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Portuguese Commercial Fisheries of Swordfish, *Xiphias gladius*

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ABSTRACT

Swordfish (*Xiphias gladius*) plays an important role in Portuguese fisheries. Portuguese commercial swordfish landings were analyzed from 1986 to 2012. Commercial landings of five incidental catches of pelagic sharks—bigeye thresher shark (*Alopias superciliosus*), thresher shark (*Alopias vulpinus*), shortfin mako shark (*Isurus oxyrinchus*), blue shark (*Prionace glauca*), and smooth hammerhead shark (*Sphyrna zygaena*)—were also evaluated for the same period. A total of 653 landings of swordfish (12,625 t) were observed in 62 ports. Annual landings for the fishery generally decreased over time, with a corresponding increase in price per kilogram. The most fished shark was blue shark, with 12,715 t in 48 ports. It was followed by shortfin mako, thresher, smooth hammerhead, and bigeye thresher (with 5113 t, 672 t, 19 t, and 0.45 t, respectively). Lowest landings of swordfish were observed in the first semester of each year, while catch levels of blue sharks were high during the same period. Shortfin mako catches did not raise until 2005. The remaining species studied always displayed lower landings, suggesting that most of them are bycaught.

KEYWORDS

Overfishing; European Union Common Fisheries Policy; catch controls; landings; bycatch; management

Introduction

Fisheries in Portugal are considered a traditional and cultural activity (Hill, 2001), although it does not account for more than 1–2% of the country's gross domestic product. Nevertheless, constitutes one of the main sources of income in some coastal communities, making them almost completely dependent on fishing or activities associated with it (INE, 1998).

Swordfish rank among the highest grossing species in this activity, with numbers matching other great sellers, such as multiple species of tuna (Santos et al., 2002).

Swordfish represents the only species in family *Xiphiidae* and its name derives from the superior jaw prolongation that resembles a long and flat sword (Nakamura, 1985). It is commonly found in the Atlantic, Indian, and Pacific Oceans, tropical, temperate, and sometimes cold waters, including the Mediterranean Sea, the Sea of Marmara, the Black Sea, and the Sea of Azov (Carey, 1981; Nakamura, 1985; Mejuto and Hoey, 1991; Ward et al., 2000). This distribution is associated to a high degree of seasonality, observed in northern latitudes during the summer, which is associated to feeding, and southern latitudes during autumn, which is the time of the year for reproduction (Nakamura, 1985; Mejuto and Hoey, 1991).

Over many years, swordfish fisheries were limited to capture with a spear, and were considered a subsistence fishery by coastal Mediterranean inhabitants. Pelagic longlines did not become a significant operation until the 1980s, mostly having tuna as a target. However, many bycatches of swordfish generated enough interest for it to become a target species (Ward et al., 2000). In 1978 an increment in swordfish captures in the Atlantic Ocean was observed, then justified by an increase in the European market consumption (Anonymous, 2003). In Portugal, swordfish fisheries did not gain notoriety until 1986, despite the fact that the current continental exclusive economic zone, has been exploited by other countries' fleets for many years (Azevedo, 1990).

Nowadays, swordfish is mainly caught by pelagic longlines (Santos et al., 2002). Although the main target of this fishery is swordfish, the Portuguese fleet shows a multispecific fishery that catches very substantial numbers of pelagic sharks and tuna species as well (Ferreira, 1999; Silva 2000; Simões, 2001). Of all sharks bycaught in the longline fishery, blue shark (*Prionace glauca*), shortfin mako shark (*Isurus oxyrinchus*), thresher shark (*Alopias vulpinus*), bigeye thresher shark (*Alopias superciliosus*), and smooth hammerhead shark (*Sphyrna zygaena*) are the most abundant (Simões, 1995; Silva, 2000; Santos et al., 2002; Simões, 2001; Santos and Garcia, 2008). However, while the latter three species are mainly

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bycaught by the swordfish fishery, the first two are also targeted for its commercial value (Correia, 2009).

The main goal of this work is to analyze swordfish landings from 1986 to 2012 throughout the Portuguese shore while also analyzing landings of five bycatch species of this fishery: blue shark, shortfin mako shark, thresher shark, bigeye thresher shark, and smooth hammerhead shark.

