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Effects of hook and bait on bycatch and target catches in a Southern Atlantic swordfish longline fishery

Sérgio Luís Martins e Amorim

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Mestrado em Recursos Biológicos Aquáticos
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Todas as correções determinadas pelo júri, e só essas, foram efetuadas.

O Presidente do Júri,

Porto, ______/______/________

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ABSTRACT

Bycatch is a major problem in commercial fisheries. Despite pelagic longline being more selective than other fishing gears (e.g. trawl and driftnets) a wide variety of sea “megafauna” is caught, namely sea turtles and sharks. The present dissertation examined the effects of different hook styles and bait types combinations on the: i) sea turtle bycatch composition, bycatch rates and mortality and ii) catches of target, bycatch and discarded fishes from a Portuguese commercial longline fishery targeting swordfish in the South Atlantic Ocean. A total of 310 experimental longline sets were made between October 2008 and February 2012. Three different hook styles and two bait types were tested: the traditional J hook (9/0) 10º offset was compared to two 17/0 circle hooks (a non-offset and a 10º offset) and mackerel (*Scomber* spp.) bait was compared to squid (*Illex* spp.). Two species of sea turtles were caught, the leatherback (*Dermochelys coriacea*) and the loggerhead (*Caretta caretta*) with the latter comprising the majority of the catches. The highest mean bycatch per unit effort (BPUE) values for both species combined (1.693/1000 hooks) and for the individual species (1.505/1000 hooks for loggerheads) occurred with J-style hooks baited with squid. Hooking location was species-specific, with most loggerheads hooked by the mouth, while leatherbacks were mostly hooked externally by the flippers. Overall, 65% of all sea turtles were released alive (85% for leatherbacks compared to 63% for loggerheads). For the retained catch the effect of the different hook-bait combinations was species-specific, with bait being far more important than hook style. For the target species, swordfish (*Xiphias gladius*), the catch per unit effort (CPUE) was higher with J hooks baited with squid. However, for the elasmobranchs bycatch, particularly blue shark (*Prionace glauca*), the opposite effect was observed (higher catches with circle hooks baited with mackerel). For the discarded species, the at-haulback mortality was also species-specific, with the proportions of alive *versus* dead specimens of the protected bigeye tresher shark (*Alopias superciliosus*) varying significantly by hook style. Significant reduction of accidental sea turtle catches on the swordfish longline fisheries can be achieved by changing from J hooks to circle hooks, especially if baited with mackerel. However, such gear changes results in lower catch rates of swordfish and increases the catches of elasmobranchs. Therefore, from the fisheries management point of view, it is essential to assess the consequences of such gear modifications in a wider scale, prior to the implementation of the mandatory use of circle hooks on this fishery.

Key-words: pelagic longline; circle hooks; bait types; bycatch; sea turtles; swordfish

RESUMO

A captura acidental é um problema grave da pesca comercial. Apesar do palangre pelágico ser mais seletivo do que muitas outras artes de pesca (ex. redes de arrasto e redes de deriva) uma grande variedade de “megafauna” marinha é capturada, nomeadamente tartarugas marinhas e tubarões. A presente dissertação examinou os efeitos de diferentes combinações de anzóis e iscos na i) composição, taxas de captura acessórias e mortalidade de tartarugas marinhas e ii) capturas-alvo, capturas acessórias e rejeições de peixes de uma pescaria comercial Portuguesa de palangre pelágico dirigido ao espadarte no Atlântico Sul. Um total de 310 lances experimentais foram efetuados entre Outubro de 2008 e Fevereiro de 2012. Três tipos de anzóis e dois tipos de isco foram testados: o tradicional anzol J (9/0) 10º de inclinação foi comparado a dois anzóis 17/0 circulares (um sem inclinação e um com 10º de inclinação) e o isco cavala (*Scomber* spp.) foi comparada com pota (*Illex* spp.). Duas espécies de tartarugas marinhas foram capturadas, a tartaruga-de-couro (*Dermochelys coriacea*) e a tartaruga-comum (*Caretta caretta*), com a última a compreender a maior parte das capturas. Os valores médios das capturas acessórias por unidade de esforço (BPUE) mais elevados para ambas as espécies combinadas (1.693/1000 anzóis) e para as espécies individuais (1.505/1000 anzóis para a tartaruga-comum) ocorreram para os anzóis J iscados com pota. A localização do anzol foi espécie-específico, com a maioria das tartarugas-comum a serem capturadas pela boca, enquanto as tartarugas-de-couro foram na sua maioria capturadas externamente pelas barbatanas. No total, 65% das tartarugas marinhas foram rejeitadas vivas (85% para as tartarugas-de-couro em comparação com 63% para a tartaruga-comum). Para as capturas retidas a bordo o efeito das diferentes combinações anzol-isca foi espécie-específico, com a isca a ser bem mais importante do que o tipo de anzol. Para a espécie-alvo, espadarte (*Xiphias gladius*) a captura por unidade de esforço (CPUE) foi maior com os anzóis J iscados com pota. Contudo, para as capturas acessórias de elasmobrânquios, particularmente o tubarão-azul (*Prionace glauca*) foi observado o efeito oposto (capturas mais elevadas com anzóis circulares iscados com cavala). Para as espécies rejeitadas a mortalidade aquando da alagem também foi espécie-específico com as proporções de espécimes vivos *versus* mortos do protegido tubarão raposo-olhudo (*Alopias superciliosus*) a variar significativamente com o tipo de anzol. Reduções significativas nas capturas acidentais de tartarugas marinhas podem ser alcançados, mudando de anzóis J para anzóis circulares, especialmente se iscados com cavala. Contudo tal mudança de aparelho resulta em menores capturas de espadarte e um aumento das capturas de elasmobrânquios. Assim, do ponto de vista de gestão das pescas, é essencial analisar as consequências da alteração do aparelho de pesca numa maior escala, antes da implementação obrigatória dos anzóis circulares na pescaria de palangre pelágico dirigido ao espadarte no Atlântico sul.

Palavras-chave: palangre pelágico; anzóis circulares; tipos de isca; capturas acessórias; tartarugas-marinhas; espadarte

TABLE OF CONTENTS

Acknowledgments i
Abstract iii
Resumo iv
Table of Contents vi
List of Figures viii
List of Tables xi
General Introduction and Objectives 1
CHAPTER I – FISHERIES AND RESOURCES 4
1.1. The pelagic longline fishery 5
1.1.1. Brief history of pelagic longline gear 5
1.1.2. Characteristics of the pelagic longline gear 5
1.1.3. The catch: Target and bycatch species 7
1.2. Evolution of the Swordfish fisheries and global trends 8
1.2.1. Global evolution of the swordfish fisheries 8
1.2.2. Overview of the global trends of swordfish landings 9
1.2.3. Longline swordfish fisheries in the Atlantic Ocean and Mediterranean Sea 11
1.3. The Portuguese pelagic longline fishery 12
1.3.1. Evolution of fisheries and catches of swordfish by the Portuguese fleet 12
1.3.2. Description of the swordfish pelagic longline gear 16
1.4. Mitigation of incidental catches 17
CHAPTER II – MATERIAL AND METHODS 20
2.1. Study design and data collection 21
2.2. Data Analysis 24
2.2.1. Data analysis for sea turtles 25
2.2.2. Data analysis for fishes 26
CHAPTER III – EFFECTS OF HOOK AND BAIT ON SEA TURTLES BYCATCH 28

3.1. Introduction and objectives....29
3.2. Results....30
3.2.1. Description of the incidental bycatch....30
3.2.2. Bycatch rates....30
3.2.3. Bycatch at size and hooking location....34
3.2.4. Mortality....36
3.3. Discussion....38
CHAPTER IV – EFFECTS OF HOOK AND BAIT ON FISH CATCHES....43
4.1. Introduction and objectives....44
4.2. Results....45
4.2.1. Catch composition....45
4.2.2. Effects of hook and bait on retained catches....46
4.2.3. Size distribution of retained catch....52
4.2.4. Catch rates and mortality of discarded species....54
4.3. Discussion....57
General Conclusions....64
References....66
Annexes....80

List of Figures

Figure 1.1 - Set characteristics for “shallow-set” and “deep-set” pelagic longline gear (Source: Crowder and Myers, 2001).

Figure 1.2 - Global swordfish landings from 1950 to 2010 (Source: FAO, 2012).

Figure 1.3 - Global swordfish landings (10 years period) by Ocean (Source: FAO, 2012).

Figure 1.4 - Swordfish landings in the Atlantic Ocean and Mediterranean Sea (Source: Anon., 2012).

Figure 1.5 - Estimated catches (MT) of swordfish (*Xiphias gladius*) in North and South Atlantic Ocean by the Portuguese pelagic longline fleet (Source: Anon., 2012).

Figure 1.6 - Proportion of swordfish landings by Ocean basin of the Portuguese pelagic longline fishery from 1950 to 2010 (Source: FAO, 2012).

Figure 1.7 - Schematic drawing of the swordfish pelagic longline fishing gear (Source: adapted from Santos *et al*., 2013).

Figure 2.1 - Study area and location of the 310 experimental longline sets in the Southern Atlantic region.

Figure 2.2 - Photograph of the three hook styles used during this study: (A) J – 10º offset 9/0 hook; (B) GT – 10º offset 17/0 circle hook; and (C) G – non-offset 17/0 circle hook. Hook measurements and terminology in Table 2.1.

Figure 3.1 - Spatial distribution of BPUE by longline experimental set, for turtle species combined (top), loggerhead (TTL - *C. caretta*, middle) and leatherback (DKK - *D. coriacea*, bottom).The size of the circles is proportional to the BPUE and the dark crosses represent fishing sets with 0 catches.

Figure 3.2 - Plot of the mean BPUE (with the respective standard errors) observed with the different hook styles (J, G and GT) and bait types combinations, for the species combined, loggerheads (TTL - *C. caretta*) and leatherbacks (DKK - *D. coriacea*). On the bait type, M refers to mackerel and S refers to squid.

Figure 3.3 - Hooking location per hook style (left) and bait type (right) for all species combined, loggerhead (*C. caretta*) and leatherback (*D. coriacea*). The bars refer to the percentage of each hooking location within each hook style or bait type. Numbers between brackets refer to the corresponding nominal catch of each hook style or bait type.

Figure 3.4 - Boxplots with the size distribution (median, inter-quartil range, non-outliers range and outliers) for loggerhead (*C. caretta*), for each of the three factors considered (bait type, hook style and hooking location).

Figure 3.5 - Percentage of fishing mortality at-haulback per hooking location (left), hook style (center) and bait type (right), for all species combined (top), loggerhead (*C. caretta*, middle) and leatherback (*D. coriacea*, bottom). The numbers between brackets refer to the corresponding nominal catch for each hooking location, hook style or bait type.

Figure 4.1 - Spatial distribution of CPUE by longline experimental set, for swordfish (SWO - *X. gladius*). The size of the circles is proportional to the CPUE and the dark crosses represent fishing sets with 0 catches.

Figure 4.2 - Spatial distribution of CPUE by longline experimental set, for blue shark (BSH - *P. glauca*). The size of the circles is proportional to the CPUE and the dark crosses represent fishing sets with 0 catches.

Figure 4.3 – Plot of the mean CPUE (with the respective standard errors) observed with the different hook styles (J, G and GT) and bait types (Squid and Mackerel) combinations for swordfish (*Xiphias gladius*).

Figure 4.4 - Plot design of the catch per unit effort (CPUE, Kg/1000 hooks) by the different hook styles (J, G and GT) and bait types (Squid and Mackerel) for the three tuna species: albacore tuna (*Thunnus alalunga*), bigeye tuna (*Thunnus obesus*), and yellowfin tuna (*Thunnus albacares*). The vertical lines represent the range of values while the horizontal line represents the overall mean across all observations. Bait effect was significant (*) for the three species and hook effect was only significant for albacore tuna.

Figure 4.5 - Plot design of the observed catch per unit effort (CPUE, Kg/1000 hooks) by the different hook styles (J, G and GT) and bait types (Squid and Mackerel) for four teleost bycatch species in the fishery: blue marlin (*Makaira nigricans*), white marlin (*Kajikia albida*),

dolphinfish (*Coryphaena hippurus*) and escolar (*Lepidocybium flavobrunneum*). The vertical lines represent the range of values while the horizontal line represents the overall mean across all observations. Bait effect was significant (*) for all species with exception for escolar were only hook effect was significant.

Figure 4.6 - Plot design of the observed catch per unit effort (CPUE, Kg/1000 hooks) by the different hook styles (J, G and GT) and bait types (Squid and Mackerel) for the three main elasmobranch bycatch species in the fishery: blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*) and longfin mako (*Isurus paucus*). The vertical lines represent the range of values while the horizontal line represents the overall mean across all observations. Bait and hook effect were only significant (*) for blue shark.

Figure 4.7 - Boxplots with the size distribution (median, inter-quartil range, non-outliers range and outliers) for the species bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) for each hook style.

Figure 4.8 - Boxplots with the size distribution (median, inter-quartil range, non-outliers range and outliers) for the species swordfish (*Xiphias gladius*), yellowfin (*Thunnus albacares*), albacore (*Thunnus alalunga*), blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) for each bait type.

Figure 4.9 – Mosaicplot of the percentage of alive versus dead specimens at-haulback for the most frequently discarded species: lancetfish (*A. ferox*), bigeye thresher shark (*A. superciliosus*), pelagic stingray (*P. violacea*), and crocodile shark (*P. kamoharai*). Hook effect was significant (*) for lancetfish and bigeye thresher shark.

List of Tables

Table 1.1 - General parameters and measurements of the Portuguese pelagic longline fishing gear (American-style).

Table 2.1 - Hook measurements and terminology of the different hook styles used in the study. The mean size of the hook parameters is based on the measurement of 50 hooks of each style. Standard deviation is indicated within parentheses.

Table 2.2 - List of fish species, with FAO codes, common names, scientific names (with authority) and category. In the category, T-B refers to targeted bony fish species; BC-B to bony fish bycatch; BC-E to elasmobranch bycatch; D-B to bony fish discards and D-E to elasmobranch discards

Table 3.1 - Percentage of sets with zero sea turtle incidental catches obtained with the different combination of hook style (J – 10º offset 9/0 hook; G – non-offset 17/0 circle hook; GT – 10º offset 17/0 circle hook) and bait type (S – squid; and M – mackerel) tested, for species combined and for the two sea turtle species incidentally caught.

Table 3.2 - Ratio between the mean BPUE obtained with the standard fishing gear (J hook baited with squid - control) and the different combinations of hook style (J – 10º offset 9/0 hook; G – non-offset 17/0 circle hook; GT – 10º offset 17/0 circle hook) and bait type (S – squid; and M – mackerel) tested, for species combined and for the two sea turtle species caught.

Table 3.3 - Odds-ratios, with the respective 95% confidence intervals, for the effects of changing hook style and bait type in the loggerhead (*Caretta caretta*) BPUE, accounting for the model interactions.

Table 4.1 - Mean catch per unit effort (CPUE, kg/1000 hooks) with respective standard deviation in parentheses for the various hook-bait combinations. J = 10º offset 9/0 hook; G = non-offset 17/0 circle hook; GT = 10° offset 17/0 circle hook. P-values are from Mann-Whitney tests comparing bait types and the Kruskal-Wallis tests comparing hook styles. p<0.05 are in bold. NT = not tested.

Table 4.2 - Coefficients for the swordfish (A) and blue shark (B) CPUE Tweedie GLM with the respective odds-ratios, considering the covariates hook style and bait type. The parameter estimation of the model, the standard errors (SE), the Wald Statistic (Wald) and the respective p-values are presented. For the odds-ratios the point estimate with the lower and upper 95% confidence intervals (CI) are listed.

Table 4.3 - Mean (standard deviation) size (LJFL and FL, in cm) for the species: swordfish (*Xiphias gladius*), bigeye (*Thunnus obesus*), yellowfin (*Thunnus albacares*), albacore (*Thunnus alalunga*), blue marlin (*Makaira nigricans*), blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*). P-values refer to the Mann-Whitney tests comparing sizes with different baits and the Kruskal-Wallis tests comparing sizes with different hooks. J = 10º offset 9/0 hook; G = non-offset 17/0 circle hook; GT = 10° offset 17/0 circle hook. p<0.05 are in bold.

Table 4.4 - Mean (standard deviation) catch per unit effort (CPUE, n/1000 hooks) of discarded species for the various hook-bait combinations. P-values refer to the Mann-Whitney tests comparing baits and the Kruskal-Wallis tests comparing hooks. J = 10º offset 9/0 hook; G = non-offset 17/0 circle hook; GT = 10° offset 17/0 circle hook. p<0.05 are in bold. NT = not tested.

Table 4.5 – Percentage of alive versus dead specimens at-haulback for the most frequently discarded species: lancetfish (*A. ferox*), bigeye thresher shark (*A. superciliosus*), pelagic stingray (*P. violacea*), and crocodile shark (*P. kamoharai*). The statistical comparisons refer to Chi-square tests for contingency tables. J = 10º offset 9/0 hook; G = non-offset 17/0 circle hook; GT = 10° offset 17/0 circle hook. p<0.05 are in bold. NT= not tested

GENERAL INTRODUCTION AND OBJECTIVES

Sea fisheries, a primary source of protein for billions of people globally (FAO, 2009) are the major anthropogenic influence on sea systems worldwide, affecting sea animal populations and ecosystem function (Pauly *et al*., 2005). The pelagic longline fishery is the world's most widespread harvest activity, with approximately 5 million baited hooks set each day on 100.000 miles of line throughout the world's oceans (Crowder and Myers, 2001). It is a passive fishing method based on fish attraction by means of bait and can be used from small-scale artisanal fishing boats to modern mechanized vessels.

Pelagic longline fishing evolved in Japan during the 19th and early 20th centuries. Sailboats equipped with hemp longlines would venture as far as 30 nautical miles (nm) offshore from Japan in search of tuna and billfish. By 1912 there were over 100 registered sailboat tuna longliners in Japan and in 1920 the first diesel powered steel longline vessel appear (Beverly *et al*., 2003) expanding the fleet to the rest of the Pacific Ocean in the following decades. Global expansion of longline fisheries began in the 1950's and 1960's with Japanese tuna fleet spreading throughout the Atlantic Ocean and Mediterranean Sea (Watson and Kerstetter, 2006). The swordfish incidental catches of longlines targeting tuna were high, reason that attracted interest for it use and has enabled the development of a directed fishery for this species by the fleets of Canada, United States and Spain in the early 1960's. During the 1980's and 1990's, longliners increased swordfish catches to high levels, driven by the increase of fishing boats and fishing effort. Geographical expansion and improvements in fishing efficiency and targeting (e.g. introduction of monofilament gear, better freezing capacity and electronic aids to navigation and fish finding) contributed to the increase catch rates (Ward *et al*., 2000). Nowadays longlines are used to target many pelagic fish species throughout the world's oceans and are responsible for most of the world's swordfish (*Xiphius gladius*) catches and a large proportion of global tuna (*Thunnus* spp.) catches (Lewison *et al.,* 2004).

Human impacts on the world's oceans are extensive and varied, warranting urgent and comprehensive management of sea resources in many places of the world (Halpern *et al*., 2008). Despite the widespread nature of longline fishing, only from the 1990's there has been global concern about the bycatch of sea turtles, sharks, birds and sea mammals in fishing operations (Lewison *et al.,* 2004). The incidental mortality of these species has been widely held responsible for the declining populations and threatened conservation status of several species (Lewison *et al.,* 2004). Although concerns about impacts of pelagic longlining on both target and non-target species have already led to some changes in management and policy, there are lack of comprehensive and objective assessment of the problem. The knowledge of the status of biodiversity in the high seas is minimal compared with that on land and in coastal waters. Because pelagic longlines have the potential to catch a large number of both target and non-target organisms, some of which are already overfished and/or protected under international treaty's, it is important to evaluate the impact of mitigation procedures on populations that are potentially vulnerable (Crowder and Myers, 2001).

A variety of measures have been developed to reduce the bycatch mortality of sea turtles, sharks and seabirds in pelagic longline fisheries (Gilman *et al.,* 2006). Techniques to address bycatch include: time-area closures; voluntary measures (e.g. moving after a by-catch); bycatch quotas; and more recently circle hooks and bait types intended to reduce both capture rate and post-release mortality (Lokkeborg, 2004; Gilman *et al.,* 2006, Santos *et al*., 2012). Therefore in order to increase the area covered for circle hook studies in the Atlantic Ocean, the Portuguese Fisheries and Aquaculture Directorate and a private fishing company funded a project (SELECT-PAL: "*Redução das capturas acessórias na pescaria de palangre de superfície*") to test the influence of different hook style and bait type combinations on the catch of target and non-target species caught by the Portuguese pelagic longline fishery operating in three major areas in the Atlantic Ocean: North-eastern Tropical, Equatorial and Southern Temperate.

