Size distribution of blue shark (*Prionace glauca*) by-catches in the large pelagic fisheries of the eastern Mediterranean Sea

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ABSTRACT

A total of 116 blue sharks (*Prionace glauca*), the most abundant and important shark by-catch in the large pelagic fisheries was sampled during the period 1998-2001 in the eastern Mediterranean Sea, to study the size distribution of this species. Total length (TL) and dressed weight (DW) ranged from 100.5 to 329.0 cm and from 2.5 to 81.0 kg respectively. Statistically significant differences in total lengths (*Multifactor ANOVA* test) were found amongst the various fishing gears (albacore, swordfish and American type swordfish longline), indicating that different fishing gears target different size classes. The larger specimens were observed in the Levantine basin area, while the smaller ones in the Ionian Sea. Although blue sharks in the region were relatively larger than in most areas worldwide, still a significant fraction of the catches consisted of immature to sub-adult fish, pointing out the immediate need for conservation measures and a sustainable management policy for blue shark stocks.

Keywords : *Prionace glauca*; blue shark; size distribution; longline; eastern Mediterranean

INTRODUCTION

Blue shark, *Prionace glauca* (Linnaeus, 1758) is a wide-ranging, oceanic-epipelagic shark that can attain a size of 4 meters in total length. Although its' dark blue color suggests a surface dwelling fish of the open sea it frequently swims into the sunless depths (Carey *et al*., 1990). Males and females are known to segregate in different areas by size (Nakano, 1994; Castro *et al.*, 1999). Highly migratory in nature it may travel considerable distances each year. While blue sharks are among the most abundant, widespread, fecund and faster growing of the elasmobranches, they are also the most heavily fished sharks in the world. Its meat although generally considered edible, has not been in great demand. So far, the fins have been of the highest value since they've been used in various dishes of the Far East cuisine (Draganik *et al*, 1984). Most blue sharks are discarded after they are usually finned (Castro *et al.*, 1999). The impact of annual fisheries mortality (mainly of by-catch), estimated at 10 to 20 million individuals, is likely to have an effect on the world population, but monitoring data are inadequate to assess the scale of any population decline. Nevertheless, there is concern over the removal of such large numbers of this apex predator species from the oceanic ecosystem, since historical fisheries have shown that sharks are intrinsically sensitive to sustained exploitation (Castro *et al.*, 1999; Froese *et al.*, 2003).

In the eastern Mediterranean Sea, blue sharks are primarily captured as by-catches in the large pelagic fisheries, targeting swordfish or tuna, comprising as much as 4% of total catches (Megalofonou *et al.*, 2000). This paper analyzes length and weight data from blue shark caught by the Greek swordfish and albacore longline fleet through a four-year period to estimate the size frequency distributions and the average sizes by area and gear.

MATERIALS AND METHODS

Collection of data took place between April 1998 and September 2001, in the Ionian Sea, Aegean Sea and Levantine basin (Figure 1). Observers were stationed at pilot ports, where fishing boats landed their catches and on board the vessels targeting swordfish (*Xiphias gladius*) or albacore (*Thunnus alalunga*) (Table 1). Fishing gears sampled were: the traditional swordfish longline ($SWO\text{-}LL_T$), American type swordfish longline ($SWO\text{-}LL_A$) and albacore longline (ALB-LL). In