Material and methods

The swordfish data and their bycatch landings was provided by the Direção-Geral de Recursos Naturais, Segurança e Serviços Marítimos (DGRM, i.e., Portuguese Fisheries Board), which in turn had its origin from multiple fishing ports, administered by the government owned company Docapesca (Correia, 2009). The data correspond to the period from 1986 to 2012 and were grouped as follows: year, month, fishing port, species, weight (kg), and mean selling price (€/kg). The mean selling price refers to the "first sale" price at the fishing docks, immediately after landing.

The sum of these gross values allowed for the calculation, for each species (e), of total weight (TLW) and respective mean price (MSP) landed by year (y), equation 1 and 2, by month (m), equation 3 and 4, and by fishing port (p), equation 5 and 6, in kilograms and percentage. Calculation of MSP had into consideration the total number of landings records (n).

$$\mathrm{TLW(kg)} = \sum_{y=1986}^{2012} \sum_{e=A.\ superciliosus}^{X.\ gladius} kg_y kg_e \tag{1}$$

$$\mathrm{MSP} = \frac{\sum_{y=1986}^{2012} \sum_{e=A.\ superciliosus}^{X.\ gladius} €_y €_e}{n_e} \tag{2}$$

$$\mathrm{TLW(kg)} = \sum_{m=January}^{December} \sum_{e=A.\ superciliosus}^{X.\ gladius} kg_m kg_e \tag{3}$$

$$\mathrm{MSP} = \frac{\sum_{m=January}^{December} \sum_{e=A.\ superciliosus}^{X.\ gladius} €_m €_e}{n_e} \tag{4}$$

$$\mathrm{TLW(kg)} = \sum_{p=Água\ de\ pau}^{Zambujeira} \sum_{e=A.\ superciliosus}^{X.\ gladius} kg_p kg_e \tag{5}$$

$$\mathrm{MSP} = \frac{\sum_{p=Água\ de\ pau}^{Zambujeira} \sum_{e=A.\ superciliosus}^{X.\ gladius} €_p €_e}{n_e} \tag{6}$$

As some fishing ports did not have sufficient data to perform the analysis, these were excluded from the remaining calculations as such, only those fishing ports with more than 50 registered landings for species *Xiphias gladius, Isurus oxyrinchus*, and *Prionace glauca* were considered. Also, only fishing ports with a minimum of 25 registered landings for *Alopias vulpinus* and a minimum of 20 landings for *Sphyrna zygaena* were considered. Similarly, the monthly analysis for *Alopias superciliosus* was excluded because of insufficient data.

Analysis of variance (ANOVA) or Kruskal–Wallis (Zar, 2010) nonparametric tests (depending on the violation or not of the normality and homogeneity of variance assumptions) were applied to compare mean weight (kg) and selling price (€/kg) between years, months, and fishing port (that is, each variable was analyzed by year, month and fishing port separately). Games-Howell and Bonferroni tests were performed as a post-hoc test when significant differences were observed (Zar, 2010). All data were transformed (log(x+1)) to normalize data sets distribution and to equalize variances between groups (Legendre & Legendre, 1979; Underwood, 1997). Differences at p value ≤ 0.05 level were accepted as significant. All statistical analysis was done using IBM SPSS Statistics for Windows, version 21.0.

Results

Annual analysis

Data processing of swordfish yielded a total of 12,625,112 kg landed during the timeline studied. This quantity corresponds to a mean price of 4.82 €/kg. The first number allowed to infer average landings of 467,596 kg per year ($n = 27$). The annual analysis revealed that there are statistically significant differences in the quantity landed and on mean price (Kruskal–Wallis test followed by Games-Howell, p value ≤ 0.05). Figure 1A displays a general trend of increasing landings until 1995 (maximum = 1,029,310 kg), a decreasing trend after 1996 and a generally upward trend in mean price, except in the last 4 years of the series, where this patterns reverses.

A total of 12,715,330 kg landed was calculated to the *Prionace glauca* data, which corresponds to a mean price of 0.79 €/kg. This corresponds to annual mean landings of 470,938 kg per year ($n = 27$). Data analysis of annual landings revealed statistically significant differences in both quantities landed and mean price (Kruskal–Wallis test followed by Games-Howell, p value ≤ 0.05). Annual landings for this species presented a predominantly ascending pattern, particularly between 1986 and 1997 (Figure 1B). There are some unusually high peaks in 2002, 2003, 2005, and 2006 and also a steady rise after 2009. Price increased slowly until 1997, after which it suffered a strong increase. In 1997, 2004, and 2009, there were substantial increases in mean price.