The aim of the present dissertation is to assess the effect of circle hook styles and bait types in reducing the mortality of sea turtles in the Portuguese pelagic longline fishery in Southern Atlantic Ocean. In addition, it was examined the effects of circle hooks and bait types on the catch of target species and on other non-target species taken as bycatch. To achieve the proposed objectives, the present thesis was structured in the following chapters:

- Chapter I focus on the "state of the art" regarding the description of the fishery, including a brief description of the history, characteristics and catch species; evolution of the swordfish fisheries and global trends; characterization of the Portuguese pelagic longline fisheries and; mitigation measures of incidental catches;
- On chapter II it was described the Material and Methods with the description of the study design, data collection and data analysis for sea turtles and fishes.
- Chapter III focuses on the assessment of the effects of hook styles and bait types on sea turtles bycatch, particularly on catch composition by species, hooking location and mortality.

- Chapter IV concentrates on the influence of different hook styles and bait types combinations on the catches of target and non-target fish species, namely in terms of catch composition, catch rates, catch at size, and mortality at-haulback of discarded taxa.

CHAPTER I – FISHERIES AND RESOURCES

1.1. THE PELAGIC LONGLINE FISHERY

1.1.1. Brief history of pelagic longline gear

The most widespread form of pelagic longline gear appears to have been originally developed by the Japanese (Watson and Kerstetter, 2006 and reference therein). The introduction of the internal combustion engine in the early 1900´s, resulted in an expansion of fishing grounds, enabling the Japanese to target albacore in the central Pacific (Watson and Kerstetter, 2006). At the beginning of the 20th century, longline use was documented in the Mediterranean (Watson and Kerstetter, 2006 and reference therein) and in the mid-1940´s an early form of pelagic longline in western North Atlantic was developed to target bluefin tuna (*Thunnus thynnus*) on Stellwagen Bank combining keg-line swordfish harpoon gear and halibut line-trawl (Wilson, 1960). In Norway in the late 1960´s a form of pelagic longline gear which used multifilament synthetic line floated just under the surface of the water was developed, to target porbeagle shark (*Lamna nasus*) (Gibson, 1998). During this period, small vessels using a very similar gear were also fishing swordfish at night off the coast of Cuba (Watson and Kerstetter, 2006 and reference therein). In the course of the 1950´s, the Japanese distance-water longliners operating in the north Pacific started targeting swordfish and albacore (Ward *et al.,* 2000) and during late 1950´s and early 1960´s began the global expansion of longline fisheries. By then, many Japanese distance-water longliners started targeting tuna such as yellowfin and bigeye for sashimi markets throughout the Atlantic (North and South) Ocean and Mediterranean Sea. This expansion was initially driven by the Japanese tuna market and supported by international transportation, freezing technology, emerging markets for swordfish and shark fins that encouraged additional fleet expansion from others countries (Watson and Kerstetter, 2006). Multifilament nylon mainlines still dominate the international fishery, but the development of single-strand monofilament line in the 1970´s and the use of light dispositive (chemical light sticks) resulted in the expansion of the pelagic longline as the primary worldwide method of commercially harvesting of large pelagic fishes (Watson and Kerstetter, 2006).

1.1.2. Characteristics of the pelagic longline gear

Pelagic longline gear is composed of a long length of mainline deployed across the ocean, to which numerous branch lines are attached, being suspended in the water column between regularly spaced floats. A branch line is a single line with a snap at one end and a hook at the other and connects the mainline to a single baited hook, with anywhere from 4 to 30 branch lines (baited hooks) between floats (Swenarton and Beverly, 2004). A typical longline set from a medium-scale longliner would be about 30 to 40 nm long and have about 1200 to 2500 hooks (Beverly *et al*., 2003).

Since the 1970´s longline fishing has evolved due to a better knowledge of vertical distribution of main target species, relationships of catches to temperature, dissolved oxygen, thermocline depth, and other environmental factors (Campbell *et al*., 1997; Hampton *et al*., 1998; Bertrand *et al*., 2002). These fisheries are opportunistic, switching gear style and making subtle changes to the fishing gear configuration to target the best available economic opportunity of each individual trip (Brothers *et al*., 1999). Depending on the target species, pelagic longlines can be set at a variety of depths from the surface layer, down to the thermocline, however even deep-set lines have a high percentage of their hooks (the ones nearest the floats) fishing in shallow water.

Swordfish targeted longline gear, categorized “shallow-set” fishing, deploys surface gear by using usually four to five hooks between floats and no weight on the branch lines (Figure 1.1). Swordfish vessels make ample use of light emitting devices (lighsticks, battery powered light, etc.) placed near the hooks to attract fish (Swenarton and Beverly, 2004). To target “deep-dwelling” species such as bigeye tuna, more hooks are set between floats, small weight may be attached to each branch line, longer floatlines are used and the velocity of the vessel during the setting is slowed while the mainline is expelled from the boat at a high rate through a line shooter (Beverly *et al*., 2003). This gear configuration defines the “deep-set” tuna targeted gear, with hooks reaching depths of 300 meters (m) or more (Figure 1.1).

Because several fish species exhibit dial rhythms in feeding activity, setting times affect catch rates (Løkkeborg and Pina, 1997). The “shallow-set” style gear is set at night to catch swordfish as they rise to surface waters to feed, with the gear being hauled in the day. “Deep-set” gear normally sets in the day and hauls at night in order to catch bigeye tuna (Beverly *et al*., 2003).

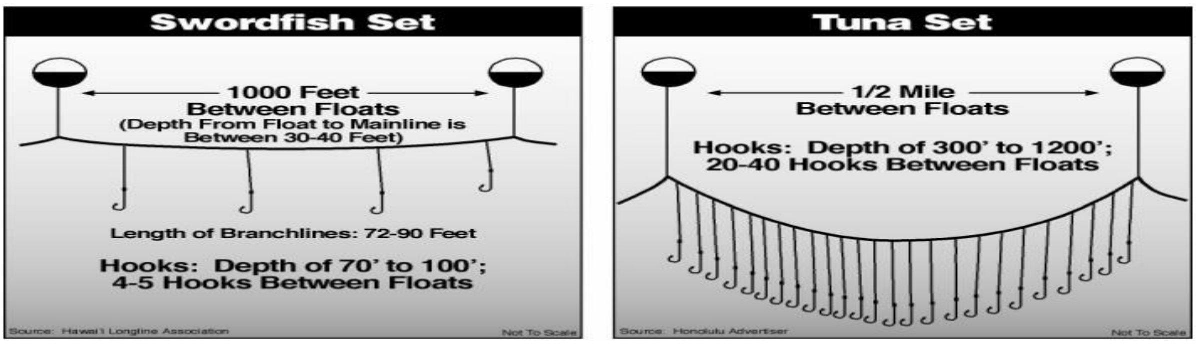

Figure 1.1 - Set characteristics for “shallow-set” and “deep-set” pelagic longline gear (Source: Crowder and Myers, 2001)

Sharks comprise a large proportion of the total catch in some pelagic longline fisheries. For instance, sharks comprise more than 25% of the total catch in fisheries like the Australia longline tuna and Fiji longline tuna fishery. Location of fishing grounds, characteristics and methods of fishing gear are the primary factors determining a fleet's shark catch rate (Gilman *et al.,* 2007a). In recent years, has been observed a trend related to the gear design in order to maximize shark catches such as the use of wire leader and depth of baited hooks where "shallow-set" generally have higher shark catch rates than deeper setting fisheries (Gilman *et al.,* 2007a). Some artisanal longline fisheries in the Pacific Ocean such as the Chilean and Peruvian artisanal longline, target dolphinfish (*Coryphaena hippurus*) during the austral summer and sharks are targeted from autumn to spring. Fishers target dolphinfish seasonally when this species is abundant in coastal waters due to shorter distance to fishing grounds and shorter trip length, with concomitant reduced costs in fuel and food. Wire leaders are not typically used during the dolphinfish season, whereas are used during the shark season to maximize shark retention and reduce gear loss (Gilman *et al.,* 2007a). The same trend of the Pacific Ocean is observed in Atlantic Ocean (e.g. Portuguese coast and Azores islands) for the swordfish pelagic longline fishery where some vessels from spring to summer, making use of wire leaders on the branch lines direct their fishing effort to blue shark due to the lower availability of swordfish, reduced costs for fuel and rising market prices for shark meat and fins (pers. obs.)

1.1.3. The catch: Target and bycatch species

The main target species of pelagic longline fisheries are tunas and billfishes, while other species including sharks are also an important component of the catch. The catch is normally divided into two distinct categories: target and bycatch. Tunas are by far the most important target species for pelagic longline and the main captured species are bluefin (*Thunnus thynnus thynnus*), bigeye (*Thunnus obesus*), yellowfin (*Thunnus albacares*), and albacore tuna (*Thunnus alalunga*). Some billfishes are also targeted, with broadbill swordfish (*Xiphias gladius*) being the most important, followed by striped marlin (*Tetrapturus audax*) (FAO, 2012).

Bycatch are species that are caught incidentally (not targeted) that can be retained aboard for sale because of their commercial value, or discarded as they have no commercial value or are protected under management measures requiring they not to be landed. Some of those species include shortbill spearfish (*Tetrapturus angustirostris*), sailfish (*Istiophorus albicans*), dolphinfish (*Coryphaena hippurus*), wahoo (*Acanthocybium solandri*), escolar (*Lepidocybium flavobrunneum*), amongst others. A range of pelagic shark species such as blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*), oceanic whitetip

(*Carcharhinus longimanus*) and silky shark (*Carcharhinus falciformis*) are also taken as bycatch, although they are mainly prized for the value of their fins. The most common bycatch species that are discarded include lancetfish (*Alepisaurus ferox*) snake mackerel (*Gempylus serpens*), pelagic stingray (*Pteroplatytrygon violacea*), sea turtles and sea birds. Snake mackerel, lancetfish and pelagic rays can be taken at various depths on a longline, and are not associated with a particular type of pelagic longline style (Beverly *et al.,* 2003). Sea turtles (e.g. loggerhead and leatherback turtles) and seabirds (such as albatrosses and petrels) are also caught, where sea turtles are often taken on the shallow hooks, generally near the floatline and the seabirds attack the baits on the gear as it is being set.

1.2. EVOLUTION OF THE SWORDFISH FISHERIES AND GLOBAL TRENDS

1.2.1. Global evolution of the swordfish fisheries

The swordfish fisheries started around 1000 BC as near-shore subsistence activities of Mediterranean countries with the fishing methods mostly involved being the harpooning of large female specimens as they were basking at the sea surface (Ward *et al*., 2000). During the 1900´s, harpoon became more sophisticated in many areas, with the introduction of motorized boats, spotting planes and harpoons that give the fish a lethal electric shock (Ward *et al*., 2010). Nevertheless, most harpoon fisheries declined during 1980´s as a result of increased labour costs and introduction of more efficient fishing gears, such as the driftnets and longlines (Ward *et al*., 2000). Distance-water longliners targeting albacore tuna and swordfish started during the early 1950´s by Japanese fleet, operating in the north Pacific and in the late 1950´s many longliners vessels started targeting yellowfin and bigeye tuna for sashimi markets in Japan (Ward *et al*., 2000). In that period, more than half of the world´s swordfish catches were taken as incidental catch by the longliners targeting tuna (Ward and Elscot, 2000).

The driftnet was introduced by Japanese fleet in early 1960´s to target pelagic species, particularly tunas. Encouraged by government incentives many small scale commercial fishers from Japan and Taiwan industrialized their fleets and in the mid-1980´s it was widely used to target pelagic species in international waters creating an outcry over wastage and incidental catch of sea wildlife that took in 1991 the United Nations (UN) banning the use of driftnets longer than 2.5 km long in international waters (Ward *et al*., 2000).

In the 1960´s smaller locally based longliners began to make shorter trips, storing their catches in ice to be sold in local markets and in the 1980´s with the improvement of air freight to distant markets the fresh-chill fleet quickly developed in many parts of the world (Ward *et al.,* 2000), which contributed to the increased swordfish catches during that time. In the mid-1980´s the techniques to target swordfish became widespread (e.g. use of squid as bait, attached light, set at shallow depths at night, etc.) and catch rates became much higher than those for longliners targeting tuna. Improvements in gear such as the hauled speed, hydraulic powered reels and monofilament mainlines also contributed for an improvement on catch rates as well as in efficiency. Nowadays, swordfish is mainly caught with longline while fishing gears such as the harpoon represent a small portion of the total fishing effort (Ward *et al.,* 2000).

1.2.2. Overview of the global trends of swordfish landings

The swordfish landings started to increase during the mid-1950's keeping this trend until 1970 when reached a peak of 39.000 Metric Tons (MT) (Figure 1.2), where the Pacific was responsible for 55%, the Atlantic 30%, the Mediterranean Sea 10% and the Indian Ocean less than 4% of the total swordfish landings (Figure 1.3). A 1971–78 reduction by the Food and Drug Administration (FDA) in the tolerance level for mercury in swordfish reduced imports and severely depressed consumption worldwide. However, in 1978 FDA revised its limits and from then swordfish landings return to exponentially increase, particularly in the Atlantic and Indian Oceans, where in 1980 the catches in the Atlantic waters overcome those from the Pacific Ocean (FAO, 2012). The redirection of the Taiwan fleet from the Pacific to Indian and Atlantic Oceans was the main factor contributing to the increase of swordfish catches in these oceans (Ward *et al.,* 2000). In 1991 a slight decrease in the total swordfish landings occurred due to the United Nations (UN) ban on the use of driftnets longer than 2.5 km long in international waters. However, the vessels quickly shifted to the longline gear and total landings return to increase (Figure 1.2). In 2003 the historical maximum of the swordfish landing (119157 MT) was reached with the Indian, Pacific, Atlantic Oceans and Mediterranean Sea responsible for 33%, 31%, 21% and 13% of the total landings, respectively (Figure 1.2 and Figure 1.3). In the last decade a slightly decline on swordfish catches has been observed mainly due to the conservation and management measures implemented by tuna Regional Fisheries Management Organizations (tRFMO).

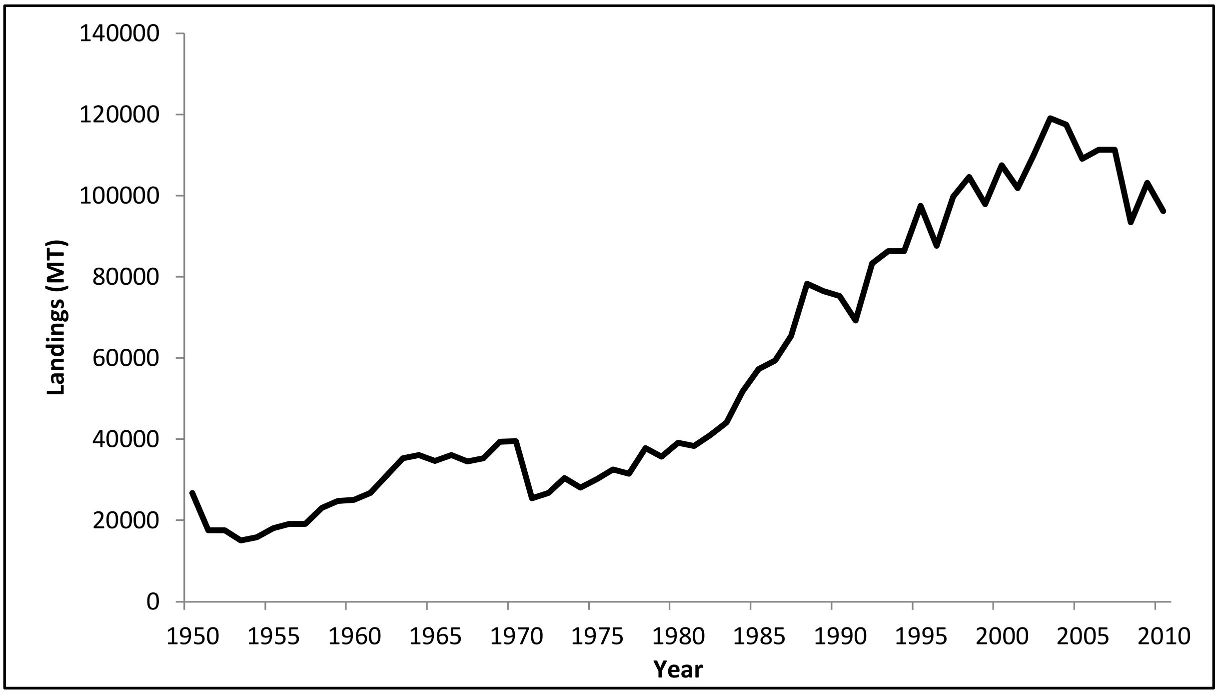

Figure 1.2 – Global swordfish landings from 1950 to 2010 (Source: FAO, 2012)

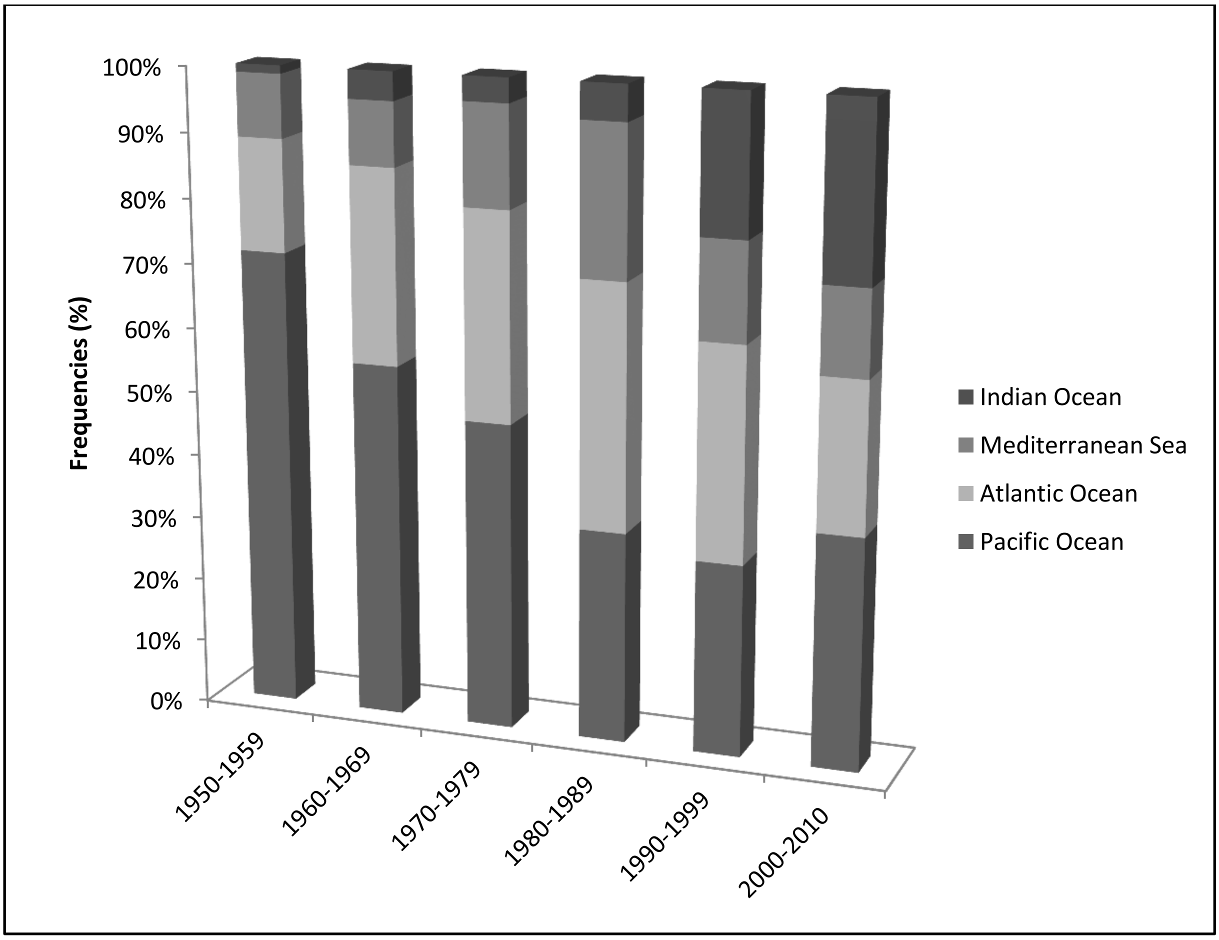

Figure 1.3 - Global swordfish landings (10 years period) by ocean (Source: FAO, 2012).