general, the swordfish longline consisted of a nylon monofilament main line from 1 to 3 mm Ø in cross section hung in a sagging curve between surface floats. Branch lines with a length of 10 up to 50 meters descended from the main line, each terminating with a single baited hook. The number of hooks ranged from 350 to 1200 and hook size varied from type No 2 to 3, depending on the gear. The albacore longline was a much delicate version of the longline gear described above, having thinner lines and characteristically shorter branch lines (3-6 meters), while the number of hooks ranged from 1000 to 3000 of size No 7. In Greece, fishing period for swordfish longlining lasts from February to September while albacore longlining takes place in September and October. Fishing grounds cover the east Ionian Sea, the Aegean Sea and the Levantine basin as far as the Israeli and North African coasts. Records included type of fishing gear, fishing location, date of capture, species identification and various morphometric measurements according to Compagno (1984). Total length (TL) was measured from the rear tip of the upper caudal lobe to the snout tip, along the horizontal line of the body axis. Accordingly, fork length (FL), from the fork between the upper and lower caudal lobes to the snout tip, while interdorsal space (IDS) was measured from the end of the first dorsal fin base to the origin of the second dorsal fin. All length measurements were taken to the nearest cm. Dressed weight (DW) measurements were recorded to the nearest tenth of kg after the fish was gilled, gutted, finned and decapitated. The species was identified by the: (1) long conical snout, (2) large dark eyes, (3) curved triangular serrated teeth, (4) bright blue coloration of skin and (5) absence of interdorsal ridge. In a few cases classification was done after examining the pattern of caudal vertebrae.

Size distribution of blue sharks was calculated in total length and dressed weight. Since the most common measurements available were dressed weight (DW) and interdorsal space (IDS), in all cases where total length was impossible to record, it was estimated using conversion formulas derived from other studies on blue sharks (Hazin *et al.*, 1991; Megalofonou *et al.*, 2000):

$$TL = 71.87 * DW^{0.3229} \text{ and } IDS = -4.24 + 0.22*TL$$

A multifactor Analysis of Variance was applied to determine the effect of fishing gear type, fishing area and sampling type (on board or at landing observations) on blue sharks total length. Ordinary univariate regression analysis was used to determine the relation between length and weight measurements.

RESULTS

A total of 116 blue sharks, were sampled during the 714 fishing days studied (Table 2). Mean total length and dressed weight of those specimens was 216.4 cm and 24.8 kg respectively. The smallest specimen had a total length of 100.5 cm and was caught in the N. Aegean Sea in October 1998 by an albacore longliner. It had a dressed weight of 2.5 kg. The largest specimen came from the Levantine basin and was captured by an American type swordfish longliner in September 1999. Its' dressed weight and total length was 81.0 kg and 329.0 cm respectively (Figure 2 and 3). Seven fish had a total length greater than 300 cm.

As a fact, more than half of the fish studied (66 out of 116) were caught by American type swordfish longliners in the Levantine basin area. Albacore longline catches consisted of small individuals (100.5 – 114.6 cm TL), while the American type swordfish longliners captured larger ones (127.5 – 329.0 cm TL) (Table 3 and Figure 4).

Multifactor Analysis of Variance determined that only the type of fishing gear had a statistically significant effect on blue shark total length (Table 4).

Regarding the three different geographical areas: larger fish came from the Levantine basin, while smaller ones from the Ionian Sea.

Comparison of sharks sampled on board (217.3 cm average TL) with those at landing (215.9 cm average TL), concluded that landed specimens had similar sizes with those measured on board by observers.

Regression analysis between dressed weight (DW) and interdorsal space (IDS) showed a fairly high correlation (r=0.93) and the corresponding relation was: $DW=0.000129 * IDS^{3.1578}$.

DISCUSSION

Size distributions and mean values of lengths suggested that the eastern Mediterranean is inhabited from quite large blue sharks, especially when compared with the central and western regions of the Mediterranean Sea (Figure 5). The few studies regarding blue sharks in the Mediterranean waters cite mean lengths from 120 to 200 cm (De Metrio *et al.*, 1984; Buencuerpo *et al.*, 1998; Megalofonou *et al.*, 2000). In general, mean total lengths of 216.0 cm or more are rare in the existing literature (Draganik *et al.,* 1984; Amorim *et al.*, 1996; Kotas *et al.*, 2000). Usually specimens are smaller than 200.0 cm in total length (Strasburg, 1958; Hazin *et al.*, 1994; Nakano, 1994; McKinnell *et al.*, 1998; Stevens, 1990; Henderson *et al,* 2000).