Treatment of *Isurus oxyrinchus* data yielded a total of 5,113,006 kg landed, which corresponds to a mean price of 2.73 €/kg. This corresponds to annual mean landings of 189,371 kg ($n = 27$). Annual analysis

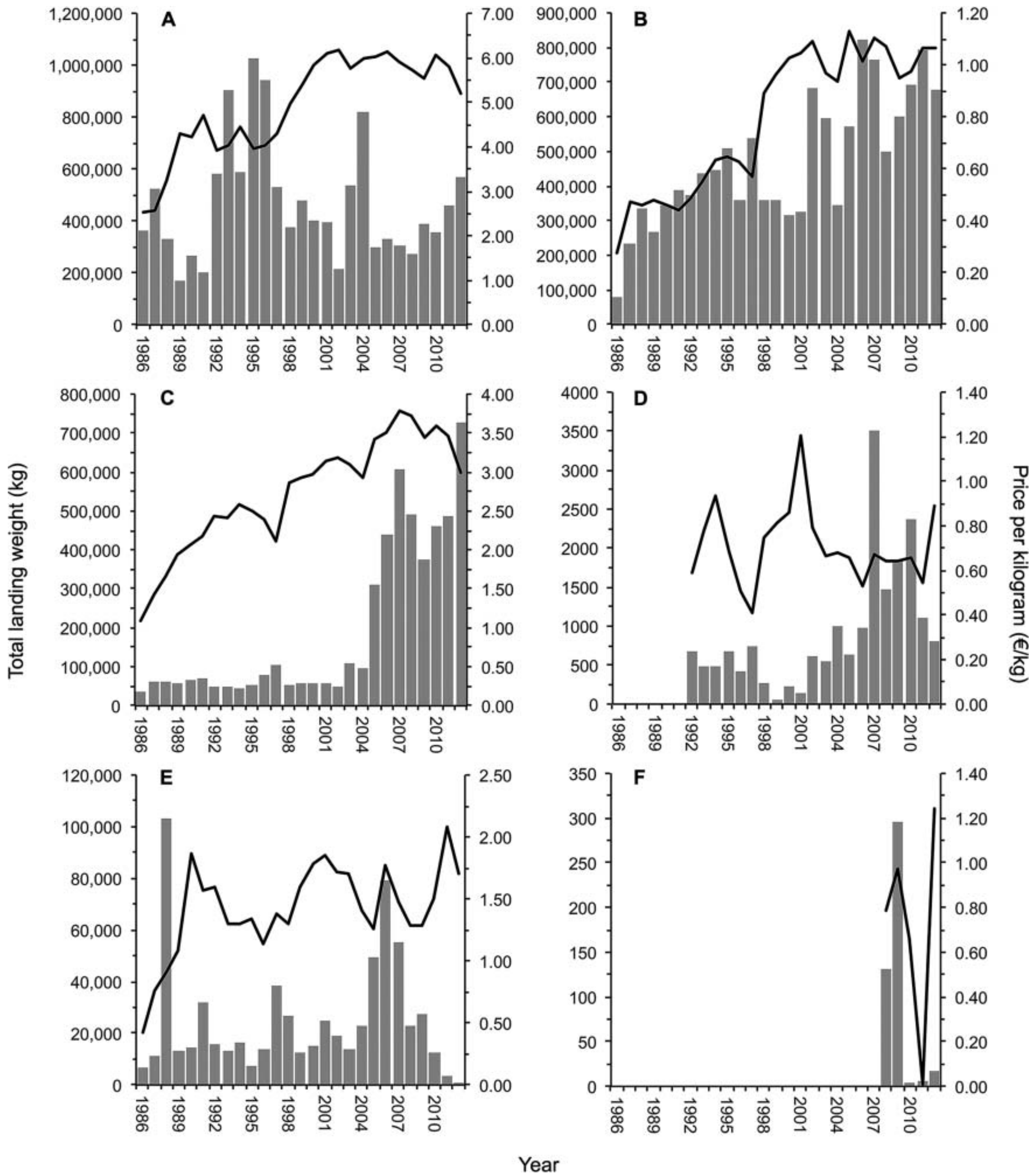

Figure 1. Annual landings of *Xiphias gladius* (a), *Prionace glauca* (b), *Isurus oxyrinchus* (c), *Sphyrna zygaena* (d), *Alopias vulpinus* (e), and *Alopias superciliosus* (f) and respective mean price (line) from 1986 to 2012.

showed that there are statistically significant differences in the quantity landed and mean price (Kruskal–Wallis test followed by Games-Howell, p value ≤ 0.05). Annual landings (Figure 1C) show low values until 2004 and a very steep increase in the last 8 years of the time interval.

