Levene's test showed that the variance in catch rates differed significantly across hook and bait types ($p < 0.01$).

The Generalized Linear Model (GLM) indicated that both bait type and hook type significantly influenced the catch rate of blue sharks ($p < 0.05$). The use of circle shape O83 hooks had a strong positive effect on blue shark catch rates ($\beta = 0.38$, $p = 0.009$), while J26 hooks also showed a significant positive effect ($\beta = 0.29$, $p = 0.017$).

Catch Per Unit Effort (CPUE) of the blue sharks in 2 020 0.0039 (ind/1000hooks) while in 2021 it was 0.0315(ind/1000hooks). The CPUEs were estimated as 0.0654 and 0.0857 ind/1000hooks in 2022 and 2023 respectively. The lowest mean CPUE value was recorded in February and November 2020, while the highest mean CPUE was recorded in July 2023. Zero shark landings were recorded during the survey.

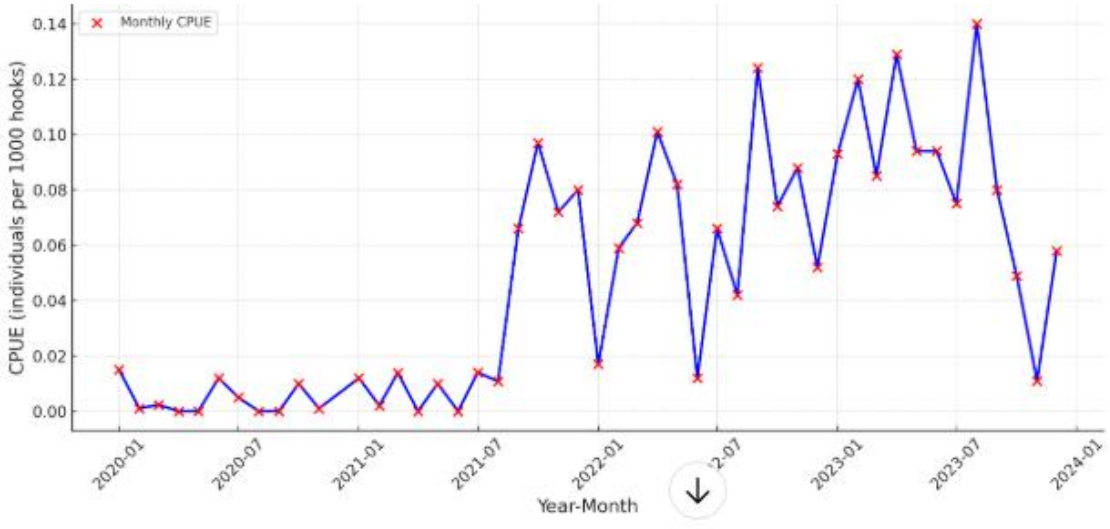

Figure 4: Monthly CPUE variation of blue shark landings in major fishery harbours of Sri Lanka

During the study period, no significant increase or decrease can be observed. Therefore, blue shark landings can be considered regular and vary throughout the year with some seasonal fluctuations.

During the survey period, 218 male blue sharks and 209 female blue sharks were landed and measured. The total length range for males was 102-310 cm, while for females it was 113-298 cm. Most male blue sharks measured between 160-220 cm, and for females, this range was between 150-210 cm. Compared to both males and females, fewer individuals below 140 cm were recorded. However, male blue sharks in the >250 cm length range were recorded more frequently than females.