Regarding the maximum size of blue sharks, the largest specimen (329 cm TL) in this study was caught in the Levantine Basin and it was much smaller than the 426 cm (356 cm fork length converted[*]) reported by Kohler *et al.* (1981). Other authors have reported maximum sizes of 383 cm (Compagno, 1984), 382 cm (Kotas *et al,* 2000), 349 cm (Megalofonou *et al.*, 2000) and 323 cm (Simpfendorfer *et al.*, 2002 -270 cm fork length converted[*]). Individuals greater than 300 cm of total length are quite exceptional catches and it is noteworthy that Nakano (1994), studying a total of 105,600 blue sharks in the Pacific Ocean, found no shark greater than 292 cm (220 cm body length converted[**]).

The smallest blue shark observed in this research (100.5 cm TL), was quite larger than the minimum sizes reported by other researchers to date. In the Mediterranean, Buencuerpo *et al.* (1998) reports a minimum size of 70 cm and Megalofonou *et al.* (2000) 55 cm. Compagno (1984), after consulting several researchers, summarizes on the biology of the species and suggests that size at birth is more likely to be in the 35 - 44 cm TL range.

To evaluate the sexual maturity of blue sharks caught, we followed Pratt's (1979) suggestions. Pratt's findings suggest that sexual maturity occurs for both sexes at a similar body length, 180 cm FL for males and 185 cm FL for females. We can speculate that a high percentage of blue shark catches in the eastern Mediterranean consists of immature specimens. Out of 116 blue sharks observed in the present study, 48.3% had a fork length below 180 cm and 55.2% below 185 cm. However, Pratt proposed that before maturation and at a size between 145–185 cm FL, females should be considered as sub-adults, a separate group that possesses differentiated though not completely functional reproductive organs. It is alarming that a significant proportion of eastern Mediterranean blue shark catches have not reached maturity. In the central and western Mediterranean Sea the situation is more dramatic, 92.5% and 94.4% of specimens reported being below 180 and 185 cm FL respectively (Megalofonou *et al.*, 2000).

[*] TL = 1.203*FL – 1.676 (Kohler et al., 1995)

[**] Body Length = 0.9075 * FL – 0.3956 (Kohler et al., 1995)

The quite large sized fish (231.8 cm mean total length) in the Levantine basin area, plus the presence of four specimens above 300 cm, is a pinpointing observation. Under-exploitation of marine resources in this vast area could be a reasonable explanation. Large pelagic fisheries targeting swordfish or tuna do not have the intensive extent that is been experienced in other Mediterranean regions or the Atlantic and Pacific Ocean. Thus the population might be under a lesser fishing pressure and not as heavily affected as elsewhere. This hypothesis is been supported by the fact that swordfish average size in this region is also larger than the sizes reported from most of the areas comprising the Mediterranean Sea (De Metrio *et al*, 2001).

Fishing gears targeted different size classes, showing that the configuration of the gear affected the composition of catches. Albacore longline caught exclusively immature fish, while swordfish longline immature to sub-adult sharks. This distinctive feature -each gear targeting different size classes- could be due to the design of the fishing gear. A more delicate version of a longline catches smaller sharks (albacore longline), while the larger and stronger fish can be maintained hooked only on a more robust gear (swordfish longline). Beside the gear characteristics, setting depth is also a considerable factor that affects the size composition of the catches. It should be taken in account that albacore longline sets rarely exceed 10 m in depth from sea surface, while the American type swordfish longline might go below 50 m. Adult sharks mostly congregate in deeper waters below 10 m (Carlson *et al.*, 1999). The effect of fishing gear on Mediterranean blue shark catches, has already been confirmed by De Metrio *et al.*, 1984; Buencuerpo *et al.*, 1998 and Megalofonou *et al.*, 2000.

Since there is no specific regulation prohibiting landings of undersized blue sharks, the almost equal mean size of specimens recorded by observations on board fishing boats and when fish were landed at the ports was an expected result. Fishermen do not tend to hide or discard shark catches, like they do for undersized swordfish or tuna.