1.2.3. Longline swordfish fisheries in the Atlantic Ocean and Mediterranean Sea

Harpoon fishery in the Atlantic Ocean started thousands of years ago (Mejuto and Hoey, 1991). In 1800, at the beginning of the industrial era, harpooning commercial fishing reached the Atlantic Ocean in New England, quickly expanding to northern Canada where, the fishing was practiced seasonally, starting in late June in Georges Bank and in September in areas east and north of the Grand Banks (Tibbo *et al.,* 1961). In 1956, the Japanese fleet began their longline operations in the equatorial Atlantic area, to target tuna and few years later the Russians also began their activity (Hazin, 2006). In the early 1960´s, encouraged by the results obtained by the Japanese and Russian vessels in swordfish catches, American and Canadian fleet quickly replaced the harpoon by the longline. The swordfish landings in the Atlantic Ocean and Mediterranean Sea significantly increased since 1970, reaching its peak in 1995, with about 43000 MT (Figure 1.4). From then, the landings in the Atlantic Ocean showed a decreasing trend related to the relocation of the main fleets to other oceans and due to regulatory measures like quotas and Total Allowable Catches (TAC) imposed by International Commission for the Conservation of Atlantic Tunas (ICCAT) (Anon., 2009).

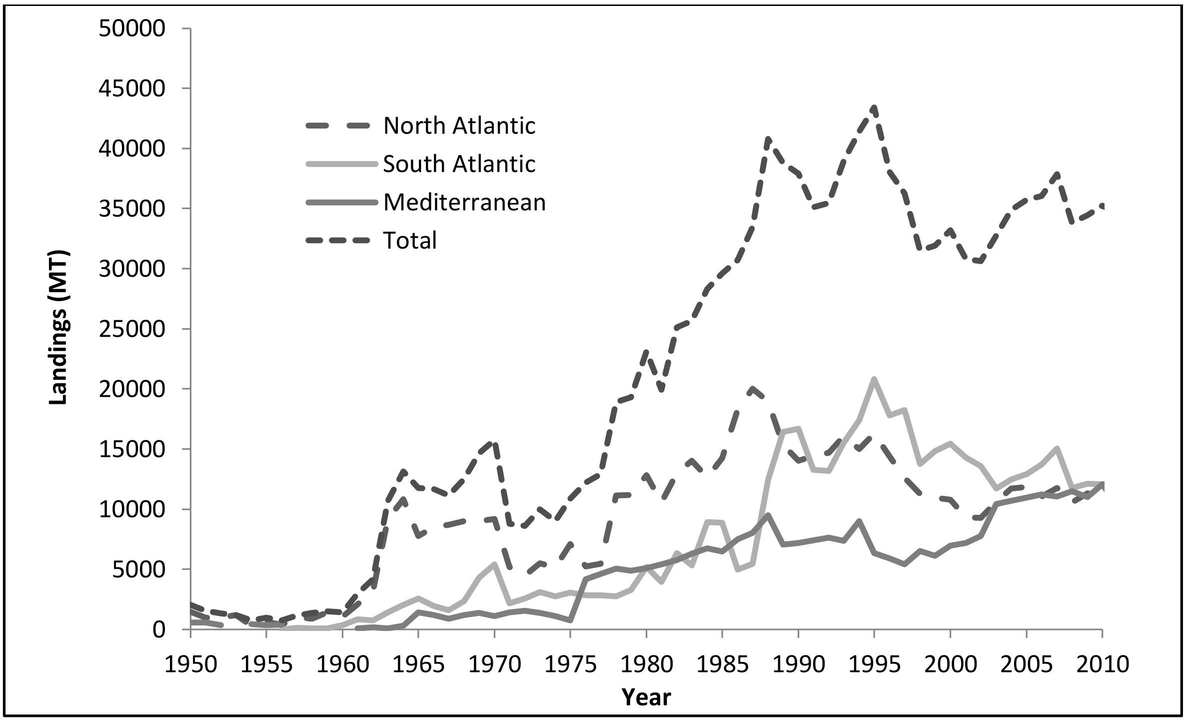

Figure 1.4 - Swordfish landings in the Atlantic Ocean and Mediterranean Sea (Source: Anon., 2012)

The North Atlantic Ocean was the area where the majority of the fisheries developed (Figure 1.4), which is why this stock has been subject to greater fishing effort. Since the beginning of the fisheries, the swordfish landings showed an increase trend following the evolution patterns of the Atlantic total catches. The North Atlantic catches reached its maximum in

1987, with about 20000 MT where the American and Spanish fleets accounted for 80% of the total. The landings in 2011 (12836 MT) in the North hemisphere represented a 37% decrease of those for 1987. From that year, has been a steady decline in catches due to displacement of part of the longline fleet to other areas, a reduction in the species abundance, introduction of catch quotas and minimum size of capture by ICCAT (Anon., 2012). In addition some fleets, including at least the United States, EU-Spain and EU-Portugal, taking advantage of market prices and higher relative catch rates, have changed operating procedures to opportunistically target species previously considered as bycatch, such as tunas and/or sharks.

The historical trend of catch in the South Atlantic waters can be divided in two periods: before and after 1980. The first period was characterized by relatively low catches, generally less than 5000 MT, with an average value of 2300 MT. After 1980, landings increased continuously up to a peak of 21930 MT in 1995, with the Spanish fleet responsible for the highest catches (41% of landed fish) (Anon., 2012). This increase of landings was, in part, due to progressive shifts of fishing effort to the South Atlantic, primarily from the North Atlantic, as well as other waters. Regulatory measures implemented by the ICCAT, shift in the target species, and expansion of fishing activities by southern coastal countries, such as Brazil, Uruguay, Namibia and South Africa also contributed to this increase in catches (Anon., 2012). In 2011 it was reported 12763 MT of swordfish catches in the South Atlantic Ocean which was approximately 40% lower than the 1995 reported level. According to the Report of the Standing Committee on Research and Statistics (SCRS) of the ICCAT (2012), in 2011 the proportion of catches of swordfish in the Atlantic Ocean was equally distributed between the two hemispheres (Anon., 2012).

1.3. THE PORTUGUESE PELAGIC LONGLINE FISHERY

1.3.1. Evolution of fisheries and catches of swordfish by the Portuguese fleet

In Portugal, the swordfish fishery began in 1986, despite the area that now constitutes the continental Exclusive Economic Zone (EEZ) had previously been exploited by foreign fleets. As a result of the growing interest by the markets for swordfish, ship owners modified their fishing vessels and gears to catch swordfish. The experiments of exploratory fishing carried out by the Directorate General of Fisheries and Aquaculture in collaboration with the then National Research Institute of Fisheries were an important contribution to the beginning of this activity (Azevedo, 1990). Until then the catches of swordfish by the Portuguese fleet were incidental, with an average of 20 MT/year. Catches fluctuated until 1993, when they reached the historical peak of 1961 MT (Anon., 2012). In this period, the longline fleet expanded its exploration area looking for new fishing grounds like the Gorringe Bank (Southwestern of Portugal) and even in the Southern Hemisphere. In 1997 a decrease in the catches was observed due to the implementation of the Total allowable catches (TAC) and the corresponding quotas.

The criteria and conditions for the licensing of Portuguese vessels fishing swordfish was first established in 1997 through “Portaria nº 1221 - A/97 de 5 de Dezembro” and revised in 2002, with the publication of “Portaria nº 34/2002 de 9 de Janeiro”. From the application of the diploma “Portaria nº1466/2007 de 15 de Novembro” resulted the existence of a small number of vessels that were licensed to harvest swordfish, with a percentage allocation of the quota attributed to the fishing vessels operating north of 5ºN in the Atlantic area. It also considered that measures should be taken to redirect the North Atlantic fleets to the South Atlantic, in order to reduce pressure on certain species as well as stimulate a better utilization of stocks traditionally less explored by the Portuguese fleet, and for which Portugal has fishing quotas, as is the case of tuna. Based on the experience gained in recent years in the management of these fisheries and the worsening of the security conditions of the fleet licensed to operate in the Indian Ocean, made appropriate an amendment of the criteria and conditions in place, in favor of solutions that promote better use of available quotas by the Portuguese fleet. Therefore a new diploma “Portaria nº90/2013 de 28 de Fevereiro” established a new system of management for the Portuguese swordfish quotas in the North and South Atlantic Ocean, assigning specific responsibilities to producer organizations and associations in this field, which reinforces the importance of these organizations. This new legislation also defines the allocation of quotas for the Continental Portuguese swordfish fishing vessels operating in the North and South Atlantic Ocean. The swordfish quota available for the Atlantic Ocean north of 5º N is distributed by 51 licensed vessels while the quota for the Atlantic Ocean south of 5º N is distributed as follows: i) 81% to 9 vessels licensed to target swordfish and ii) 19% intended to be used as bycatch, where the maximum allowed quantity is 5% by weight of retained catch aboard, or an exemplar in case of the weight exceeds that value. Particularly for the North Atlantic Ocean not all of the licensed vessels are permanently fishing with pelagic longlines, as is the case for a significant part of the fleet based in Peniche, which shift for bottom longline or netting during part of the year.

The catches of the national fleet, operating in the North Atlantic Ocean have always been above those for the South Atlantic (Figure 1.5) as a consequence of the reduced number of fishing licenses assigned to the South Atlantic area and weak freezing capacity of some fishing vessels of the national fleet, which does not allow long trips. From the 1990´s an increase in fishing effort in the South Atlantic Ocean has been observed as a result of technological development and number of fishing licenses assigned. Portuguese catches in the South Atlantic Ocean have only been reported to ICCAT since 1995, with an average of 372 MT/year up to 2011 when it reach 17% of the total catch by the national fleet in the Atlantic Ocean (Anon., 2012).

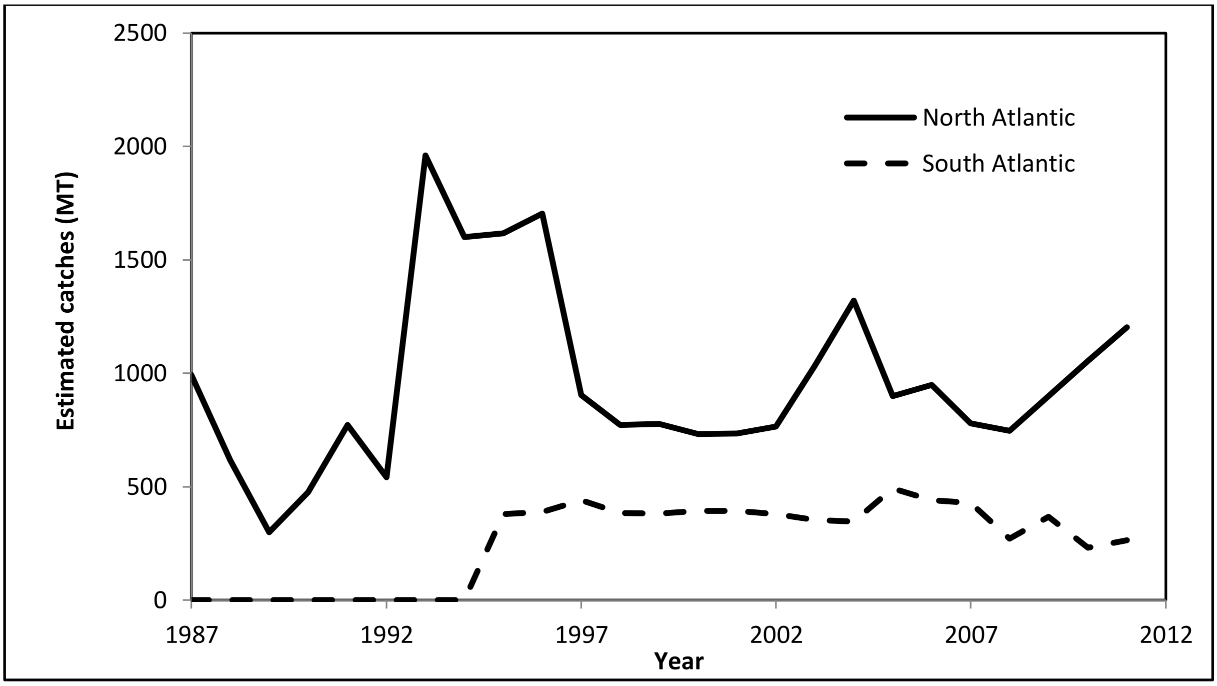

Figure 1.5 – Estimated catches (MT) of swordfish (X*iphias gladius*) in North and South Atlantic Ocean by the Portuguese pelagic longline fleet (Source: Anon., 2012).

The Portuguese fishing fleet only began operating in the Indian Ocean in 1998, mostly in the Southwest (FAO area 51) and Central (FAO area 57) waters (FAO, 2012). The number of vessels licensed increased from the beginning of the fishery (five vessels) until 2009 (24 vessels) and the number of active vessels followed a similar trend reaching 17 vessels in 2006 with total landings of 2205 MT. However, during the last 5 years the active vessels decreased to as low as three (in 2009), mainly due to piracy. Although, Portuguese vessels only began harvesting swordfish in Indian waters 15 years ago it already represents 26% of the total swordfish landings (Figure 1.6). The Portuguese longline fleet only recently started fishing in the Pacific Ocean (Southeast), with catches of 495 and 241 MT in 2007 and 2010, respectively (FAO, 2012).

The total swordfish catch rates for the Portuguese swordfish fleet increased since the beginning of the fisheries, with a peak in 2007 (3717 MT) followed by a sharp decrease in 2008 (1649 MT). In recent years a slight increase trend has been observed with an overall production in 2010 of 2567 MT (FAO, 2012).

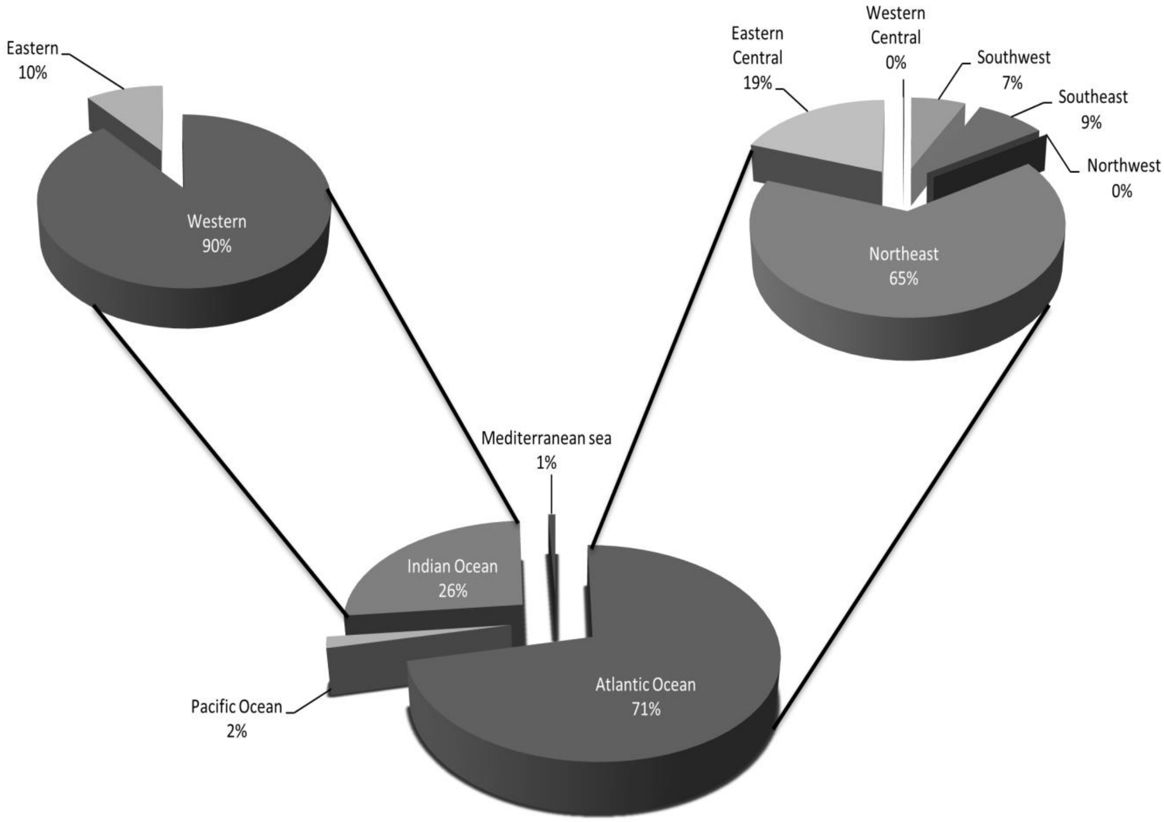

Figure 1.6 - Proportion of swordfish landings by ocean basin of the Portuguese pelagic longline fishery from 1950 to 2010 (Source: FAO, 2012).

The surface longline fishery conducted by national fleet is a multispecies fishery, and other species beside swordfish which is the more economically profitable species are often catch, including tuna, marlins and pelagic sharks. Among the pelagic sharks, the blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) are the most important species (Santos *et al*., 2002). In the early years of the Portuguese pelagic longline fishery, pelagic sharks (mainly blue shark) were discarded and were not recorded in the logbooks or reported in the official statistics. However, in the recent years changes in the behavior of longline fleet has been observed, where occasionally some vessels direct their fishing effort to shark species along with swordfish, taking advantage of the international growing interest of the market for these species.

1.3.2. Description of the swordfish pelagic longline gear

As mentioned before, the Portuguese pelagic longline fishery targeting swordfish began in the 1980´s and the fishing method has remained almost unchanged since then (Santos *et al*., 2012). Although a few changes have been incorporated in the last decade: i) fishermen shifting from the traditional gear, described by Rey and Alot (1984) to the so-called automatic or "American-style", making use of mainlines and branch lines of monofilament and using flashlights and ii) in specific areas and seasons, pelagic sharks may be the target species, as a consequence the branch lines material are shifted to multifilament steel (wire leaders). There are no significant differences at the level of the material used in the preparation of the fishing gear, with the main difference being the automation of procedures carried out during the setting and hauling operations. As a result, the needs of skilled manpower are smaller compared to the traditional style longline.

The automatic pelagic longline is based on a basic unit, consisting of four parts: the mainline, the branch lines, the hook and the bait. The mainline which varies in length, stretch for tens of kilometers rigged with a certain number of hooks off the branch line. Polyamide (nylon) monofilament is the most common material used for branch lines and mainline targeting swordfish, because the catch performance has been shown to be superior to those with multifilament (Brothers *et al*., 1999). The branch lines are connected to the mainline trough a snap. A swivel is placed immediately after the snap, which is attached to a nylon monofilament with 2.0 to 2.5 mm diameter. In the middle of the branch line a swivel with a lead of 60-80 g maybe adapted and a luminescent device is connected to it. Another swivel is than attached to the hook by a nylon monofilament of approximately 2 m with a diameter of 1.8 to 2.2 mm. The shape and size of hooks has been affected by both catch and bycatch considerations, however historically J-style hooks have been used. In Figure 1.7 a schematic drawing of the swordfish pelagic longline fisheries is shown. Depending on the target species and/or area, variations can be found in terms of type, length and dimension of branch line and mainline, type of hook and bait.

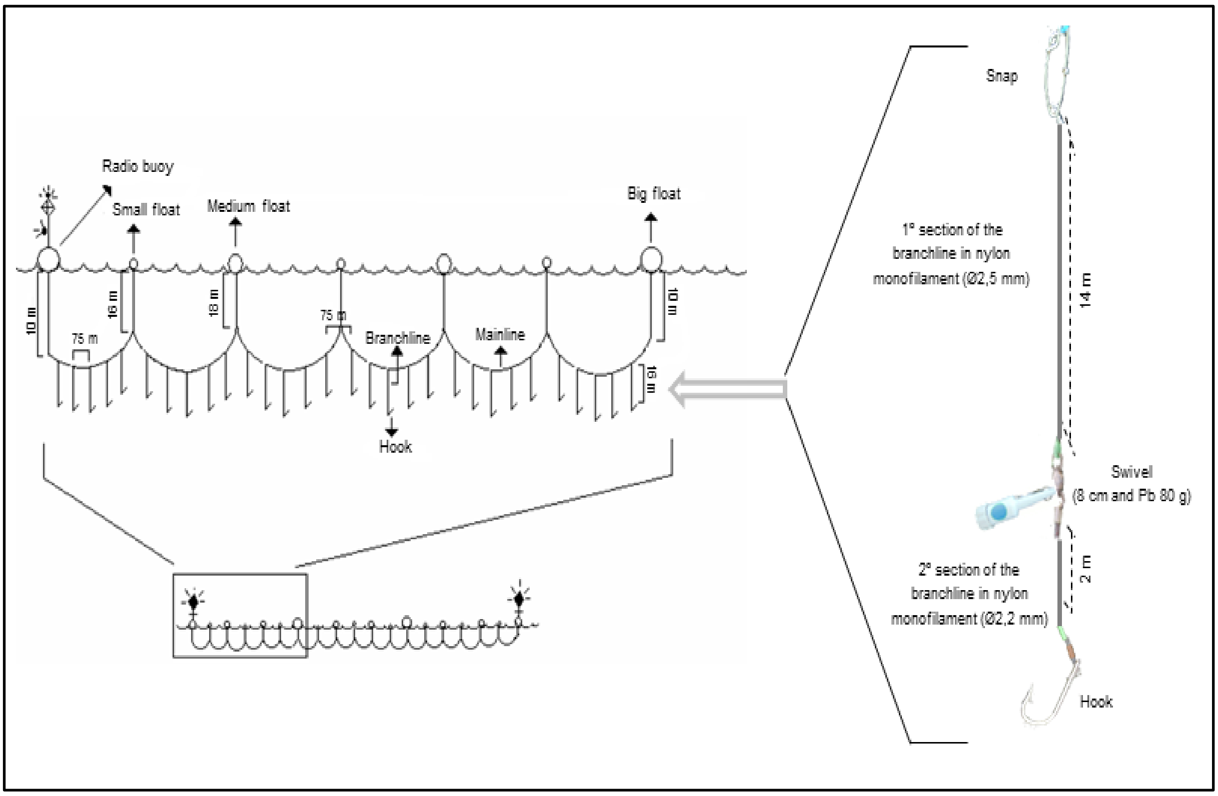

Figure 1.7 - Schematic drawing of the swordfish pelagic longline fishing gear (Source: adapted from Santos *et al.,* 2013).