A total of 19,021 kg landed was displayed to *Sphyrna zygaena* data, which corresponds to a mean price of 0.71 €/kg. This corresponds to annual mean landings of 906 kg ($n = 21$). The first record of landings of this species occurred only in 1992. Annual analysis revealed no statistical differences in quantity landed (ANOVA, p value > 0.05) as well as in mean price (Kruskal–Wallis, p value > 0.05). Landings of *Sphyrna zygaena* (Figure 1D) vary greatly from year to year, presenting no definite pattern. Despite the decrease observed in 2011 and 2012, the last 7 years have been characterized by increased catches of this species. Note that such increase was accompanied by a decrease in swordfish catches… During the whole analysis, the mean price remained relatively low.

Landings of *Alopias vulpinus* yielded a total of 672,480 kg, which corresponds to a mean price of 1.42 €/kg. This corresponds to mean annual landings of

24,907 kg ($n = 27$). Annual analysis showed no statistically significant differences in quantity landed and mean price (Kruskal–Wallis test followed by Games-Howell, p value ≤ 0.05). Annual landings (Figure 1E) are mostly low, although years 1988, 2005, 2006, and 2007 show more substantial catches.

The data of *Alopias superciliosus* revealed a total of 452.65 kg landed, which corresponds to a mean price of 0.73 €/kg. This corresponds to annual mean landings of 90.53 kg ($n = 5$). Annual analysis showed no statistically significant differences in quantity landed or in mean price (ANOVA, p value > 0.05). This analysis (Figure 1F) revealed that the first record of this species was in 2008 and the landings were always in low numbers.

Monthly analysis

Monthly landings of swordfish are shown in Figure 2A. In general, the results revealed statistically significant differences both in monthly quantity landed (Kruskal–Wallis test followed by Games-Howell, p value ≤ 0.05) and mean price (ANOVA followed by Bonferroni test, p value ≤ 0.05). The analysis thus showed that catches of this species are lower during the first semester of each year, resulting in a seasonal pattern.