The relatively large average size of blue sharks in the eastern Mediterranean Sea is a discovery that needs a more thorough examination. A series of more systematic investigations in a larger scale, taking into account stock structure data and abundance indices is needed to adequately comprehend the phenomenon.

This study brings to light that although blue sharks in the region were relatively larger than in most areas worldwide, still a significant fraction of the catches consisted of immature to sub-adult fish. This observation is worrying and points out the immediate need for conservation measures and a sustainable management policy for blue shark stocks.

ACKNOWLEDGEMSNTS

This study was performed with the finance of the Commission of the European Communities (Project No 97/50 DG XIV) and does not necessarily reflect the views of the European Commission.

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Table 1. Sampling scheme monthly coverage of the eastern Mediterranean large pelagic fisheries during 1998-2001, including number of pilot ports, commercial vessels involved and fishing days monitored (Some ports and vessels overlap between months and years).

Month		**Year**				**Total**
		1998	1999	2000	2001	
March	No ports				3	3
	No vessels				4	4
	Fishing days				23	23
April	No ports	1		3	1	5
	No vessels	1		7	2	10
	Fishing days	1		18	3	22
May	No ports	2	2	1	3	8
	No vessels	2	2	11	4	15
	Fishing days	16	9	45	18	88
June	No ports	2	2	2	1	6
	No vessels	2	6	3	2	10
	Fishing days	27	64	13	12	116
July	No ports	2	1	1	2	6
	No vessels	2	3	6	3	12
	Fishing days	33	52	29	39	153
August	No ports	1	3	1	1	6
	No vessels	3	4	7	2	12
	Fishing days	22	20	35	19	96
September	No ports	1	6	2	1	7
	No vessels	16	18	5	2	37
	Fishing days	31	102	21	10	164
October	No ports	2	1			2
	No vessels	21	1			21
	Fishing days	51	1			52
Total	No ports	4	8	8	5	15
	No vessels	31	27	14	7	64
	Fishing days	181	248	161	124	714

Table 2. Number of blue sharks (*Prionace glauca*) captured in the eastern Mediterranean Sea during 1998-2001 by area and fishing gear, with ports, vessels and fishing sets monitored (Some ports and vessels overlap between areas and gears).

						No of observations								
Area	**Gear**	No of Ports	No of vessels	Fishing days On board	Fishing days At landing	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Total
Aegean	ALB-LL	2	38	0	99	*	*	*	*	*	*	0	6	6
Levantine	SWO-LL_T	1	3	2	13	0	-	0	-	-	-	0	*	0
Aegean	SWO-LL_T	2	5	20	24	-	-	0	0	0	2	0	*	2
Ionian	SWO-LL_T	1	1	15	30	-	0	0	4	4	-	-	*	8
Levantine	SWO-LL_A	9	20	27	331	2	4	2	13	9	6	30	*	66
Aegean	SWO-LL_A	3	14	59	86	-	-	-	-	10	11	11	*	32
Ionian	SWO-LL_A	1	2	0	8	-	-	-	-	2	-	-	*	2
		15	**64**	**123**	**591**	**2**	**4**	**2**	**17**	**25**	**19**	**41**	**6**	**116**

(*) indicates closure of fishing period for a fishing gear
(-) indicates absence of data, no sampling

Table 3. Total length summary statistics for blue shark (*Prionace glauca*) captured in the eastern Mediterranean Sea during 1998-2001.