Monofilament gear is set from the stern of the boat with the aid of a line setter and can last for between 5 to 7 hours, depending on the number of hooks deployed and/or velocity of the vessel. As the line is sent out during setting, baited branch lines and floatlines with floats are attached at intervals usually controlled by an audible signal and the baited hooks remain at/or near the surface for a short period of time before they start sinking. Longlines targeting swordfish preferably set their gear at sunset due to adaptation to phototropism of this species. Once released, the gear drifts for a few hours (6 to 7 hours) until it is hauled, normally at sunrise. The hauling procedure is made at a velocity inferior to that of setting and normally takes between 7 to 10 hours, depending on the catches and constraints that might arise. The most used baits are squid (*Illex* spp.) and mackerel (*Scomber* spp.) that can be lured by the head or lower body. In Table 1.1 (Annex I) a summary of the main characteristics of the Portuguese pelagic longline fishery is shown.

1.4. MITIGATION OF INCIDENTAL CATCHES

Drifting pelagic longlines catch a wide variety of bycatch, the unintended non-target organisms that are captured during fishing operations (Lewison *et al*., 2004). Despite the differences in bycatch types and the magnitude of their effects from one fishery to another, bycatch can be a major driver from sea “megafauna” to lower trophic-level species, critical for the structure and functioning of the sea ecosystems and therefore the provision of ecosystems services (Gilman, 2011). Unsustainable bycatch fishing mortality of keystone species that play critical roles in regulating ecosystems processes can alter trophic interactions and change ecosystem structure and functioning, including reduced ecosystem resistance and resilience to environmental fluctuations, and possibly exceeding “tipping points”, where permanent regime shifts occur (Pauly *et al.,* 1998). Under the “United Nations Convention on the Law of the Sea (UNCLOS)”, states are obligated to protect and preserve the sea environment and consider the effects of fishing on species associated with/or dependent upon commercially exploited species (United Nations, 1982). Additionally the Food and Agriculture Organization of the United Nations (“FAO Code of Conduct for Responsible Fisheries”) require nations to develop and apply safe and selective fishing gear to minimize waste, discards catch of non-target species and effects on associated or dependent species (FAO, 1995). Therefore, in recent years has been increased concern with regards to bycatch (Soykan *et al*., 2008) and several recent studies have addressed this issue in pelagic longline fisheries (Gilman *et al*., 2006). Most bycatch studies have focused on the more vulnerable, and charismatic sea “megafauna”, including sea turtles (e.g. Watson *et al*., 2005; Gilman *et al*., 2006; Santos *et al*., 2012), sea birds (e.g. Bugoni *et al*., 2008; Gilman *et al*., 2008; Jiménez *et al*., 2009) and sharks (e.g. Yokota *et al*., 2006; Ward *et al*., 2009; Coelho *et al*., 2012; Foster *et al*., 2012).

Several measures to mitigate the incidental capture and bycatch have been proposed and/or implemented in different fisheries, including management measures such as i) regulatory controls on fishing effort, seasonal bycatch levels, fishing areas ii) programmes to avoid by-catch hotspots through voluntary fleet communications and iii) handling and release practices to increase post-survival (Gilman *et al*., 2006). Because of problematic turtle by-catch levels an area of western North Atlantic (including the productive Grand Banks) was partially closed to the US pelagic longline fleet in 2000, and completely closed in 2001 (US National Sea Fisheries Service 2000, 2001a, b) only reopening in 2004 after regulations were amended to require the use of recently tested turtle bycatch avoidance methods (US National Sea Fisheries Service 2004b). In the Hawaii longline swordfish fishery, similar restrictions were implemented, where it was closed for over 4 years and is now subject to strict management measures, including prescribed use of large circle hooks and fish bait, restricted annual effort, annual limits on turtle captures and 100% onboard observer coverage (US National Sea Fisheries Service 2004a).

In recent years scientists have been developing, testing and implementing fishing techniques and gear modifications to improve the selectivity and sustainability of pelagic longline fisheries and increase post-release survival (Soykan *et al*., 2008). This approach might be better accepted by fishers over other management strategies that reduce available fishing areas, such as time/area closures, which have predominated U.S. bycatch reduction measures. Longline gear operating characteristics including, fishing depth, gear soak time, bait type and hook style can have significant effects on the selectivity of the pelagic longline gear (Watson and Kerstetter, 2006). One such technique that has broadly been developed and tested to reduce bycatch is the circle hooks (see review by Graves *et al*., 2012). Circle hooks also seem to reduce the incidence of deep hooking trauma and post-release mortality in a variety of sea turtles (see review by Read, 2007) and freshwater/sea fishes (Cooke and Suski, 2004) and their overall benefit to commercial fisheries was recently reviewed by Graves *et al*., (2012).

The tuna Regional Fisheries Management Organizations (tRFMOs) in the last decade have been encouraging their contracting parties and cooperating members (CPCs) to undertake research trials of circle hooks in their commercial pelagic longline fisheries. In January of 2010, Western and Central Pacific Fisheries Commission (WCPFC) was the first tRFMO to include the use of large circle hooks with an offset (that does not exceed 10º) as one available bycatch mitigation method required for implementation by all CPCs fishing for swordfish using shallow longline sets (WCPFC, 2008). However, conflicting results among studies (e.g. review paper by Read, 2007) conducted under several locations, seasons, and experimental protocols have hindered the development of regulations requiring the use of circle hooks in the others tRFMO´s. In some cases, the gear modifications can reduce the catches of the target species to such a degree that their use is impractical [e.g. the case study of the dolphinfish fishery in Ecuador reported by Largarcha *et al*. (2005)]. Given these complexities that involve possible modifications in fishing gears, different approaches have been recommended for different researchers. While Read (2007) recommends that bycatch mitigation measures should be tested (in rigorous experiments) before being mandatory in any fishery, Serafy *et al*. (2009) considered that this perspective is counter to the precautionary approach and rigorous field testing is preferable, considering that in cases of severely overfished, threatened or endangered populations, highly complex and time consuming field experimentation should not be a precondition for a given fishery change that could potentially benefit those populations.

CHAPTER II – MATERIAL AND METHODS

2.1. STUDY DESIGN AND DATA COLLECTION

For this study, a total of 310 longline sets were carried out during five trips along the Southern Atlantic region (Figure 2.1) that took place between October 2008 and February 2012. A commercial fishing vessel ("ALMA LUSA, PM-1269-N) from the Portuguese swordfish pelagic longline fleet participated in the study, with experimental fishing taking place between 11^{o} to 34^{o} S latitude and 044^{o} W to 007^{o} E longitude. The fishing gear consisted in a standard US style monofilament polyamide longline of 3.6 mm of diameter, approximately 62 nm (~ 110 km) long, with five polyamide branch lines between two buoy floats at intervals of approximately 80 meters (range from 70 - 90 m) and a depth of 20-50 m below the surface. Each branch line was 18 m in length and was composed by two sections, the first consisting of 2.5 mm monofilament (9 m length) connected by a swivel to a 2.2 mm monofilament gangion (9 m length) with a hook in the terminal tackle. A battery flashlight (green color) was attached to each gangion. On each set, gear deployment (1440 hooks) commenced around dusk (traditionally at 17:00 hours), with haulback starting around dawn of the next day (about 06:00 hours).

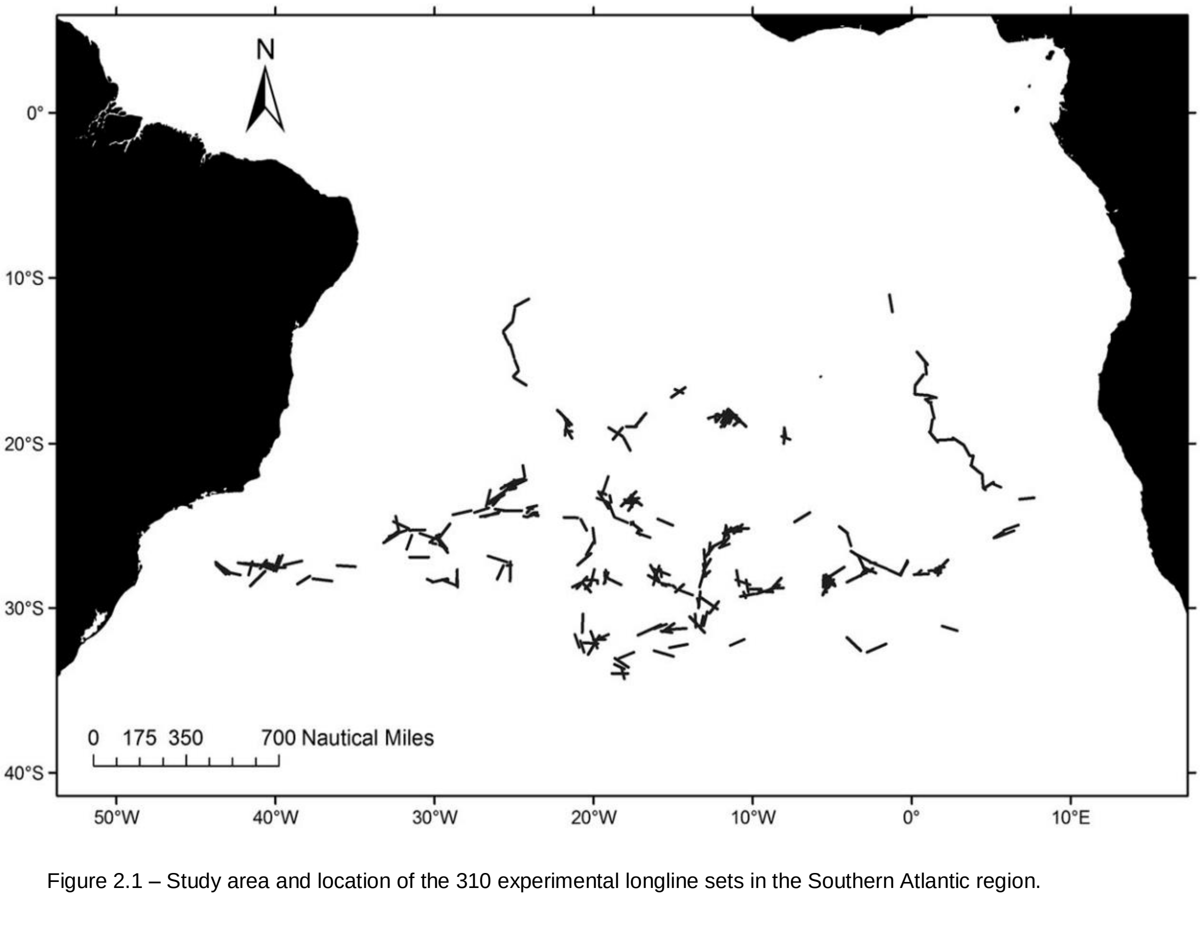

Figure 2.1 – Study area and location of the 310 experimental longline sets in the Southern Atlantic region.

Three different stainless steel hook styles (Figure 2.2), produced by WON YANG, Korea were used in each longline set, where the control corresponding to the traditional J hook on the fishery (EC-9/0-R), and the treatments corresponding to: GT hook, a 10º offset circle hook (H17/0-M-R); and G hook, a non-offset circle hook (H17/0-M-S).

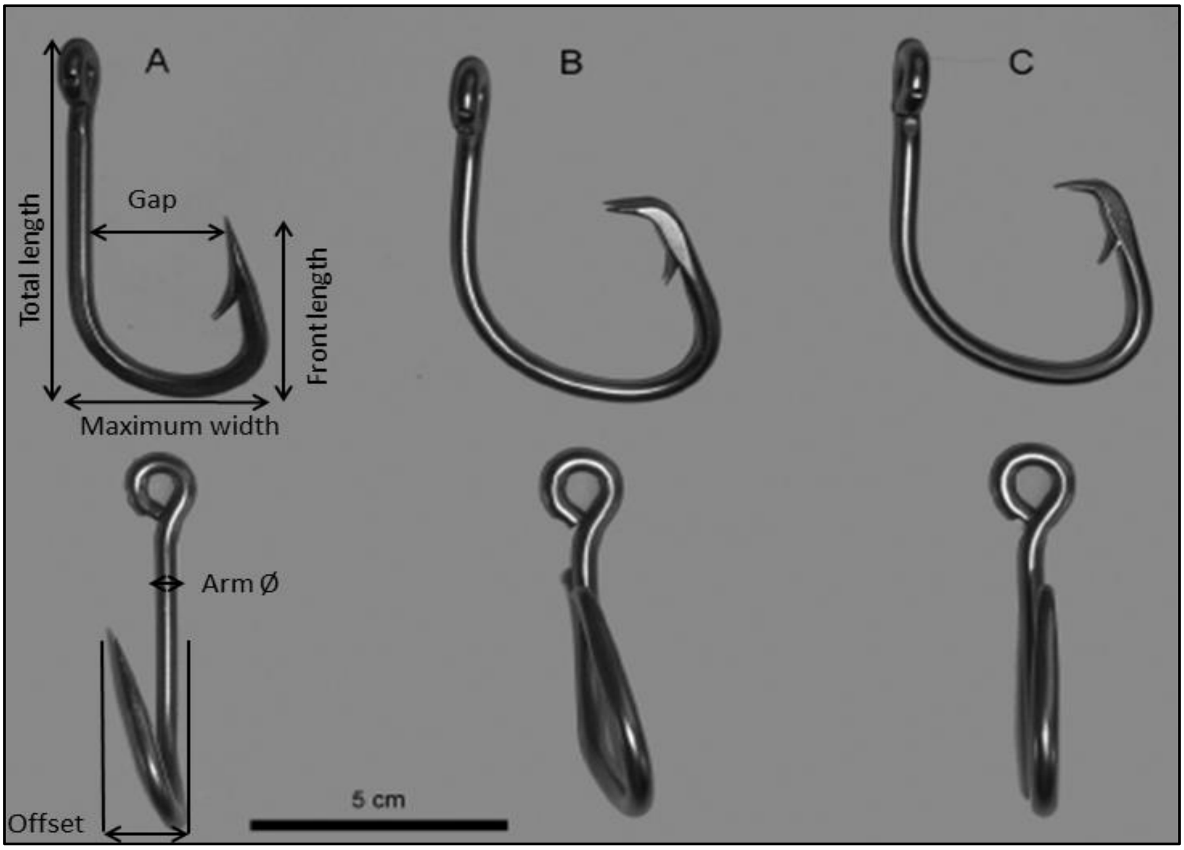

Figure 2.2 – Photograph of the three hook styles used during this study: (A) J – 10º offset 9/0 hook; (B) GT – 10º offset 17/0 circle hook and (C) G – non-offset 17/0 circle hook. Hook measurements and terminology in Table 2.1.

The specifications of the different hooks are summarized in Table 2.1. In order to minimize the potential for confounding effects specific to a set (e.g. location, water temperature, chlorophyll, thermocline or other factors) hook style was alternated section by section of the longline. Each section was delimited by radio beacon buoys, and had 80 hooks of only one style. Furthermore, the hook style of the first section in the water changed every set, following a fixed scheme (i.e., J, G, GT, J, G, GT and so on). Two different bait types were used, mackerel (*Scomber* spp.) and squid (*Illex* spp.) but as recommended by Watson *et al*. (2005) only one type of bait was used in each set in order to avoid possible interaction effects. Standardized bait sizes were used in all longline sets. Mackerel and squid baits had 35.1±1.19 cm fork length and 27.8±0.97 cm mantle length, respectively (based on the measurement of 200 individuals of each genus).

Table 2.1 - Hook measurements and terminology of the different hook styles used in the study. The mean size of the hook parameters is based on the measurement of 50 hooks of each style. Standard deviation is indicated within parentheses.

Parameter	Hook style		
	J (EC-9/0-R)	GT (H17/0-M-R)	G (H17/0-M-S)
Total length (mm)	87.2 (±1.11)	77.7 (±0.92)	
Front length (mm)	40.4 (±1.10)	43.9 (±0.45)	
Maximum width (mm)	43.3 (±0.64)	49.4 (±0.88)	
Gap (mm)	33.2 (±0.59)	27.0 (±0.51)	
Arm diameter (mm)	5.0 (±0.00)	5.0 (±0.00)	
Offset angle	10º	10º	0º

All characteristics of the fishing gear and practices (e.g. hook placement, flashlight color, bait size and hook manufacture) were standardized along the study. Length of mainline was allowed to slightly vary, as a result of sea conditions. The fishing effort in terms of deployed number of hooks of each style per set was kept constant throughout the study. For every set the first baskets of the gear deployment was monitored in order to ensure the correct execution of the experiment. All data was recorded by onboard scientific fisheries observers during hauling operations using standardize forms and procedures. For every experimental set, date, location (initial and final latitude and longitude) and number of hooks of each hook style was recorded. Sea Surface Temperature (SST) was also collected, being recorded at the beginning of haulback.

Whenever a sea turtle was caught in the longline, the onboard observer identified the species, recorded the hook style and bait type used, the condition/status of the turtle at-haulback (alive/dead), the type of interaction (i.e. location of the hook: flippers, mouth, esophagus or entangled) and the condition when released (alive/dead). When possible, turtles were boated with a large dip net. Further, and whenever possible, observers and crew attempted to remove fishing gear using long-handled de-hookers and line cutters. Observers attempted to remove all gear immediately. They were instructed to remove all external hooks and those in the mouth, as well as hooks in the esophagus when the insertion point of the barb could be seen. Whenever possible the sex of the specimen was determined and the curved carapace length (CCL) was measured to the nearest lower 1 cm. However, due to the size and weight of leatherback turtles, *Dermochelys coriacea*, only a limited number of specimens of this species were measured, with most specimens being immediately released by cutting-off the line without bringing the turtle onboard. Following Watson *et al*. (2005), power tests were carried out in order to estimate the experimental fishing effort required to detect a fishing method that has different degrees of effectiveness in reducing bycatch of sea turtles in comparison with the control fishing method. The control fishing method was assumed to be the combination most commonly used in the fishery, specifically J-style hooks baited with squid, and the power calculations were based on the necessary number of hooks required to detect a 25% and 50% reduction in bycatch rate in the case of loggerheads and leatherbacks, respectively.

For every fish captured the hook style and bait type were recorded and the species identified and measured to the nearest lower 1 cm. For swordfish and marlins length measurements were registered in lower jaw fork length (LJFL) and fork length (FL) for sharks, tunas and other teleosts. Information of catch disposition (retained/discarded), condition at-hauback (alive/dead), sex and its condition if discarded (alive/dead) was also collected. Large fishes (e.g. manta rays and sunfish) were released by cutting the leader as close to the animal as safely possible. Fish catches were placed into three categories depending on the species: target, bycatch or discard. For this fishery and using these specific fishing techniques, the main target species was swordfish. Bycatch included species that were not targeted, but were retained if caught such as tunas, billfishes, large pelagic sharks and other teleosts. Discards included species that were unintentionally caught, but not retained, mostly small sized elasmobranchs, teleosts with no commercial value and also larger elasmobranchs that are now forbidden to be retained aboard (e.g. thresher and hammerhead sharks) (Table 2.2, Annex II).

2.2. Data Analysis

All statistical analyses were performed using the R project for Statistical Computing version 2.15.1 (R Development Core Team, 2012), primarily using functions available in the core R program. Exceptions were the Levene test for the homoscedasticity that is available in library “car” (Fox and Weisberg, 2011); non-parametric multiple test procedure for all-pairs comparisons available in library “nparcomp” (Konietschke, 2012); contingency table analysis that was performed with library “gmodels” (Warnes *et al*., 2011); Generalized Linear Model (GLM) fitting and maximum likelihood estimation of the index parameter using the Tweedie distributions available in library “tweedie” (Dunn, 2010) and the plots of means available in the “Rcmdr” (Fox *et al.,* 2011). All maps in the thesis were created through ArcGis Desktop 10 software (ESRI, 2012). The shapefile (world borders) with the continental contours was obtained in the “Thematic mapping” website (Sandvik, 2009). A Pearson´s product-moment correlation coefficient between SST and latitude and longitude was performed in order to evaluate the strength of linear dependence between these variables. For all tests performed, significant differences were declared at p<0.05.