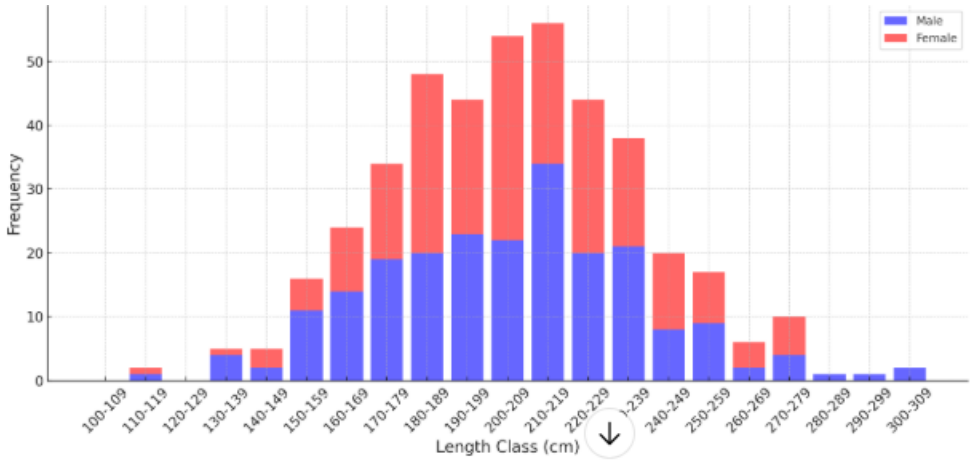

Figure 5: Length frequency distribution of male and female Blue sharks recorded during the study period

During the years 2020 and 2021, fewer individuals were recorded, and there were no catches in several months. Limited access to fishery harbours and fishing activities during the COVID-19 situation may be one reason for these lower recordings. Length frequency distributions showed irregular and lower values compared to other years. A minimal number of male blue sharks were recorded and were not significant in the graphs. In 2021, length frequencies were dominated by juveniles and sub-adults, with a smaller number of larger individuals present. However, in 2022, blue shark landings showed a consistent pattern throughout the year for both males and females. In 2023, a significant seasonal pattern was observed in March, September, and October, with peak

seasons. During these peak seasons, both mature and immature blue sharks were recorded in various length classes.

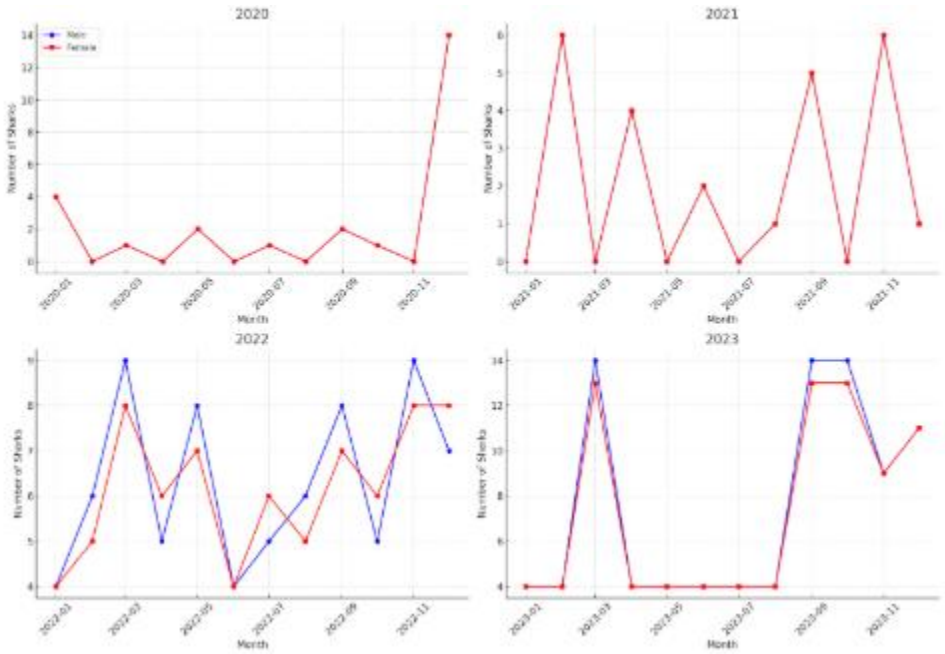

Figure 6: Length frequency distribution pattern in different years from 2020 to 2023.