		Total Length (cm)				
Area	**Gear**	**N**	**Mean**	**S.D.**	**Min**	**Max**
Aegean	ALB-LL	6	106.8	4.91	100.5	114.6
Aegean	SWO-LL_T	2	185.9	28.14	166.0	205.8
Aegean	SWO-LL_A	32	221.2	38.58	159.5	317.0
Ionian	SWO-LL_T	8	156.6	36.99	111.0	215.0
Ionian	SWO-LL_A	2	228.4	25.95	210.0	246.7
Levantine	SWO-LL_A	66	231.8	39.10	127.5	329.0
Total		**116**	**216.4**	**48.98**	**100.5**	**329.0**

Table 4. Multifactor analysis of variance for blue shark Total length - Type III Sums of Squares

Source	Sum of Squares	D.f.	Mean Square	*F*-ratio	*P*-value
Area	4121.8	2	2060.9	1.42	0.2468
Gear	57697.9	2	28848.9	19.84	0.0000
Sampling	387.2	1	387.2	0.27	0.6070

Level codes for Area: (Aegean, Ionian, Levantine) Gear: (ALB-LL, SWO-LL_T, SWO-LL_A) Sampling: (At landing, On board)

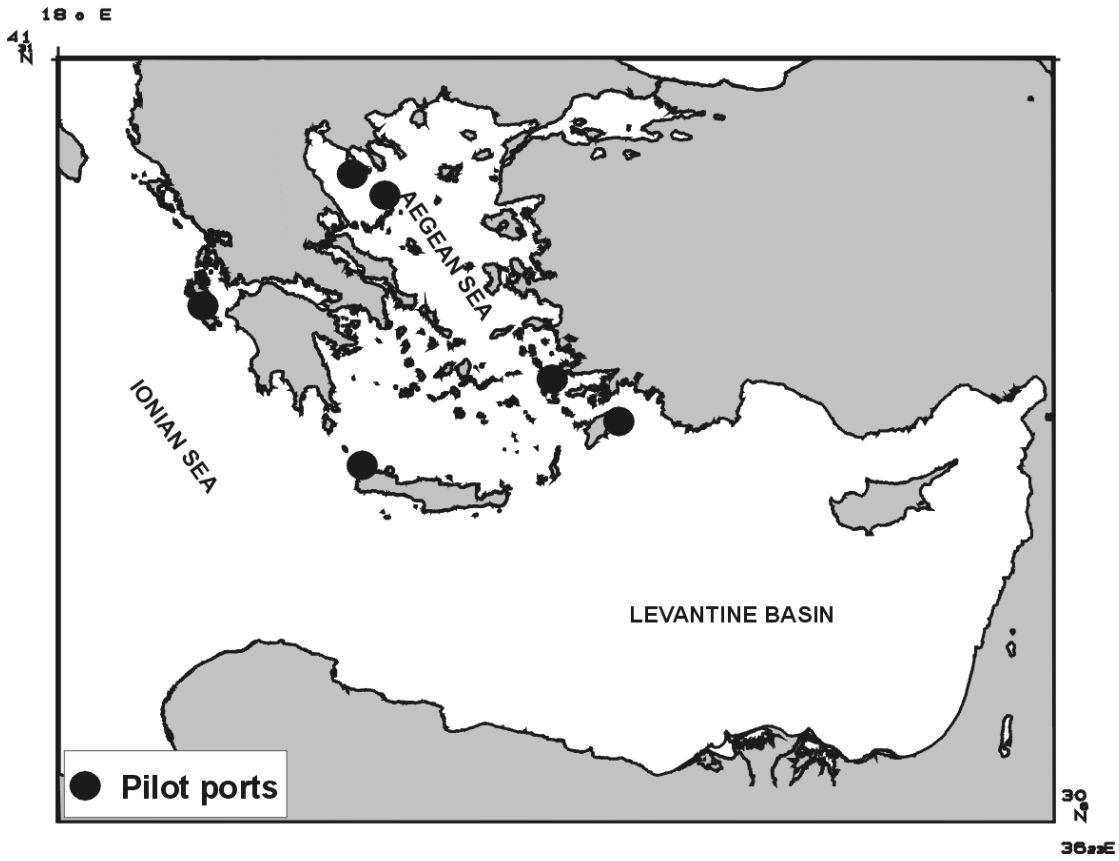

Figure 1. Map of the investigated areas and the pilot ports sampled during 1998-2001 in the eastern Mediterranean Sea.