2.2.1. Data analysis for sea turtles

Catch rates were expressed as bycatch per unit effort (BPUE), calculated as the number of specimens caught per 1000 hooks. Given the lack of normality of the BPUE data verified with Kolmogorov-Smirnov tests with Lilliefors correction (Lilliefors, 1969) and heterogeneity in the variances (verified with Levene tests), Kruskal-Wallis tests were used to compare BPUE between different hook styles, and Mann-Whitney tests were used to compare BPUE between the two baits.

A logistic-binomial generalized linear model (GLM) was used to determine the influence of hook style and bait type on turtle bycatch. Due to the small sample sizes, this model was only applied to the loggerheads. For this model, the response variable was the proportion of loggerhead catches in each longline set, calculated as the number of catches given the number of hooks used in each set. A binomial error distribution and a logit link function were used in the model. The explanatory variables tested were the hook style (J, G or GT) and the bait type (squid or mackerel), with their significance verified by the Wald statistic. The interaction between the two variables was tested with a likelihood ratio test and by comparing the Akaike information criterion (AIC) values of the models. This interaction was used in the final model because it was considered significant and relevant for interpreting the results. The odds-ratios of the parameters, with their respective 95% confidence intervals, were calculated considering the model parameters and the interaction.

With regards to the size structure of the sea turtles caught, only the most abundant species (loggerheads) was analyzed, while the CCL of leatherbacks was not compared due to the small samples size. Loggerhead CCL was tested for normality and homogeneity of variances, and the skewness and kurtosis were calculated. Considering the results of these analyses, the application of parametric tests seemed reasonable, and therefore the mean CCL for the two different baits were compared with Student´s t-test, while the mean CCL for the three different hook styles were compared with Analysis of variances (ANOVAs). Additionally, the mean CCL for the different hooking locations were also compared using ANOVAs. When the ANOVA results were significant, Schefee *post-hoc* multiple comparisons were carried out.

The relationship between hooking location and hook style was assessed using contingency tables and Chi-square tests of independence. Analyses were conducted for the two species combined, as well as for the loggerhead separately. For this analysis, the hooking location was re-categorized into three categories: mouth, esophagus and external (combining flippers and entangled) due to the existence of very low values in some of the combinations using the original categories. Chi-square proportions tests were also used to assess differences in the proportions of live/dead sea turtles between hook styles, bait type and hooking locations. This analysis was only carried out for the loggerheads, as the contingency table analysis assumptions could not be validated for the leatherback species due to their very low bycatch rates.

2.2.2. Data analysis for fishes

For most fish caught, statistical analyses were performed at the species level, with exception for *Cubiceps* spp. and Myliobatidae, where only a classification to the genus or family taxon was possible due to most of those species not being hauled onboard and therefore precluding a complete identification (at the species level). Catch rates were expressed in catch per unit effort (CPUE), estimated as catch in weight (kg) per 1000 hooks. Catch in weight (kg) was calculated using length-weight conversion equations from the Portuguese Sea and Atmosphere Institute (unpubl. data). CPUE for discarded species was also estimated, but using the number of specimens per 1000 hooks instead of captured biomass. Mean CPUE with the respective standard deviations were calculated for each species in each fishing set (including sets with zero catches) for each hook-bait combination. For this same combinations for each species it was also calculated the frequency of occurrence (presence/absence per set). CPUE data were tested for normality with Kolmogorov-Smirnov tests with Lilliefors correction (Lilliefors, 1969) and for homoscedasticity with Levene tests. If the continuous variable (CPUE) violated normality and homoscedasticity assumptions, non-parametric tests were employed to test for differences between the two bait types (Mann-Whitney) and between the three hook styles (Kruskal-Wallis). Whenever the Kruskal-Wallis results were significant non-parametric multiple tests for all-pairs comparisons with Bonferroni p-value adjustment method as described by Gao *et al.* (2008) was carried out. A Spearman´s rank correlation coefficient (given lack of normality of the CPUE and heterogeneity in the variances) between swordfish and blue shark CPUEs with latitude and longitude were tested in order to assess the relationship between those variables.

For swordfish and blue shark, a GLM for the response variable CPUE was applied using bait type and hook style as explanatory variables. A Tweedie distribution with a log link function was used in the GLM given that the response variable (CPUE) is a continuous variable with a discrete mass at 0 (corresponding to the fishing sets with zero catches). The Tweedie distribution is part of the exponential family of distributions, and is defined by a mean (μ), and a variance (φμp) in which φ is the dispersion parameter and p is the index parameter. When the index parameter has values between 1 and 2, the distribution is continuous for positive real numbers, but has an added discrete mass at 0, which is appropriate when modeling CPUE data (Shono, 2008). The baseline reference levels for the covariates were J-style hooks baited with squid, and the other levels of the covariates were compared against this combination. Given that the log link function was used, the odds-ratios for model interpretation were calculated as the exponential values of the estimated parameters.

Size distribution of the target species (*Xiphias gladius*) and most abundant bycatch species (*Prionace glauca, Makaira nigricans, Thunnus albacares, Thunnus obesus, Thunnus alalunga* and *Isurus oxyrinchus*) were compared among the different hook styles and bait types. The skewness and the kurtosis of the size data were calculated to assess departures from normality. Results of these analyses indicated that parametric tests were not appropriate to compare mean sizes among treatments, so for each hook-bait combination, the mean size (LJFL or FL) and its respective standard deviation were calculated. Kruskal-Wallis and Mann-Whitney tests (non-parametric tests) were used to compare the fish sizes among hook styles and bait types, respectively.

The mortality rate of discarded species at-haulback for each hook style and bait type combination was assessed as the proportion of the number of fish that were dead at gear retrieval (haulback) to the total number of fish caught. Contingency tables and Chi-square proportion tests were computed to assess for differences in the proportions of alive/dead between hook styles and bait types. Due to the existence of zero values in some of the combinations, this analysis was only applied for the most frequently caught discarded species.

CHAPTER III – EFFECTS OF HOOK AND BAIT ON SEA TURTLES BYCATCH

3.1. INTRODUCTION AND OBJECTIVES

Sea turtle bycatch occurs in a wide range of fisheries, from small to large-scale fishing fleets, using many gear types such as: trawls, longlines, gill and pound nets, dredges and to a lesser extent, pots and traps (De Metrio and Megalofonu, 1988; Magnuson *et al*., 1990; Poiner and Harris, 1996; Julian and Beeson, 1998; Chuenpagdee *et al*., 2003; Lewison and Crowder, 2007; Moore *et al*., 2009; Wallace *et al*., 2010; Casale, 2011). Sea turtle bycatch is of special concern as five of the seven species living in the world's oceans have been listed as either critically endangered (e.g. leatherback - *Dermochelys coriacea* (Vandelli 1761)) or endangered (e.g. loggerhead – *Caretta caretta* (Linnaeus 1758)) (IUCN, 2012). Moreover, one of the main causes for the worldwide failure of most sea turtle populations to recover is their incidental capture in fisheries (Hillestad *et al*., 1995, Lutcavage *et al*., 1996). Even though longline sea turtle bycatch is only one of many threats faced by these species, it has been gaining international attention in the recent years (FAO, 2009).

Several measures to mitigate the incidental capture of sea turtles have been proposed and/or implemented in different fisheries. These include management measures (e.g. time/area closures, fishery bans, limitation of fishing effort, maximum annual quota), but also technical measures (gear technology approaches), such as the use of: turtle excluding devices on trawl fisheries, deterrents, including sonic "pingers", shark silhouettes, lights or chemical repellents on set and drift nets and use of specific circle style hooks (FAO, 2009 and reference therein). As regards the mitigation of longlines bycatch, a number of research initiatives have focused on testing several technological and methodological changes, all aiming at increasing the fishing gear selectivity and reducing bycatch mortality of sea turtles (Polovina *et al*., 2003; Gilman *et al*., 2007b; Swimmer *et al*., 2005; Werner *et al*., 2006; Yokota *et al*., 2009). Particular attention has been given to the use of circle hooks, as a means to reduce bycatch mortality (see reviews by: Read, 2007; Wallace *et al*., 2010; Serafy *et al*., 2012). However, in the Atlantic Ocean these studies on circle hooks were mostly limited to the Northern Hemisphere. To the author´s best knowledge, only a few studies were conducted in recent years on the Southern Atlantic Ocean (Anon., 2008; Domingo *et al*., 2009; Sales *et al*., 2010; Pacheco *et al*., 2011), but these were limited in terms of the number of sets and/or geographical area covered, as well as in terms of the baits used and tested. Therefore, in order to increase the area covered for such circle hook studies in the Southern Atlantic Ocean, within the scope of the SELECT-PAL Project, we tested the influence of different hook style and bait type combinations on the incidental catch of sea turtles on the Portuguese pelagic longline fishery. In the present chapter we compared the sea turtle incidental catch composition and rates, bycatch at size, hooking location and status at-haulback, throughout the experimental use of different combinations of hook styles and bait types.

3.2. RESULTS

3.2.1. Description of the incidental bycatch

Overall, a total of 446,400 hooks were used during the 310 experimental fishing sets, corresponding to 148,800 hooks of each style. According to the power analysis carried out, the number of hooks required to detect a 25% reduction in the loggerheads bycatch per unit effort (BPUE) (with 95% confidence interval) was 166,597 (corresponding to 116 fishing sets). Comparative efforts required to detect a 50% reduction in the leatherback BPUE was 333,632, corresponding to 232 sets. The sea surface temperatures (SST) ranged from between 16.5ºC and 28.3ºC, with an average of 21.9 ± 2.76ºC. A correlation between SST with latitude and longitude was observed, with higher SSTs tending to be mainly recorded towards northern latitudes (Pearson correlation=0.225, t=4.0; df=299, p<0.001) and for the western regions of the sampling area (Pearson correlation=-0.498, t=-9.9, df=299, p<0.001).

3.2.2. Bycatch rates

A total of 286 sea turtles were caught during this study, specifically 260 loggerheads and 26 leatherbacks. Most of the experimental fishing sets had zero (78.4%) or very limited catches of sea turtles. The maximum number of specimens caught in a single set was 20, but for most of the sets (95%) less than five sea turtles were caught. The specific proportions of fishing sets with zero catches of sea turtles also varied for each hook-bait combinations, with a tendency for more sets with zero catches when mackerel bait was used (Table 3.1.).

Table 3.1 - Percentage of sets with zero sea turtle incidental catches obtained with the different combination of hook style (J – 10º offset 9/0 hook; G – non-offset 17/0 circle hook; GT – 10º offset 17/0 circle hook) and bait type (S – squid; and M – mackerel) tested, for species combined and for the two sea turtle species incidentally caught.

Hook style:bait type	Loggerhead	Leatherback	Combined species
J_S	78.0%	92.2%	73.6%
J_M	92.2%	98.8%	91.0%
G_S	87.8%	97.4%	85.9%
G_M	93.6%	100%	93.6%
GT_S	85.2%	98.0%	83.8%
GT_M	94.8%	99.4%	94.2%

The highest BPUEs were observed in the western part of the study area, between 37ºW and 44ºW, both for species combined, but also for loggerheads (Figure 3.1). Overall, the highest mean BPUE values for the leatherback tended to occur with J-style hooks ($J_{mackerel}$=0.040 and J_{squid}=0.188 per 1000 hooks) than circle hooks ($GT_{mackerel}$=0.013 and GT_{squid}=0.054 per 1000 hooks). For the loggerhead such tendency was not so evident, although the traditional combination still showed the highest value (J_{squid}=1.505/1000 hooks, see Figure 3.2). These differences between the three hook styles were significant for the species combined, but also for the leatherbacks (Kruskal-Wallis: Species combined - Chi-square=9.86, df=2, p=0.007; leatherback - Chi-square=9.33, df=2, p=0.009) and loggerheads (Chi-square=6.07, df=2, p=0.048). The BPUE tended to be significantly lower when mackerel bait was used instead of squid for the two species combined, as well as for the two species individually (Figure 3.2) (Mann-Whitney: Species combined: W=94766, p<0.001; loggerhead: W=96921, p<0.001; leatherback: W=104398, p<0.001). The ratio between the standard fishing practice and the other hook-bait combinations tested showed reductions in BPUE between 2.3-8.4, 2.2-8.0 and 3.5-14.0 times, for species combined, loggerhead and leatherback turtles, respectively (Table 3.2.).

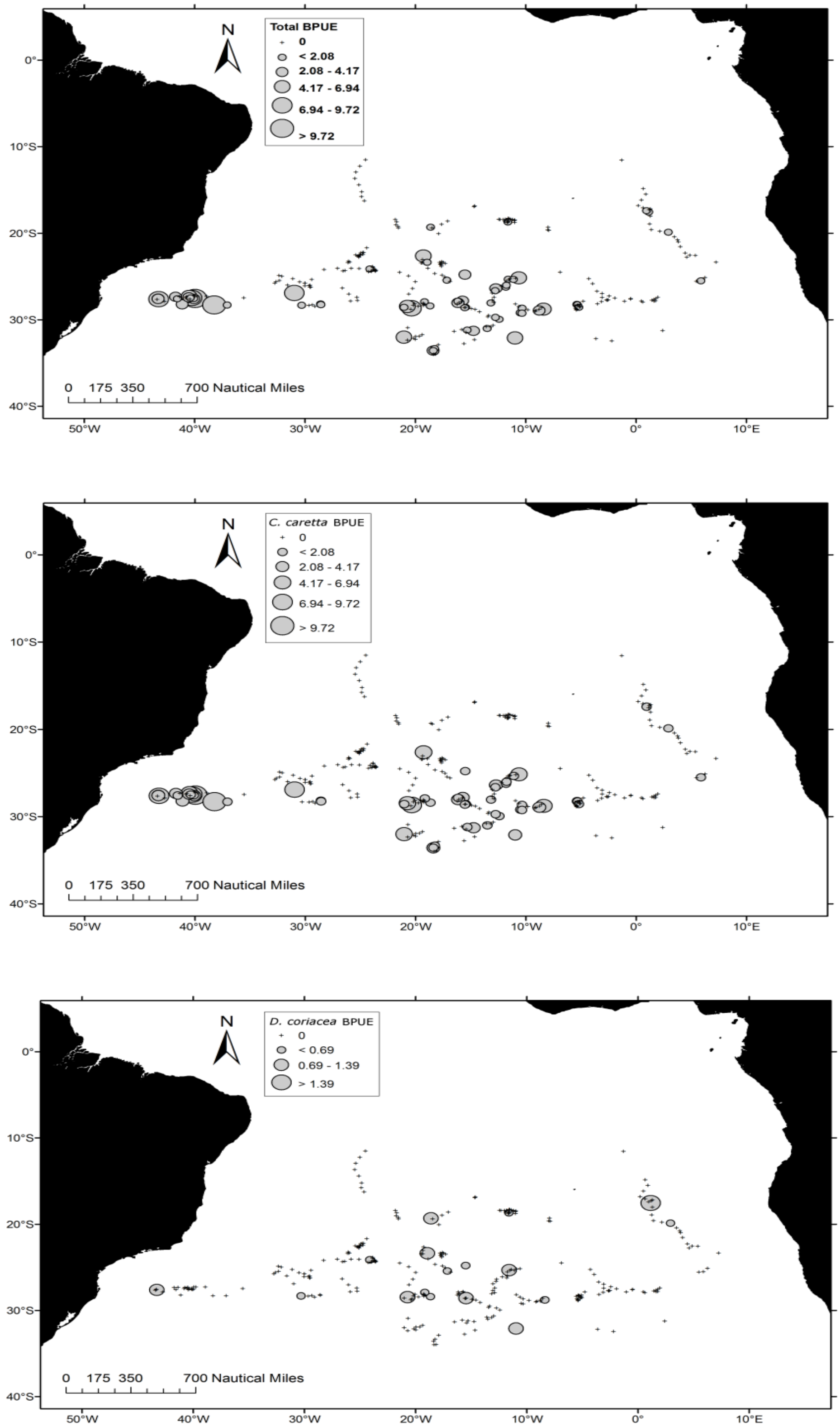

Figure 3.1 - Spatial distribution of BPUE by longline experimental set, for turtle species combined (top), loggerhead (TTL - *C. caretta*, middle) and leatherback (DKK - *D. coriacea*, bottom).The size of the circles is proportional to the BPUE and the dark crosses represent fishing sets with 0 catches.

For the loggerhead sea turtle, and using the binomial modeling analysis, both the hook style and the bait type were significant for explaining the BPUE rates. Additionally, the interaction between hook style and the bait type was marginally significant (likelihood ratio test: diff. residual deviance=5.32, p=0.07), and produced a slightly lower AIC value (simple effects model AIC = 1404.3; model with hook-bait interaction AIC = 1402.9). When changing the bait type from squid to mackerel the odds-ratios of catching loggerhead sea turtles decreased significantly regardless of the hook style used, with these decreases ranging between 67-82% (Table 3.3). However, and due to the interaction observed, changing from J-style to one of the circle hooks was only significantly different when using squid bait (with the odds-ratios decreasing between 54% and 63%), but not when using mackerel bait (with the 95% confidence intervals of the odds-ratios ranging between reductions of 65% to increases of 86%).

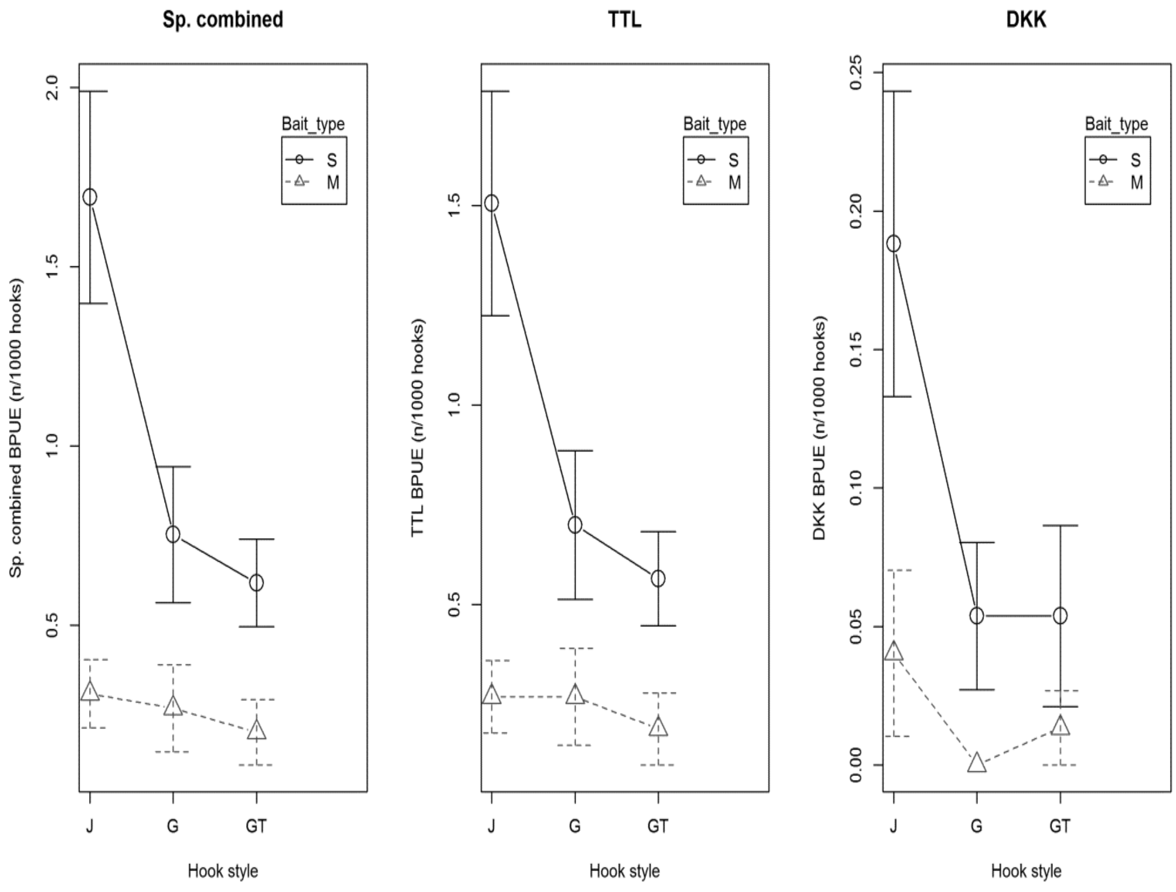

Figure 3.2 - Plot of the mean BPUE (with the respective standard errors) observed with the different hook styles (J, G and GT) and bait types combinations, for the species combined, loggerheads (TTL - *C. caretta*) and leatherbacks (DKK - *D. coriacea*). On the bait type, M refers to mackerel and S refers to squid.