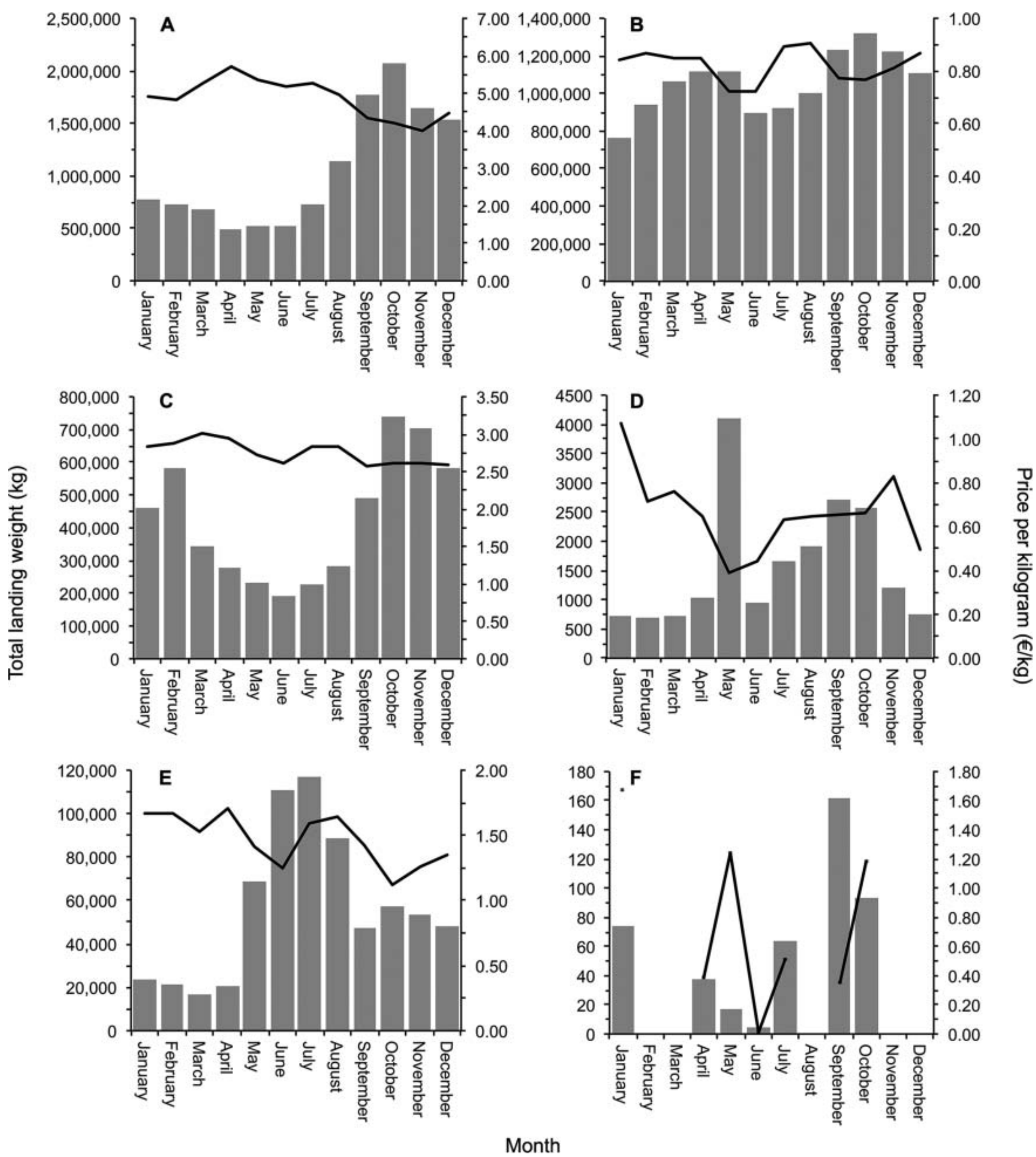

Figure 2. Monthly landings of *Xiphias gladius* (a), *Prionace glauca* (b), *Isurus oxyrinchus* (c), *Sphyrna zygaena* (d), *Alopias vulpinus* (e), and *Alopias superciliosus* (f) and respective mean price (line) from 1986 to 2012.

Results on *Prionace glauca* monthly analysis (Figure 2B) revealed statistically significant differences both in quantity landed (Kruskal–Wallis test followed by Games-Howell, p value $\leq$ 0.05) and mean price (ANOVA followed by Bonferroni test, p-value $\leq$ 0.05). This analysis shows that catches of blue sharks tend to increase twice in the year, from January to May and from August to November. October showed the maximum weight landed.

Regarding *Isurus oxyrinchus* the monthly differences were not statistically significant for quantity landed (Kruskal–Wallis, $p >$ 0.05) nor mean price (ANOVA, p value $>$ 0.05). Although statistically significant differences have not been detected, the results showed a noticeably lower catches during the summer season (Figure 2C).

Monthly landings of *Sphyrna zygaena* showed statistically significant differences in terms of quantity landed and mean price (ANOVA followed by Bonferroni test, p value $\leq$ 0.05). This analysis also revealed that there is a marked increase in catches from July to October (Figure 2D), with a peak catch in May.

Data analysis of *Alopias vulpinus* revealed no statistically significant differences in quantity landed (Kruskal–Wallis test, p value $>$ 0.05). Nevertheless, mean price revealed statistically significant differences (Kruskal–Wallis test followed by Games-Howell, p value $\leq$ 0.05), showing a substantial increase in catches during the warm season. On the other hand, landings tend to decrease during the cold season (Figure 2E).

Fishing port analysis

Analysis by fishing port allowed the identification of 62 ports with swordfish landings. There were statistically significant differences in the results (Kruskal–Wallis test followed by Games-Howell, p value $\leq$ 0.05) between fishing ports, with landings more abundant along some specific fishing ports, such as Peniche (45.4%), Ponta Delgada (24.4%), and Sesimbra (13.1%).

The fishing port data of *Prionace glauca* allowed the identification of 48 ports of landings.. This shark is abundantly landed across the Portuguese coast, particularly in Peniche (41.9%) and Sesimbra (34.9%). These results showed statistically significant differences (Kruskal–Wallis test followed by Games-Howell, p value $\leq$ 0.05).

Data analysis of *Isurus oxyrinchus* allowed the identification of 43 fishing ports of landings and results revealed statistically significant differences (Kruskal–Wallis test followed by Games-Howell, p value $\leq$ 0.05). Landings of this shark are not particularly abundant along the Portuguese coast, but reach significantly higher numbers in Peniche (52.7%), Sesimbra (34.5%), Olhão (4.5%), and Ponta Delgada (3.6%).