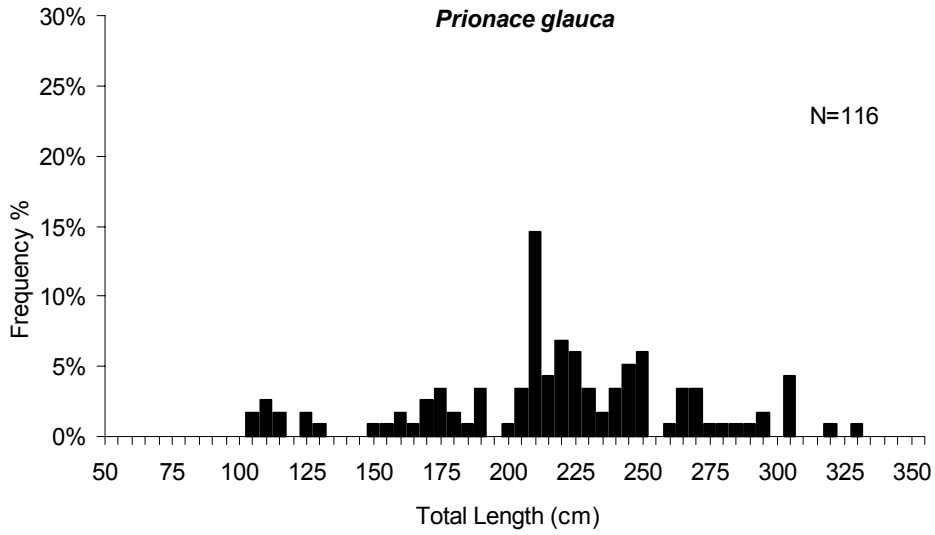

Figure 2. Total length frequency distribution for blue shark (*Prionace glauca*) sampled in the eastern Mediterranean Sea during 1998-2001.

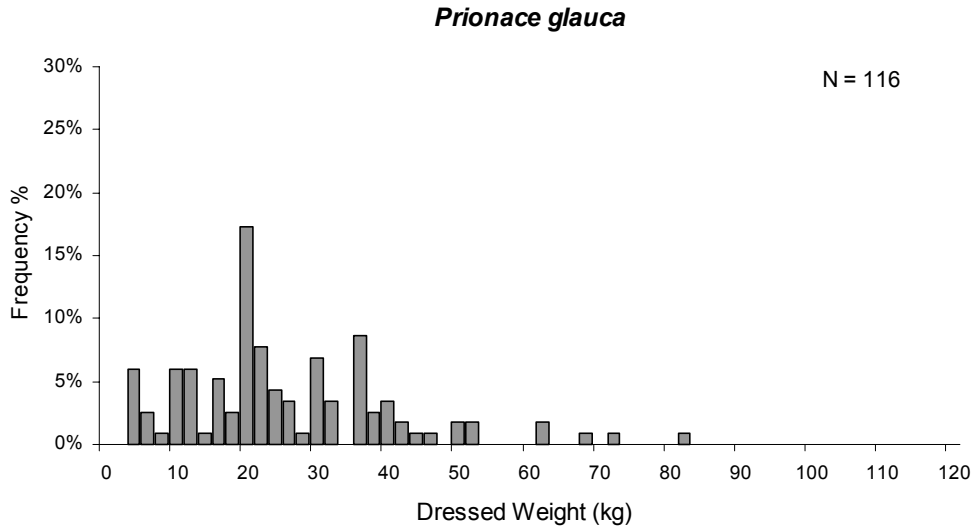

Figure 3. Weight (DW) frequency distribution for blue shark (*Prionace glauca*) sampled in the eastern Mediterranean Sea during 1998-2001.