Table 3.2 - Ratio between the mean BPUE obtained with the standard fishing gear (J hook baited with squid - control) and the different combinations of hook style (J – 10º offset 9/0 hook; G – non-offset 17/0 circle hook; GT – 10º offset 17/0 circle hook) and bait type (S – squid; and M – mackerel) tested, for species combined and for the two sea turtle species caught.

Comparison	Loggerhead	Leatherback	Combined species
J_S *vs.* G_S	2.2	3.5	2.3
J_S *vs.* GT_S	2.7	3.5	2.7
J_S *vs.* G_M	5.6	-	6.3
J_S *vs.* GT_M	8.0	14.0	8.4
J_S *vs.* J_M	5.6	4.7	5.5

Table 3.3: Odds-ratios, with the respective 95% confidence intervals, for the effects of changing hook styles and bait types in the loggerhead (*Caretta caretta*) BPUE, accounting for the model interactions.

Interaction	Main factor	Estimate	Lower 95%CI	Upper 95% CI
Using squid bait	Change from J to G	0.46	0.33	0.64
	Change from J to GT	0.37	0.26	0.53
Using mackerel bait	Change from J to G	1.00	0.54	1.86
	Change from J to GT	0.70	0.35	1.39
Using J-style hook	Change from Squid to Mackerel	0.18	0.11	0.29
Using G-style hook	Change from Squid to Mackerel	0.38	0.23	0.64
Using GT-style hook	Change from Squid to Mackerel	0.33	0.18	0.61

3.2.3. Bycatch at size and hooking location

Loggerheads ranged in CCL from 41 to 78 cm and averaged 61.5 (±6.09) cm (N=260, n=234). Only 42% (N=26) of leatherback turtles (CCL from 48 to 140 cm and averaged 92.9 (±33.82) cm) were measured. For both species combined, the mouth was the most frequent hooking location (65.7%) regardless of the hook type used (Figure 3.3). However, when the species were analyzed separately it was possible to determine species-specific patterns of hooking locations. Leatherbacks were almost exclusively hooked by the flippers (73.1%) or entangled (19.2%) on the lines, whereas most loggerhead turtles bite the bait, with 71.5% hooked in the mouth and 17.7% hooked in the esophagus (Figure 3.3).

The relative proportions of the different hooking locations were statistically different between hook styles (Figure 3.3), as confirmed by Chi-square tests between the two factors. This analysis was carried out for species combined (Chi-square=17.80, df=4, p=0.001) and for the loggerhead (Chi-square=20.87, df=4, p<0.001). On the contrary, the relative proportions of the different hooking locations were not statistically different between bait types for species combined (Chi-square=1.72, df=2, p=0.424) and the loggerhead (Chi-square=1.74, df=2, p=0.418) (Figure 3.3). These analyses were not performed for the leatherback as most specimens were captured by the flippers, and the contingency tables had cells with zero values for most of the other combinations.

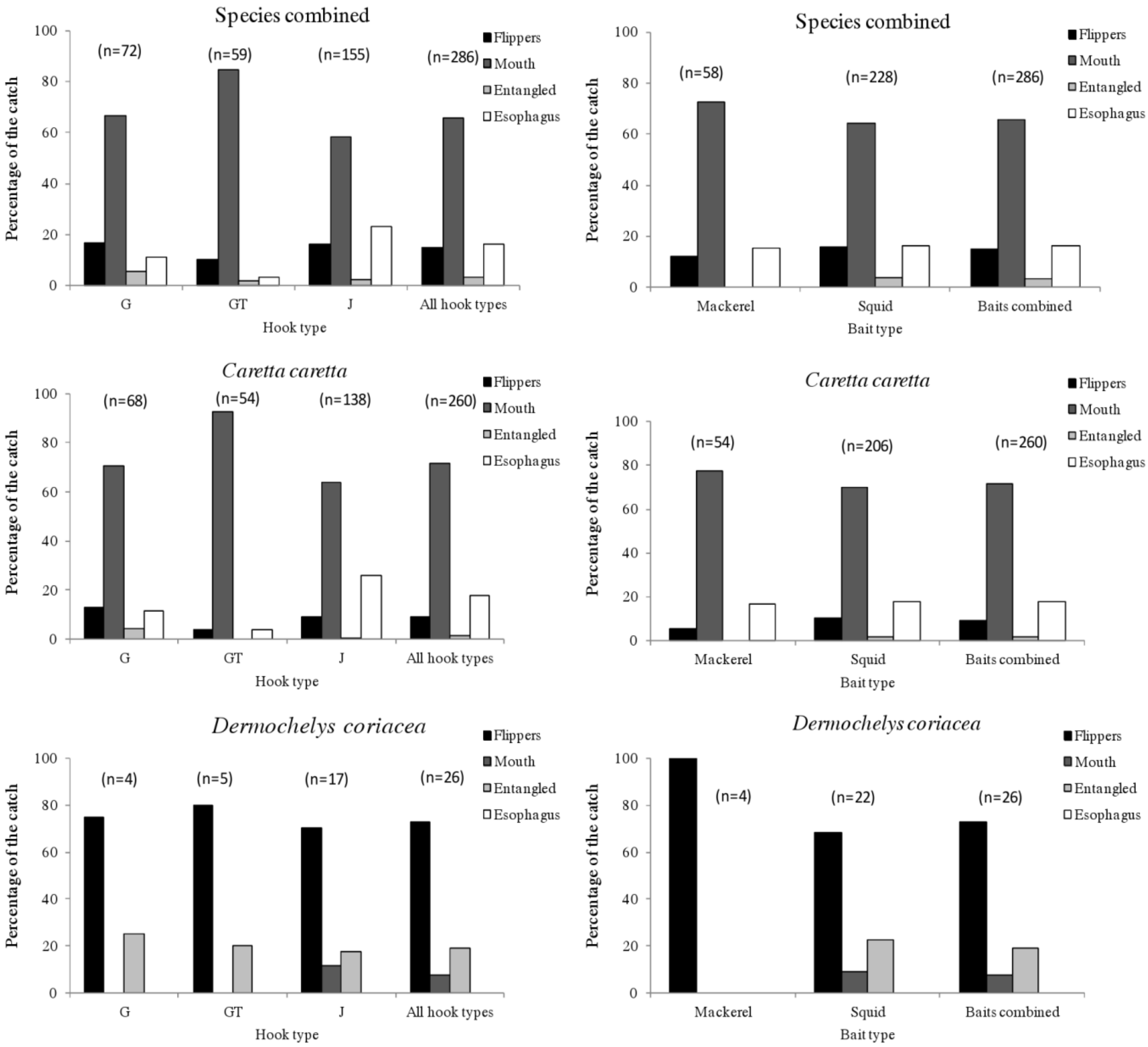

Figure 3.3 - Hooking location per hook style (left) and bait type (right) for all species combined, loggerhead (*C. caretta*) and leatherback (*D. coriacea*). The bars refer to the percentage of each hooking location within each hook style or bait type. Numbers between brackets refer to the corresponding nominal catch of each hook style or bait type.

For loggerheads the size distribution did not significantly vary depending on the bait type (t-Student: t=1.19, df=232, p=0.236) (Figure 3.4). However, significant differences in the size distributions were detected between hook styles (ANOVA: F=7.73, df=2, p<0.001), and hooking locations (ANOVA: F=8.71, df=3, p<0.001, Figure 3.4). Using Schefee *post-hoc* multiple comparison tests for hook styles, it was noted that significant differences only occurred between GT hooks and the other two hook styles (J and G), with GT hooks capturing significantly larger specimens. With regards to the hooking location, significant differences were found between entangled and the remaining hooking locations, with the entangled specimens significantly smaller (Figure 3.4).

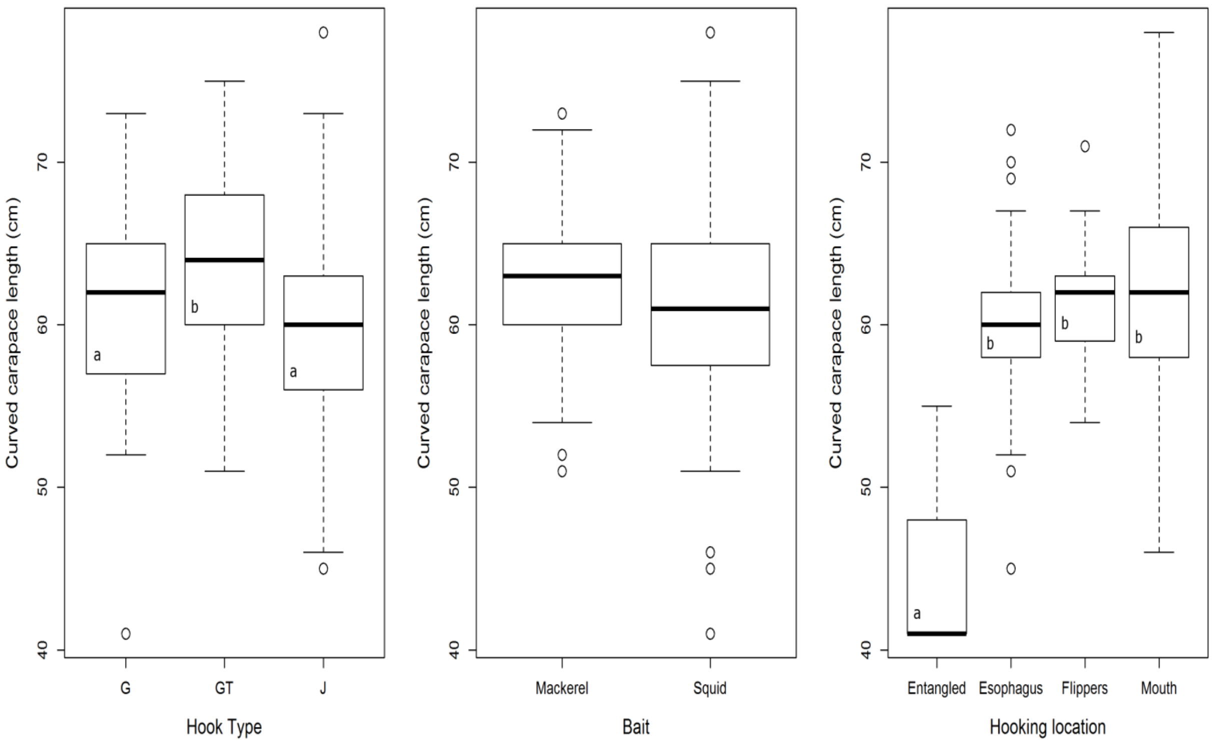

Figure 3.4 - Boxplots with the size distribution (median, inter-quartil range, non-outliers range and outliers) for loggerhead (*C. caretta*), for each of the three factors considered (bait type, hook style and hooking location).

3.2.4. Mortality

Overall, 65% of all sea turtles were alive at-haulback and were, therefore, released alive. The overall percentage of alive specimens at-haulback was higher for leatherbacks (85%) than for loggerheads (63%). The hooking location seems to have a great impact on mortality with most specimens caught by the flippers being alive at the time of haulback (88%), while the specimens entangled or hooked in the esophagus and in the mouth had lower percentages of alive specimens (22%, 48% and 66% alive at the time of haulback, respectively) (Figure 3.5). Because the two species tended to be hooked in different ways, hooking location reflected the species-specific mortality.

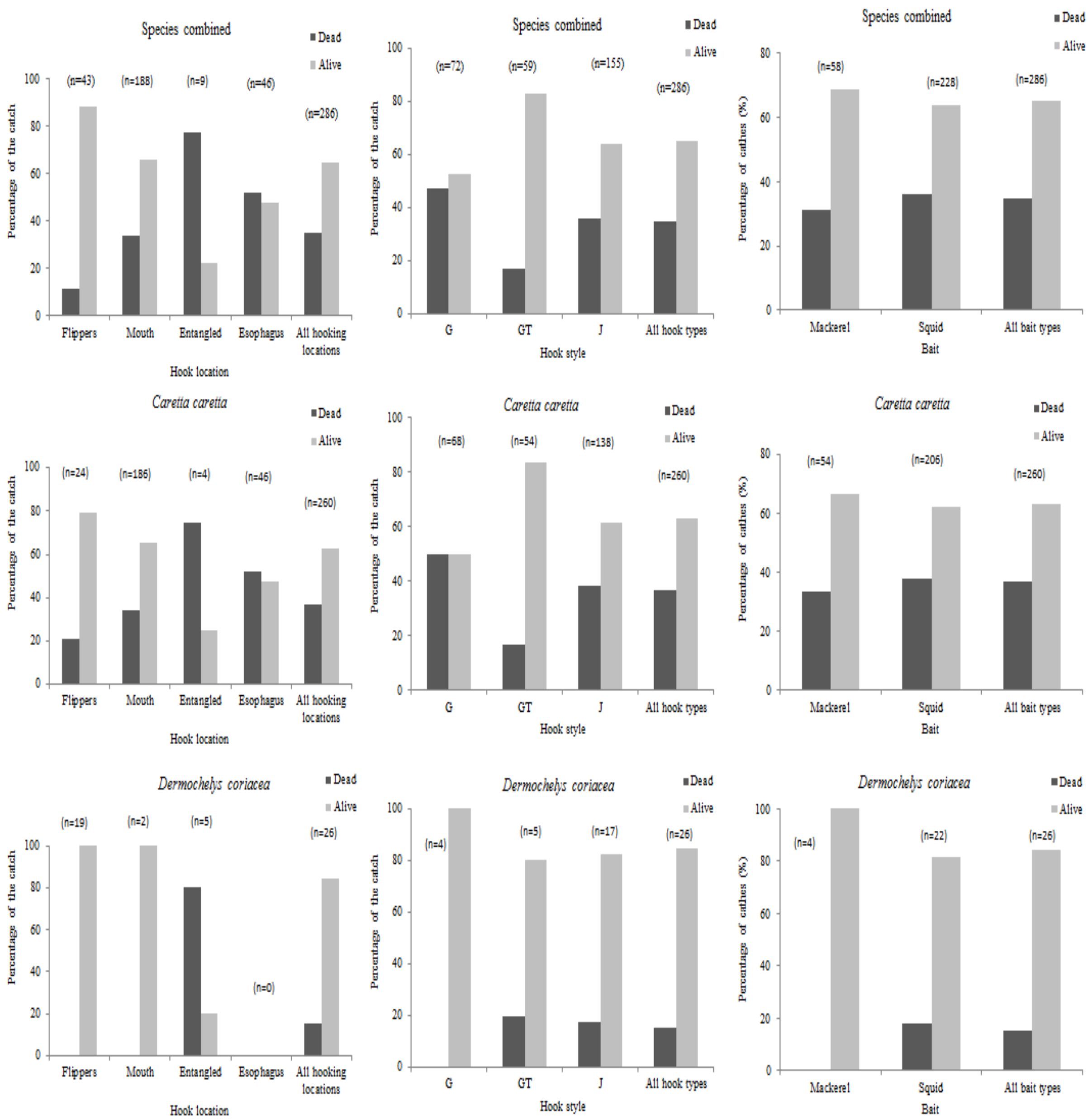

Figure 3.5 - Percentage of fishing mortality at-haulback per hooking location (left), hook style (center) and bait type (right), for all species combined (top), loggerhead (*C. caretta*, middle) and leatherback (*D. coriacea*, bottom). The numbers between brackets refer to the corresponding nominal catch for each hooking location (n), hook style and bait type.

For the factor hook style, and considering species combined, the GT-style hook had proportionally more turtles alive (83%) than dead (17%), with the percentage of alive specimens decreasing substantially for the J-style hooks (64%) and even more with the G hooks (53%), with those differences statistically significant (Chi-square Proportion test: Chi-square=13.27, df=2, p=0.001). When the loggerhead data were analyzed separately, the proportion of alive specimens was 83%, 62% and 50% for hook types GT, J and G, respectively (Figure 3.5), which was again statistically significant (Chi-square Proportion test: Chi-square=14.64, df=2, p<0.001). For leatherbacks, the proportions of alive specimens were very high for all hook styles; 100%, 82% and 80% for hook types G, J and GT, respectively (Figure 3.5). For the factor bait type, the observed *versus* expected frequencies of dead and alive turtles were not significantly different for species combined (Proportion Chi-square with Yates correction: Chi-square=0.49, df=1, p=0.48), neither for loggerheads individually (Proportion Chi-square with Yates correction: Chi-square=0.21, df=1, p=0.65).

3.3. DISCUSSION

The overall mean sea turtle BPUE observed in this study using the traditional gear configuration (1.694/1000 hooks) was similar to that reported by Sales *et al*. (2010) for another pelagic longline fishery targeting swordfish off southern Brazil (1.893/1000 hooks). However, our observed overall BPUE was higher than those reported by Pinedo and Polacheck (2004) off southern Brazil (1.48/1000 hooks), Pons *et al*. (2010) off Uruguay (average of 1.00 loggerheads/1000 hooks between 1998 and 2007), Petersen *et al*. (2009) off South Africa (0.04/1000 hooks) and Afonso *et al*. (2012) off northern Brazil (0.47-0.94/1000 hooks). Major interactions (22% of the sets) of loggerhead, and to a smaller extent leatherback sea turtles, seem to exist with the Southern Atlantic Portuguese pelagic swordfish longline fishery, particularly between 37ºW and 44ºW of longitude, as shown by the present study. A similar trend was found by Pinedo and Polacheck (2004) and Sales *et al*. (2010) in the South Atlantic, with loggerheads followed by leatherbacks also being the most captured species by the Brazilian and Uruguayan pelagic longline fleets. In the Equatorial Atlantic, the olive ridley (*Lepidochelys olivacea*) was the sea turtle species that interacted the most with the pelagic swordfish longline fishery, although other sea turtles were also present (Carranza *et al*., 2006; Sales *et al*., 2008; Santos *et al*., 2012). In comparison, for the North-west Atlantic region the loggerheads and leatherbacks seem to be the species most commonly caught in pelagic longlines (Watson *et al*., 2005; Foster *et al*., 2012). Hence, and as suggested by Gardner *et al*. (2008), the incidental capture of sea turtles seems to vary considerably by region, with the water temperature possibly playing a major role in this variability.

The present study shows that sea turtle interactions can be significantly reduced by using mackerel in place of squid bait and to a lesser extent by employing circle hooks. A combination of circle hooks baited with mackerel can result in a reduction in sea turtle catches by 87.5% and 100% for loggerheads and leatherbacks, respectively. Still, the reductions observed in this study for leatherbacks should be interpreted with care, as the catches of that species in particular were very low. Similar findings were presented for the

South-east Atlantic by Anon. (2008), where it was suggested that bait type had the greatest influence on loggerhead turtle bycatch. Previous studies have also shown that changing the bait type from squid to mackerel (or other fish) and/or the traditional J to circle hooks, were effective measures to reduce sea turtle bycatch in different oceanic areas: in the North-west Atlantic (Watson *et al*., 2005; Foster *et al*., 2012); in North-west Pacific (Yokota *et al*., 2009); in the Equatorial Atlantic (Pacheco *et al*., 2011; Santos *et al*., 2012); and South Atlantic (Domingo *et al*., 2009; Sales *et al*., 2010). However, these comparisons should be carefully analyzed as the cited studies used slightly different hooks (in terms of sizes and shapes), covered different seasons and areas (with different ranges of temperature), and were based on substantially different numbers of sets.

As loggerhead and leatherback turtles have different life histories, pelagic longlines impact both species differently, which can influence the size distribution of the captures. Leatherback sea turtles are pelagic/oceanic during all stages of their life (Bjorndal, 1997), thus a wide size range was observed in the captures, including adult specimens. It must be noted that the largest specimens captured were likely not measured due to difficulty in handling and boarding, thus no statistical inference should be made with regards to the sizes of the catches for this species. On the other hand, loggerheads typically frequent open waters feeding on pelagic invertebrates, where the juvenile development takes place, and after a decade or longer, sub-adults and adults move to neritic habitats near the continental coastline and start feeding upon benthic invertebrates (e.g. Mollusks) and fish (Bjorndal, 1997). As a result, based upon the information reported by Domingo *et al*., (2006) on the size at maturity for the South-western Atlantic Ocean, the captured loggerheads in our study were mostly juveniles. Similar catch-at-size of loggerheads were reported by other studies in the South Atlantic (Pinedo and Polacheck, 2004; Domingo *et al*., 2009; Sales *et al*., 2010). While bait type did not influenced loggerheads size distribution, significant differences were found in the size distribution between hook styles, with GT hooks capturing larger specimens. Stokes *et al*. (2012) alerts to the fact that when comparing hook type effects in size distribution a potential hook-size effect may be masked, due to the fact that most commonly used J hooks (7/0, 8/0, and 9/0) are slightly smaller than 16/0 and 18/0 circle hooks. Sales *et al*. (2010) also found significant differences in the sizes of captured loggerheads, with circle hooks capturing larger specimens, compared to those reported by Domingo *et al.* (2009) and Anon. (2008) who found no differences in the size distribution between hook types and bait in the same region. Likewise, no differences were found for the Olive ridley sea turtles caught in the Equatorial Atlantic by the Portuguese fishery (Santos *et al*., 2012).