Discussion

This study provides the systematic species-specific analysis of blue shark (Prionace glauca) landings from the Sri Lankan tuna longline fishery in recent years. Although blue sharks remain one of the most abundant pelagic shark species in the Indian Ocean (Nakano & Stevens, 2008; Zhu et al., 2023), findings of this study highlight several fisheries and management concerns related to catch composition, seasonal patterns, and gear interactions.

Catch-per-unit-effort (CPUE) indicated the considerable variability between years (0.0039–0.16 ind/1000 hooks), consistent with fluctuations observed in other regions of the Indian Ocean (Smale, 2008; Jordaan et al., 2018). This type of variabilities might be attributed with the seasonal migrations, spatioal distribution and reproductive aggregations. The observed peak CPUE in July 2023 coincides with seasonal shifts in oceanographic conditions, particularly cooler waters that are known to influence pelagic shark distribution (Nakano & Stevens, 2008).

Even though CPUE values remain comparatively low with other studies in the region (Sulaiman et al., 2018) the regular occurrence of blue sharks in catches (43% of total shark landings) underlines their high susceptibility to tuna longlines in Sri Lankan waters. This kind of consistency in landings can be identified blue shark as the predictable component of the catch rather than the incidental by-catch. This raises concerns regarding cumulative fishing mortality, particularly when immature individuals are targeted.

This study significantly highlighted the effects of both hook and bait type on blue shark catch rates. Circle hooks (O83) produced the highest proportion of blue sharks, while J-hooks (J26) also contributed significantly. Findings of this study align with earlier studies which highlighted that hook design influences species selectivity, hooking depth, and post-release survival (Godin et al., 2012). While circle hooks have been promoted as a mitigation measure for reducing the mortality of bycatch species, this study results highlight that those may increase blue shark interactions and emphasize the species-specific assessments before management implementation.

Similarly, bait choice influenced catchability, with "other" bait types (scads and artificial bait) showing higher average blue shark catch rates than squid or milkfish. These results suggest that blue shark feeding behaviour may be opportunistic, and bait composition can play a role in bycatch mitigation. The potential for bait substitution as a management measure should therefore be considered in the Indian Ocean context, as demonstrated in other longline fisheries (Clarke et al., 2006).

The length-frequency distribution indicated that most blue sharks landed were sub-adults (160–200 cm TL), with less number of individuals which exceeds total length of 250 cm. This size composition indicates high fishing pressure on immature individuals, which can have long-term impact to the population. Previous studies have shown that blue sharks mature relatively late and rely on high fecundity (Nakano & Stevens, 2008; Dulvy et al., 2008). Continous removal of juveniles and sub-adults therefore reduces recruitment potential, increasing the risk of stock depletion even in abundant species.

The nearly 1:1 sex ratio recorded in this study differs from evidence of sexual segregation reported in other regions (Veríssimo et al., 2017). However, the occasional dominance of either sex in

specific months (March, September–October) suggests possible seasonal aggregation linked to reproductive cycles. The higher presence of mature males during these periods indicates potential mating grounds or migratory patterns in the areas where these fishing happened.

Data collection in 2020–2021 was strongly affected by the COVID-19 pandemic, which limited harbour access and reduced fishing operations. This likely explains the lower sample sizes and absence of records in several months. In addition, discrepancies between logbook records and actual landings highlight underreporting issues that are common in shark fisheries (Jordaan et al., 2018). Strengthening observer coverage, improving logbook compliance, and integrating electronic monitoring systems are therefore essential to obtain more reliable catch statistics.

As a conclusion the findings highlight the persistent vulnerability of blue sharks in Sri Lankan tuna longline fisheries as a bycatch. Long-term, standardized monitoring and proactive management interventions are essential to ensure that by-catch landing of blue sharks remain sustainable in Sri Lanka.

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