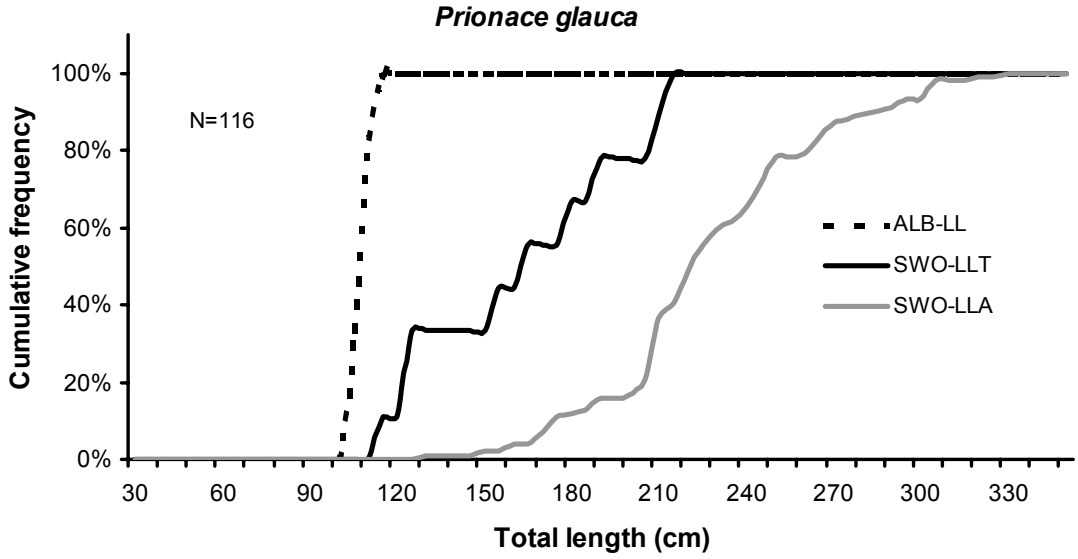

Figure 4. Cumulative total length frequency distribution for blue shark by fishing gear in the eastern Mediterranean Sea

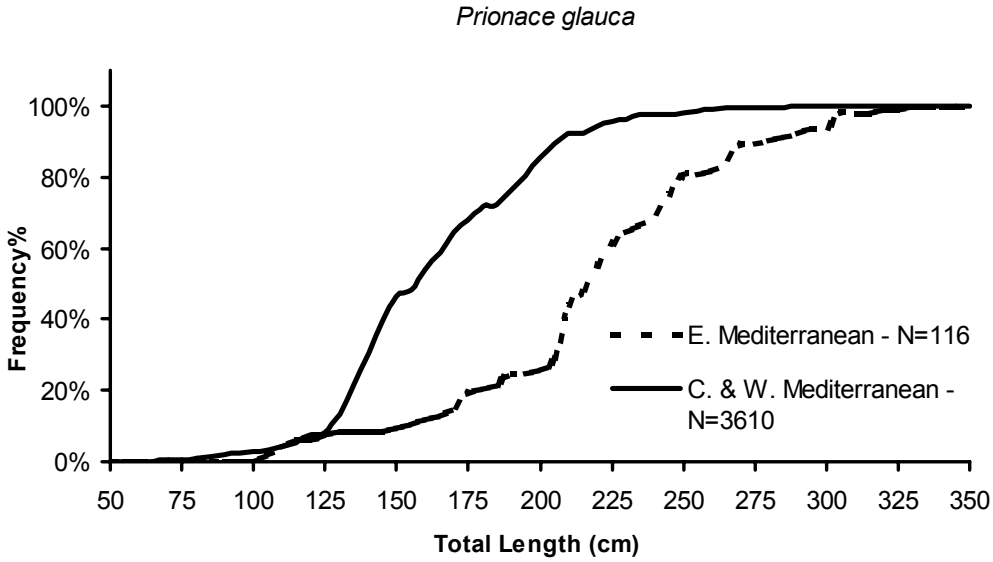

Figure 5. Cumulative total length frequency distribution for blue shark in the eastern Mediterranean and western Mediterranean Sea.

(Data for the western Mediterranean Sea derived from Megalofonou *et al.*, 2000)