Hooking location seemed to be mainly species-specific, which may be related to each species feeding behavior. While leatherbacks were almost exclusively hooked externally, mainly by the flippers (with all hook types), loggerheads were mostly hooked by the mouth in all treatments. Significant differences were found for this species in the relative proportions of the different hooking locations between hook styles, with J hooks showing a higher proportion of loggerheads retained by the esophagus, while the bait showed no significant differences. Likewise, in the North-west Atlantic, Watson *et al*. (2005) and Epperly *et al*. (2012) found no significant differences in hooking location for both loggerheads and leatherbacks upon switching between mackerel and squid bait. Anon. (2008) and Sales *et al*. (2010) also noted that deep-hooking involved more often J hooks than circle hooks, in the South Atlantic. In the North Atlantic, Stokes *et al*. (2012) also found significant differences in hooking location in loggerheads when comparing offset J hooks and non-offset and 10° offset circle hooks, with the latter hooking mostly loggerheads by the mouth while offset J hooks were swallowed more often. In contrast, Carruthers *et al*. (2009) found no significant differences in hooking location for loggerheads when comparing 16/0 circle hooks, non-offset J hooks, and offset (20°–30°) J hooks in the Canadian longline fishery for swordfish and tuna in the North Atlantic.

The main factor that seemed to influence at-haulback mortality of sea turtles was the hooking location. Turtles hooked externally (by the flippers or entangled) showed a large proportion of specimens that were alive at-haulback, while specimens that were hooked in the mouth or deep hooked in the esophagus had a higher proportion of dead specimens at time of haulback. Hence, the type of circle hook appears to be an important factor in the mortality rate as well, as there were statistical differences between the three hook types tested. In loggerheads the GT hook showed the lowest at-haulback mortality, followed by J hook and G hook, whereas Sales *et al*. (2010) found no differences in loggerhead mortality among hook types. In the Equatorial Atlantic, Santos *et al*. (2012) also found differences in mortality between the same three hook types although, contrary to this study, for both sea turtle species (olive ridley and leatherback) the J hook had the highest mortality. Our reported mortality results represent the short term at-haulback mortality, and should be interpreted as minimum mortality estimates, as post-release mortality may occur. Estimating post-interaction survival is difficult given the variety of factors involved with each unique interaction. However, lightly hooked sea turtles (external and mouth hooked) have a higher chance of survival than sea turtles that swallow the hook, particularly when all gear is removed before release (Ryder *et al*., 2006; Swimmer *et al*., 2006). Results from satellite telemetry research also support the hypothesis that deeply hooked turtles have a higher probability of mortality than lightly hooked turtles when all gear is removed (Chaloupka *et al.,* 2004).

Overall, the present study supports previous reported results on the reduction of sea turtle accidental catches in the swordfish longline fisheries, by changing the traditional configuration of J hook baited with squid to circle hooks baited with mackerel. It is important to note, however, that in this study the bait seemed to have more influence on the level of bycatch reduction than the hook style itself, and that in the case of mortality the effect of the hook type is not so evident (GT *vs* G instead of GT/G *vs* J). A high variability between results seems to exist in the literature, highlighting the influence of different aspects (e.g. region and consequently the species, season, fishery, etc.) in sea turtle accidental captures. For this reason extreme caution must be used when interpreting the results of this kind of studies. For example, Anon. (2008) mentions a remark of one observer alerting to the fact that circular hooks were much more difficult to remove than J-style hooks whether hooked in the mouth or internally. In addition, the observer stated that more traction was caused in the esophagus, producing tissue tears and hemorrhages when removing ingested circle hooks compared to J hooks. Parga (2012) illustrates another example of the uncertainty about the benefits of the use of circle hooks, stating that even though hooks in the mouth are generally considered low risk, sensitive structures are present in the mouth, such as the glottis or the jaw joint, that if damaged may cause death due to infection. The esophagus, on the other hand, has a strong muscular wall and is somewhat resistant to lesions, unless the hook lodges close to the heart or large blood vessels. The same author further noted that cutting short the branch line close to the mouth enables some deep hooked sea turtles to swallow and even expel the hooks without major harm. Therefore, gear removal seems to play a crucial role in turtle survival/mortality, and training vessel crews for onboard turtle management is essential for improving turtle survival at sea and maximizing possible positive effects of gear change.

It is clear that circle hooks baited with mackerel significantly reduce sea turtle incidental catch on the Portuguese pelagic swordfish longline fishery in the southern Atlantic. However, from the fisheries management point of view, it is essential to assess the consequences of such gear modifications in a wider scale, prior to implementing them. The human dimensions of such modifications also have to be addressed (Campbell and Cornwell, 2008) and the economic impacts in the fishery have to be considered. For instance, on some cases, possible reductions in the target species catches may occur (e.g. Largarcha *et al*., 2005; Báez *et al*., 2010; Domingo *et al*., 2012), while in other cases the reductions in the target species catches are balanced by the gains in other marketable species (e.g. Coelho *et al*., 2012). Increases in the target species catches, while decreasing sea turtle bycatch, have been also observed in some fisheries when changing to circle hooks with mackerel (e.g. Pacheco *et al*., 2011; Foster *et al*., 2012). Besides the economics, other factors to reflect on when considering gear changes are the impacts to other vulnerable species. As an example, Coelho *et al*. (2012) observed that when changing from squid to mackerel, although sea turtles bycatch decreased, the catch rates of some large pelagic sharks, like the vulnerable bigeye thresher, increased significantly.

CHAPTER IV – EFFECTS OF HOOK AND BAIT ON FISH CATCHES

4.1. INTRODUCTION AND OBJECTIVES

As described in chapter III, circle hooks and a shift from squid to fish in shallow-set (<100 m) longline fishery are very efficient on the reduction of incidental bycatch of sea turtles. Similar results were the basis for changes on fisheries management on some fisheries (e.g. USA and Australia), where their use has become mandatory in pelagic longline fisheries. Despite the demonstrated benefits of large circle hooks to mitigate sea turtle takes, different studies have yielded conflicting and variable results in terms of target and bycatch species (e.g. review paper by Read, 2007). A review by Serafy *et al*. (2009) of istiophorid-focused circle hook studies provided 30 species-specific comparisons of J hooks *versus* circle hooks in recreational rod-and-reel and commercial fisheries and found no significant differences in the catch rates for four billfish species. This author´s concluded that without evidence of negative effects from the use of circle hooks there was a scientific basis for their promotion when considering billfish fisheries. However, opposite results were obtained by Curran and Bigelow (2011), in a recent study in the Hawaii-based tuna longline fishery, where they found that catch rates on circle hooks for 16 species were significantly lower compared to Japanese-style tuna hooks and suggested a potential catch reduction of 29.2%‐48.3% for billfishes if 18/0 circle hooks were adopted throughout the Hawaii based fleet. In fact, in some cases, the gear modifications can reduce the catches of the target species to such a degree that their use is impractical and hinder their use on a voluntary basis by the fishers [e.g. the case study of the mahi-mahi fishery in Ecuador reported by Largarcha *et al*. (2005)]. Moreover, the efficiency of such gear modifications is not only taxon-specific, but also depends on the particular fishery and fishing fleet. Given these complexities that involve possible modifications in fishing gears, different researchers have recommended different approaches and studies regarding the effectiveness of circle hooks as part of a multiple species approach, so as to avoid, as far as possible, promoting a mitigation measure for one bycatch taxon that might exacerbate bycatch problems for other taxa (Anon, 2008). In recent years there has been increased concern with regards to this issue and several recent studies have been addressing it (Bigelow *et al*., 2012; Coelho *et al*., 2012; Domingo *et al*., 2012).

Therefore, in order to increase the knowledge of the effects of different hook styles and bait types combinations on the catch of target and non-target fish species caught by the Portuguese pelagic longline fishery operating in Southern Atlantic waters, experimental fishing trials were conducted within the scope of the SELECT-PAL Project. The present chapter reports the catch composition, catch rates, size, and mortality at-haulback of retained and discarded fish species encountered during this study.

4.2. Results

4.2.1. Catch composition

In total, 18176 fishes of 34 species were recorded during the present study (Table 2.2 in Annex II). Swordfish was considered the target species, 19 were assigned as bycatch (14 teleosts and 5 elasmobranchs), and the remaining 14 taxa were discards (among these, 5 were teleosts and 9 were elasmobranchs). The frequency of occurrence varied greatly depending on the species, with the target species (swordfish) being the most frequently-caught species in the fishery, occurring in 98.4% of the sets and representing a total of 34.4% of the total catch in weight. Blue shark occurred in 98.1% of the sets (51.2% of the catches in weight) and combined with swordfish, represented 85.6% of the overall retained catch in weight. The highest catches for swordfish were observed in the western part of the study area, between 20ºW and 44ºW, while for blue shark it was the opposite, with increasing catches at eastern longitudes (between 20ºW and 7ºE) (Figure 4.1. and 4.2). For *Thunnus* spp, albacore, yellowfin and bigeye, it was detected a frequency of occurrence of 34.8%, 17.1% and 16.1% (of the sets) respectively, corresponding to 3.53% of the total retained catch in weight. A correlation between swordfish catch rates and latitude and longitude was observed, with increasing CPUEs tending to be mainly recorded towards northern latitudes (Spearman´s correlation=0.199, p-value<0.001) and western longitudes (Spearman´s correlation=-0.31, p-value<0.001) of the sampling area (Figure 4.1). For blue shark it was the opposite, with increased CPUEs mainly recorded in eastern longitudes (Spearman´s correlation=0.59, p-value<0.001) and no significant differences were found in the range of latitude (Figure 4.2).

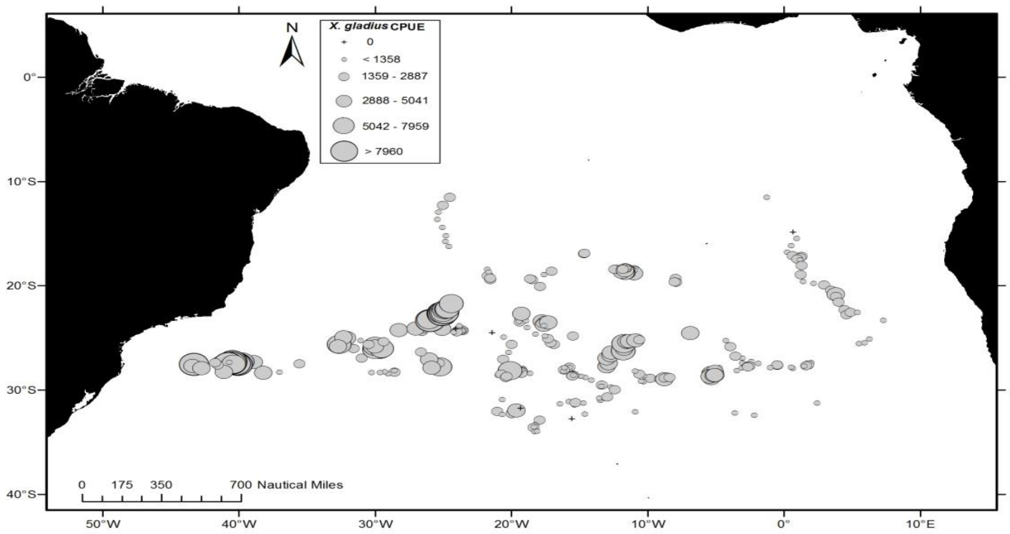

Figure 4.1 - Spatial distribution of CPUE by longline experimental set, for swordfish (SWO – *X. gladius*). The size of the circles is proportional to the CPUE and the dark crosses represent fishing sets with 0 catches.

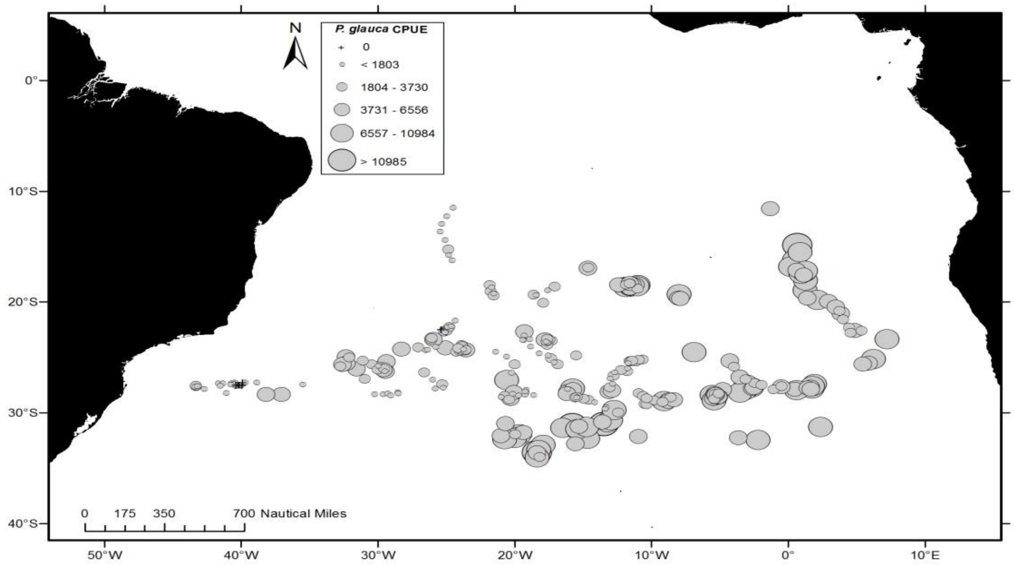

Figure 4.2 - Spatial distribution of CPUE by longline experimental set, for blue shark (BSH – *P. glauca*). The size of the circles is proportional to the CPUE and the dark crosses represent fishing sets with 0 catches.

4.2.2. Effects of hook and bait on retained catches

The effects of the various hook styles and bait types appeared taxon-specific, with the catch rates varying according to the six hook-bait combinations tested. For swordfish, the highest catch rate was obtained for the combination J hook baited with squid and significant differences were observed among hook styles (Kruskal-Wallis: Chi-square=8.46, df=2, p=0.01) and bait types (Mann-Whitney: W=146660, p<0.01, Figure 4.3; Table 4.1).

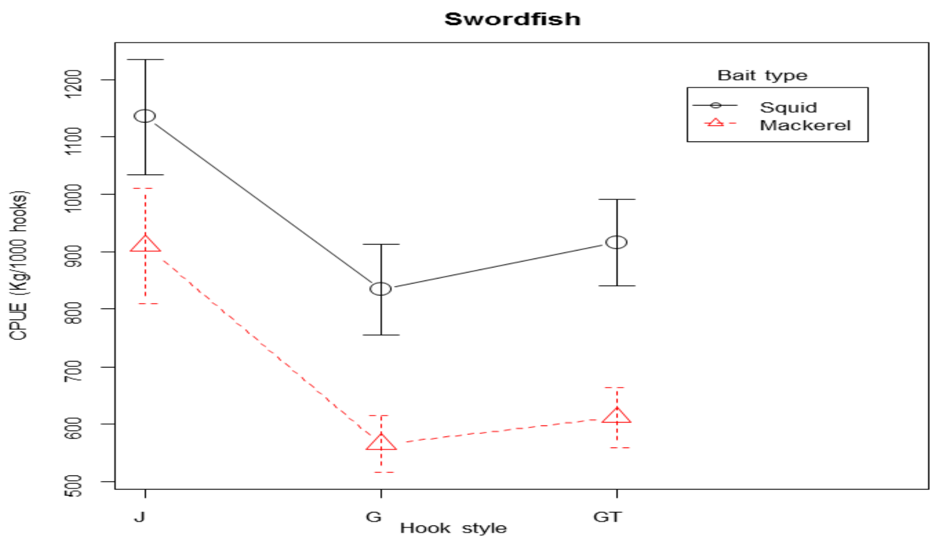

Figure 4.3 – Plot of the mean CPUE (with the respective standard errors) observed with the different hook styles (J, G and GT) and bait types (Squid and Mackerel) combinations for swordfish (*Xiphias gladius*).

There were species-specific differences for the teleost bycatch with the overall rates being higher with G hooks baited with squid. These results were highly influenced by the blue marlin (*Makaira nigricans*) and albacore (*Thunnus alalunga*) catches. For the total elasmobranches bycatch, the combination G hooks, baited with mackerel had the highest CPUE (Table 4.1). Several retained species were analyzed individually, either due to their relatively high commercial value or to the quantity of bycatch in weight (i.e. tunas, marlins, dolphinfish, escolar, blue shark, shortfin mako and longfin mako). Testing for the individual effects of hook and bait on CPUE of tuna species, revealed that the use of squid significantly increased catches of the three tuna species while the use of circle hooks only resulted in significantly higher catches for the albacore tuna (Table 4.1; Figure 4.4).

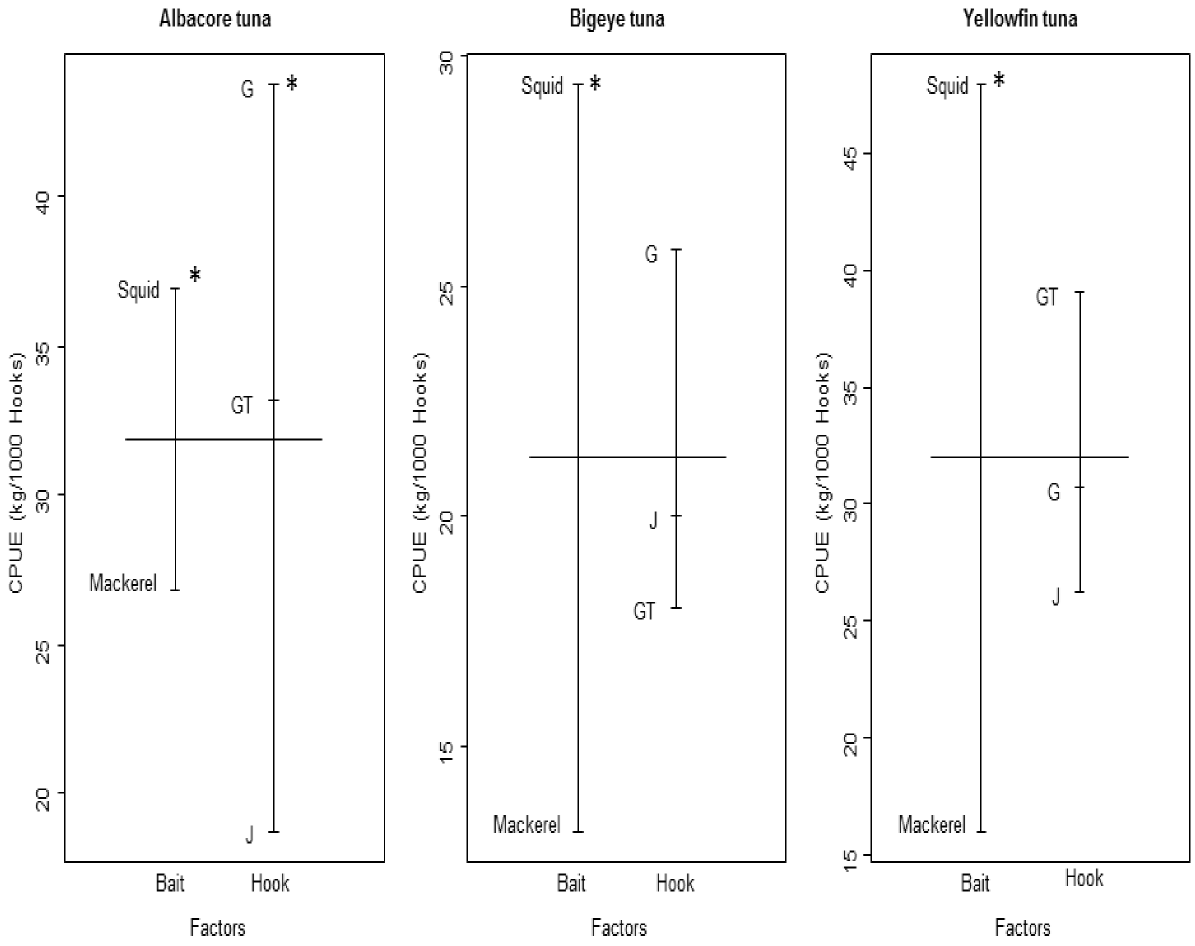

Figure 4.4 - Plot design of the catch per unit effort (CPUE, Kg/1000 hooks) by the different hook styles (J, G and GT) and bait types (Squid and Mackerel) for the three tuna species: albacore tuna (*Thunnus alalunga*), bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*). The vertical lines represent the range of values while the horizontal line represents the overall mean across all observations. Bait effect was significant (*) for the three species and hook effect was only significant for albacore tuna.

Table 4.1 - Mean catch per unit effort (CPUE, kg/1000 hooks) with respective standard deviation in parentheses for the various hook-bait combinations. J = 10º offset 9/0 hook; G = non-offset 17/0 circle hook; GT = 10° offset 17/0 circle hook. P-values are from Mann-Whitney tests comparing bait types and the Kruskal-Wallis tests comparing hook styles. p<0.05 are in bold. NT = not tested.