Analysis of *Sphyrna zygaena* allowed for the identification of only nine fishing ports with landings. Results showed statistically significant differences in quantity landed (ANOVA followed by Bonferroni test, p value $\leq$ 0.05) and respective mean price (Kruskal–Wallis test, p value $\leq$ 0.05). These landings revealed low abundance all over the country. Regarding to the fishing ports of Ponta Delgada (36.9%), Funchal (28.0%), Horta (Santa Cruz) (14.0%), and Praia da Vitória (10.2%), they revealed particularly high numbers.

Analysis of *Alopias vulpinus* allowed for the identification of 25 landing fishing ports and showed statistically significant differences both in quantity and mean price (Kruskal–Wallis test followed by Games-Howell, p value $\leq$ 0.05). Landings of this shark are not particularly abundant in Portugal. On the other hand, the fishing ports Olhão (39.6%), Sesimbra (24.0%), Peniche (20.9%), and Tavira (9.3%) showed the highest values.

Data analysis of *Alopias superciliosus* revealed landings in two fishing ports, namely, São Mateus (50.8%) and Ponta Delgada (49.2%), both in Azores. The results showed no statistically significant differences in quantity landed and mean price (ANOVA, p value$>$ 0.05).

Discussion

Swordfish annual landings showed an irregular pattern, with an increase in captures in the 90s and a decrease after 1996. The increase in captures of swordfish observed in the 90s is mostly due to a substantial increase in fishing effort as a result of this species' market consumption expansion (Guerreiro, 2005). The decrease in catches after 1996 is most likely related to ICCAT (International Commission for the Conservation of Atlantic Tuna) regulations, specifically the imposition of a 1400 t quota to Portugal (ICCAT, 2011). Another possible cause for this downward trend could be the displacement of fishing effort from the North Atlantic to the South Atlantic, which began in the 80s (Chang et al., 2013). Mean price shows a strong inversed correlation to landings, as expected in a standard supply and demand relationship for a species with commercial value (Copes, 1970). The monthly landings pattern was confirmed by Santos et al. (2002), which analyzed logbooks supplied directly by swordfish longliners. These authors reached similar conclusions and also found that catches were relatively higher from September to November, with landings peaking in October. The analysis of mean price also revealed a supply and demand pattern, as reported by Copes (1970), that is, prices increasing when landings decreased and vice-versa. The fishing ports of Peniche, Ponta Delgada, and Sesimbra recorded the highest values of swordfish landings. This is mostly due to the fact that the fleet of surface longliners is mostly based in these fishing ports (Correia, 2009).

There are some unusually high peaks on blue shark annual landings, either in catches or in mean price. In 1997, 2004, and 2009 there were substantial increases in mean price, which suggests that the demand for this species was not particularly strong until 1997, after which it increased steadily, especially in the last 9 years of the series. Note that this species is mainly a bycatch of swordfish fisheries and for a long time it was marketed as swordfish, mostly due to this species' quota being overrun (Santos et al., 2002; Correia, 2009). These results suggest that, as swordfish catches decrease because of their over-exploited state, catches of blue shark increment, assuming a better commercial role (Correia, 2009). Monthly analysis recorded a peak of catches from August to November which coincides with the increasing catches of swordfish which, once again, shows that blue shark is one of the more relevant bycatches of this species. The increase in catches during the first semester can be justified by the change of fishing effort directed from swordfish to pelagic sharks, such as blue shark, since this period of the year corresponds to a traditional low abundance of swordfish (Santos et al., 2002). As observed in a study of elasmobranch landings in Portugal (Correia, 2009), the blue shark is abundantly landed across the Portuguese coast, particularly in Peniche (41.9%) and Sesimbra (34.9%), where surface longline fleets, targeting *Xiphias gladius*, are based. Already several authors indicated the blue shark as the main bycatch in longline fisheries targeting swordfish in several areas of the world. Mejuto et al. (2006) estimated the bycatch of the Spanish longline fleet targeting swordfish was approximately 75.3%, in which 70.3% were large sharks. 86.3% corresponds to *Prionace glauca*.

As stated above, annual landings of shortfin mako shark show relatively low numbers until 2004 and a very steep increase in the last 8 years of the time series. This is most likely related to a marked increase in consumption, which is corroborated by the increase in price and values involved, as no other elasmobranch species reach prices as high as shortfin mako shark. Additionally, the increase in shortfin mako and blue shark landings could be related to a decrease in swordfish catches (Correia, 2009). The surge in 2004, coupled with a spike in price, further supports this supposition. However monthly analysis of this species' landings reveals substantially lower catches during summer, which could be related to a potential migratory pattern, whereby these animals mostly occur in those waters where surface longliners are operating during winter months. This pattern echoes that which was previously observed for swordfish and blue shark; therefore, an additional factor corroborating this is also a major incidental swordfish bycatch. Authors such as Santos et al. (2002) and Mejuto et al. (2009) previously reported that this species is the second most landed pelagic shark fished by longliners focused on swordfish fisheries, following the blue shark. This is also associated with the fishing ports that have more landings of this shark, are the same that have a strong surface longline fleet targeting swordfish.

The first landing record of smooth hammerhead was in 1992. That may happen because in the years before all hammerhead sharks were identified as *Sphyrna* sp. (Correia, 2009). Although there are no statistical differences in annual quantity landed of smooth hammerhead as well as in mean price, presenting no definite annual pattern, the increase of the last 7 years of the time accompanied the decrease in swordfish catches. Mejuto et al. (2009) also indicates this species as a bycatch of swordfish fisheries, but in much less quantity then those previously mentioned, that is, blue and shortfin mako sharks. Prices are relatively low, suggesting this is an opportunistic catch with residual commercial interest (Correia, 2009). Monthly analysis revealed there is a marked increase in catches from July to October, which follows the pattern of swordfish, therefore, corroborating again that hammerhead sharks are a bycatch of swordfish, as noted by Mejuto et al. (2009). It was also observed a peak catch of *Sphyrna zygaena* in May, potentially validating anecdotal reports that these animals migrate into the Mediterranean sea, by swimming along the Portuguese southwest shoreline, around this time of the year. The reason why these sharks are landed in the fishing ports seen above has not yet been the subject of a study but is most likely related to the abundance of this species in the fishing grounds regularly worked by these vessels. Since landings of this species are not particularly abundant anywhere, it is assumed they are bycaught and not targeted.

Thresher shark is also regarded as a classically bycaught species, hence the lack of patterns in its catches throughout time (Okamoto and Bayliff, 2003). The annual analysis of mean price reveals prices that are above those of other species, typically under 1.0 €/kg. Therefore Correia (2009) suggests that this species could have some commercial interest, albeit its predominantly bycaught status. Monthly analysis clearly shows a substantial increase in catches during the warm season, whereas in the cold season its landings tend to decrease. This may indicate that this species migrates to the fishing grounds where the fleet is operating for feeding during summer months, which was also shown to occur in the Pacific Ocean (Preti et al., 2001). As expected, the fishing ports that have highest landings values of thresher shark have a predominantly "polyvalent" fleet, which traditionally includes vessels operating longlines and/or gillnets (Correia, 2009). The low numbers landed suggest, however, that this species is mostly bycaught and not actively targeted.

Bigeye thresher shark annual analysis revealed that the first record of this species was in 2008, which means *Alopias superciliosus* were most likely landed as *Alopias vulpinus* or *Alopias* sp. before that, as noted by Correia (2009). The low numbers in landed values suggest, as with the previous species, that this species is mostly bycaught and not targeted. The few monthly and fishing port data available for this species also strongly suggests this species is often misidentified and not targeted, being mostly bycaught, as noted also by Simões (1995).

Swordfish shows a particular economic impact in Portugal and is therefore worthy of considerable attention by Fisheries Officials, legislation and even academia. This is a species that also requires special attention in light of its conservation status and in need of constant adjustment of all management measures applied to it, to ensure sustainability of its catch.

While an effort in discerning different species in official fisheries records, such as *Alopias vulpinus* and *Alopias superciliosus*, is noticeable, additional effort is required to ensure swordfish are indeed landed as such and not as other species, such as blue shark or even mako shark, to keep quotas short of closing. These results also strongly suggest that further study of these latter two species is also recommended, as their landings are reaching substantial values.

Observer programs already implemented to monitor the swordfish fishery should therefore also focus on all pelagic bycaught shark species, namely the two most abundant, blue and mako sharks.

This may well be the only way to ensure a proper sustainable use of these resources in Portuguese, and indeed, European waters.

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