FAO code	Species name	Squid			Mackerel			Comparisions (p-values)	
		J	**G**	**GT**	**J**	**G**	**GT**	**Bait**	**Hook**
SWO	*Xiphias gladius* - Target species	1135,1 (±1246,6)	834,3 (±987,2)	916,1 (±940,8)	910,6 (±1243,6)	565,4 (±614,7)	612,1 (±640,9)	**<0,01**	**0,01**
ALB	*Thunnus alalunga*	24,2 (±56,6)	53,9 (±150,4)	32,8 (±77,8)	13,3 (±76,3)	33,6 (±118,4)	33,5 (±133,6)	**<0,01**	**0,03**
YFT	*Thunnus albacares*	30,4 (±114,3)	45,4 (±165,8)	67,9 (±182,9)	22,0 (±98,5)	16,0 (±104,3)	10,1 (±63,8)	**<0,01**	0,58
BET	*Thunnus obesus*	33,6 (±107,7)	35.0 (±126,4)	19,5 (±91,5)	6,4 (±53,9)	16,6 (±84,2)	16,6 (±89,6)	**<0,01**	0,46
BUM	*Makaira nigricans*	121,7 (±407,1)	136,2 (±577,5)	80,1 (±285,3)	112,1 (±468,2)	75 (±284,8)	84,3 (±408,5)	**<0,01**	0,32
WHM	*Kajikia albida*	33,0 (±63,8)	24,7 (±66,7)	24,2 (±61,0)	19,2 (±53,1)	19,0 (±54,6)	18,7 (±60,5)	**<0,01**	0,09
LEC	*Lepidocybium flavobrunneum*	22,6 (±59,4)	18,1 (±65,3)	10,2 (±46,6)	33,0 (±97,7)	15,8 (±46,2)	14,1 (±38,4)	0,35	**<0,01**
DOL	*Coryphaena hippurus*	8,9 (±25,5)	5,8 (±18,6)	4,5 (±14,3)	6,6 (±23,6)	4,5 (±14,4)	2,7 (±11,5)	**0,01**	0,05
TAS	*Taractes asper*	1,4 (±10,5)	2,4 (±12,9)	1,4 (±10,6)			0,8 (±6,6)	**<0,01**	0,6
AMB	*Seriola dumerili*				0,2 (±3,0)	0,1 (±1,2)	0,3 (±3,4)	**<0,01**	0,78
OIL	*Ruvettus pretiosus*	1,0 (±7,4)	1,1 (±8,0)		0,9 (±6,1)	0,3 (±4,3)	0,9 (±6,1)	0,62	0,14
POA	*Brama brama*	0,1 (±0,9)			0,1 (±0,5)			0,56	NT
SAI	*Istiophorus platypterus*	0,5 (±6,0)						NT	NT
SPF	*Tetrapturus pfluegeri*				0,3 (±3,7)		0,3 (±3,6)	NT	0,61
WAH	*Acanthocybium solandri*	1,7 (±9,7)	1,6 (±7,5)	1,6 (±8,7)	2,2 (±13,6)	1,1 (±6,5)	1,2 (±7,8)	0,32	0,72
	Total teleosts bycatch	279,1 (±123,8)	324,3 (±174,2)	242,3 (±101,3)	216,4 (±136,5)	181,9 (±93,9)	183,3 (±121,8)	**<0,01**	0,38
BSH	*Prionace glauca*	701,9 (±598,3)	1016,8 (±976,8)	904,0 (±879,8)	1355,8 (±1138,5)	1778,3 (±1350,4)	1648,2 (±1303,4)	**<0,01**	**<0,01**
CCA	*Carcharhinus altimus*	0,3 (±2,9)	0,5 (±6,7)			0,2 (±2,6)		0,32	0,37
LMA	*Isurus paucus*			2,0 (±24,3)	3,8 (±25,6)	0,2 (±2,2)	2,4 (±28,1)	0,03	0,41
POR	*Lamna nasus*	1,4 (±17,3)						NT	NT
SMA	*Isurus oxyrinchus*	68,6 (±141,0)	101,5 (±221,2)	99,9 (±228,9)	100,1 (±183,9)	121,6 (±247,0)	136,8 (±300,2)	0,17	0,85
	Total elasmobranch bycatch	772,2 (±340,5)	1118,9 (±598,8)	1005,9 (±538,2)	1459,6 (±741,3)	1900,3 (±930,9)	1787,5 (±880,9)	**<0,01**	**<0,01**
	Total retained catch	2186,5 (±1733,0)	2277,5 (±1499,3)	2164,2 (±1344,7)	2586,6 (±1999,7)	2647,6 (±1443,2)	2582,8 (±1457.3)	**<0,01**	0,11

Non-parametric statistical comparisons indicated that the significant factor on the catch rates of blue marlin (*Makaira nigricans*), white marlin (*Kajikia albida*) and dolphinfish (*Coryphaena hippurus*) was the effect of bait type (higher with squid) while for escolar (*Lepidocybium flavobrunneum*) only hook style was found to be a significant factor (Table 4.1; Figure 4.5). The effects tended to be opposite for elasmobranch bycatch, with most species having higher catch rates with circle hooks baited with mackerel. Particularly, for the blue shark significant differences were observed between bait (Mann-Whitney: W=146660, p<0.01) and hook types (Kruskal-Wallis: Chi-square=13.29, df=2, p<0.01; Table 4.1; Figure 4.6). Non-parametric multiple tests for all-pairs comparisons, enhanced that significant higher CPUE for the swordfish and escolar were obtained with J hooks, while the opposite was observed for albacore and blue shark (higher CPUE with circle hooks).

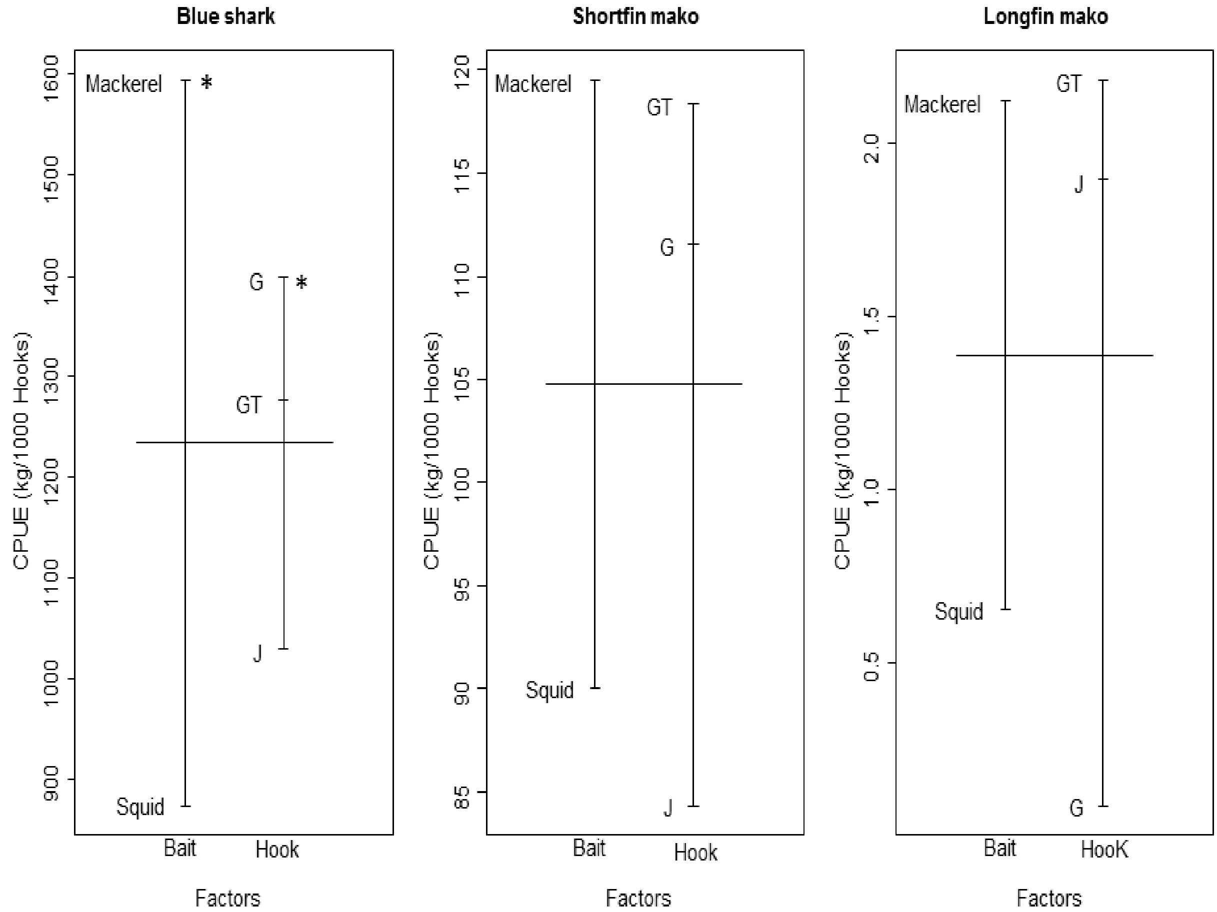

Figure 4.6 – Plot design of the observed catch per unit effort (CPUE, Kg/1000 hooks) by the different hook styles (J, G and GT) and bait types (Squid and Mackerel) for the three main elasmobranch bycatch species in the fishery: blue shark (*Prionace glauca*), shortfin mako (*Isurus oxyrinchus*) and longfin mako (*Isurus paucus*). The vertical lines represent the range of values while the horizontal line represents the overall mean across all observations. Bait and hook effect were only significant (*) for blue shark.

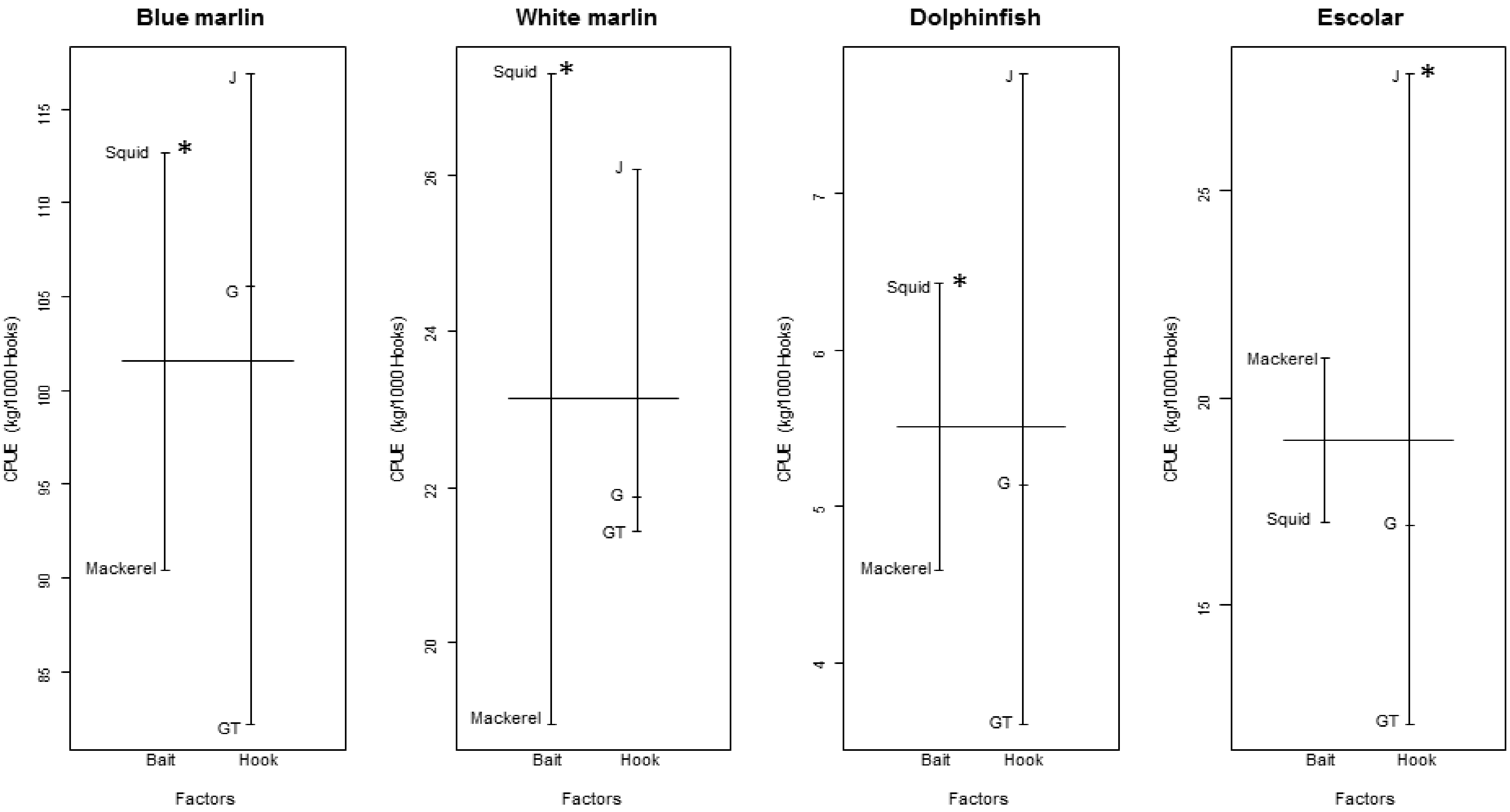

Figure 4.5 - Plot design of the observed catch per unit effort (CPUE, Kg/1000 hooks) by the different hook styles (J, G and GT) and bait types (Squid and Mackerel) for four teleost bycatch species in the fishery: blue marlin (*Makaira nigricans*), white marlin (*Kajikia albida*), dolphinfish (*Coryphaena hippurus*) and escolar (*Lepidocybium flavobrunneum*). The vertical lines represent the range of values while the horizontal line represents the overall mean across all observations. Bait effect was significant (*) for all species with exception for escolar were only hook effect was significant.

For the swordfish and blue shark (the two species with the highest catch rates) plots and univariate non-parametric statistical tests (Figure 4.3 and 4.6; Table 4.1) demonstrated that both hook style and bait type were significant covariates. To model swordfish and blue shark catch rates along with these two explanatory variables it was applied a tweedie distribution, which confirmed that both hook style and bait type were significant factors (Tables 4.2 A and B). The catch rates (CPUE) of swordfish for hook styles G and GT (circle hooks) were lower than with J-style hooks, by factors of 0.68 (95% CI between 0.57 and 0.81) and 0.74 (95% CI between 0.62 and 0.89), respectively (Table 4.2). This represents an estimate reduction in the catch rates of 32% and 26% when changing from J-styles to G and GT hooks, respectively. For the blue shark, when changing from J-style to circle hooks, catch rates increased by factors of 1.37 (95% CI between 1.19 and 1.56) and 1.24 (95% CI between 1.08 and 1.43) for G and GT hooks, representing an estimated increase of 37% and 24%, respectively. Comparing the catch rates in terms of bait type, when changing from squid to mackerel the catches of swordfish were lower by a factor of 0.72 and for blue shark the catches were higher by a factor of 1.82 with 95% CI between 1.63 and 2.04 (Tables 4.2 A and B).

Table 4.2 - Coefficients for the swordfish (A) and blue shark (B) CPUE Tweedie GLM with the respective odds-ratios, considering the covariates hook style and bait type. The parameter estimation of the model, the standard errors (SE), the Wald Statistic (Wald) and the respective p-values are presented. For the odds-ratios the point estimate with the lower and upper 95% confidence intervals (CI) are listed.

A - Swordfish

	Coefficients				Odds-ratios		
Parameter	Estimate	SE	Wald	p-value	Estimate	Lower CI	Upper CI
(intercept)	7,09	0,07	100,7	<0,01			
Hooh style G	-0,39	0,09	-3,2	<0,01	0,68	0,57	0,81
Hook style GT	-0,30	0,09	-2,8	<0,01	0,74	0,62	0,89
Bait Type mackerel	-0,33	0,07	-2,9	<0,01	0,72	0,62	0,83

B – Blue shark

	Coefficients				Odds-ratios		
Parameter	Estimate	SE	Wald	p-value	Estimate	Lower CI	Upper CI
(intercept)	6,55	0,08	80,9	<0,01			
Hooh style G	0,37	0,11	3,4	<0,01	1,37	1,19	1,56
Hook style GT	0,25	0,11	2,3	<0,01	1,24	1,08	1,43
Bait Type mackerel	0,66	0,10	6,3	<0,01	1,82	1,63	2,04

4.2.3. Size distribution of retained catch

Overall, mean sizes for all the species studied were relatively similar between different hook styles and bait types. Significant differences were detected in size distribution when comparing hook styles for bigeye and yellowfin tuna. Using non-parametric multiple tests for all-pairs comparisons for bigeye tuna, it was detected that significant differences occurred between all hook styles, with J hooks capturing significantly larger specimens. For the yellowfin tuna, significant differences only occurred for the pairwise comparison J-G hooks, with higher mean size for circle hooks (Table 4.3 in Annex I; Figure 4.7). For swordfish and shortfin mako, mean size with circle hooks were slightly lower than those recorded for J hook catches (Table 4.3 in Annex I). When comparing bait type significant differences were found for the swordfish, yellowfin, albacore, blue shark and shortfin mako (Table 4.3 in Annex I; Figure 4.8). Yellowfin tuna was the only species where significant differences were detected between the two factors (hook style and bait type). Whereas the opposite (no significant differences) was observed for blue marlin. The mean size of tuna species caught with squid were slightly lower than that found when mackerel was used as bait. In contrast higher mean size for swordfish, blue marlin, blue shark and shortfin mako were registered when squid was used (Figure 4.8).

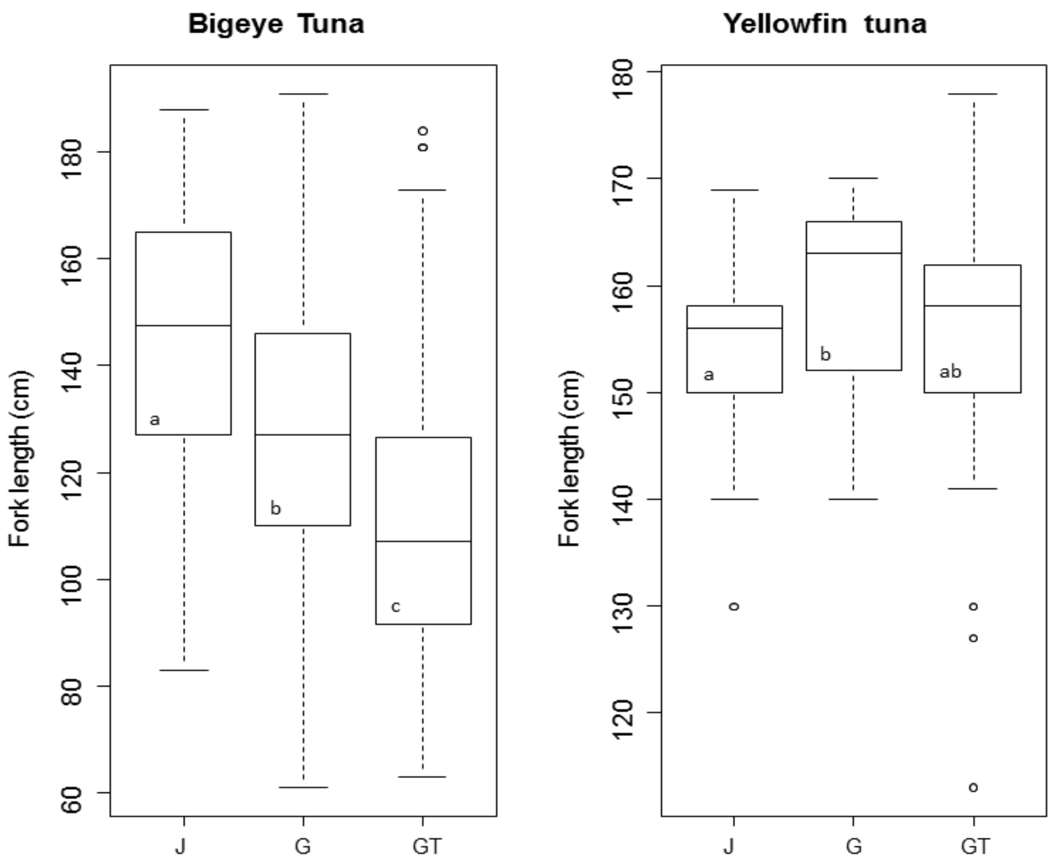

Figure 4.7 - Boxplots with the size distribution (median, inter-quartil range, non-outliers range and outliers) for the species bigeye tuna (*Thunnus obesus*) and yellowfin tuna (*Thunnus albacares*) for each hook style.

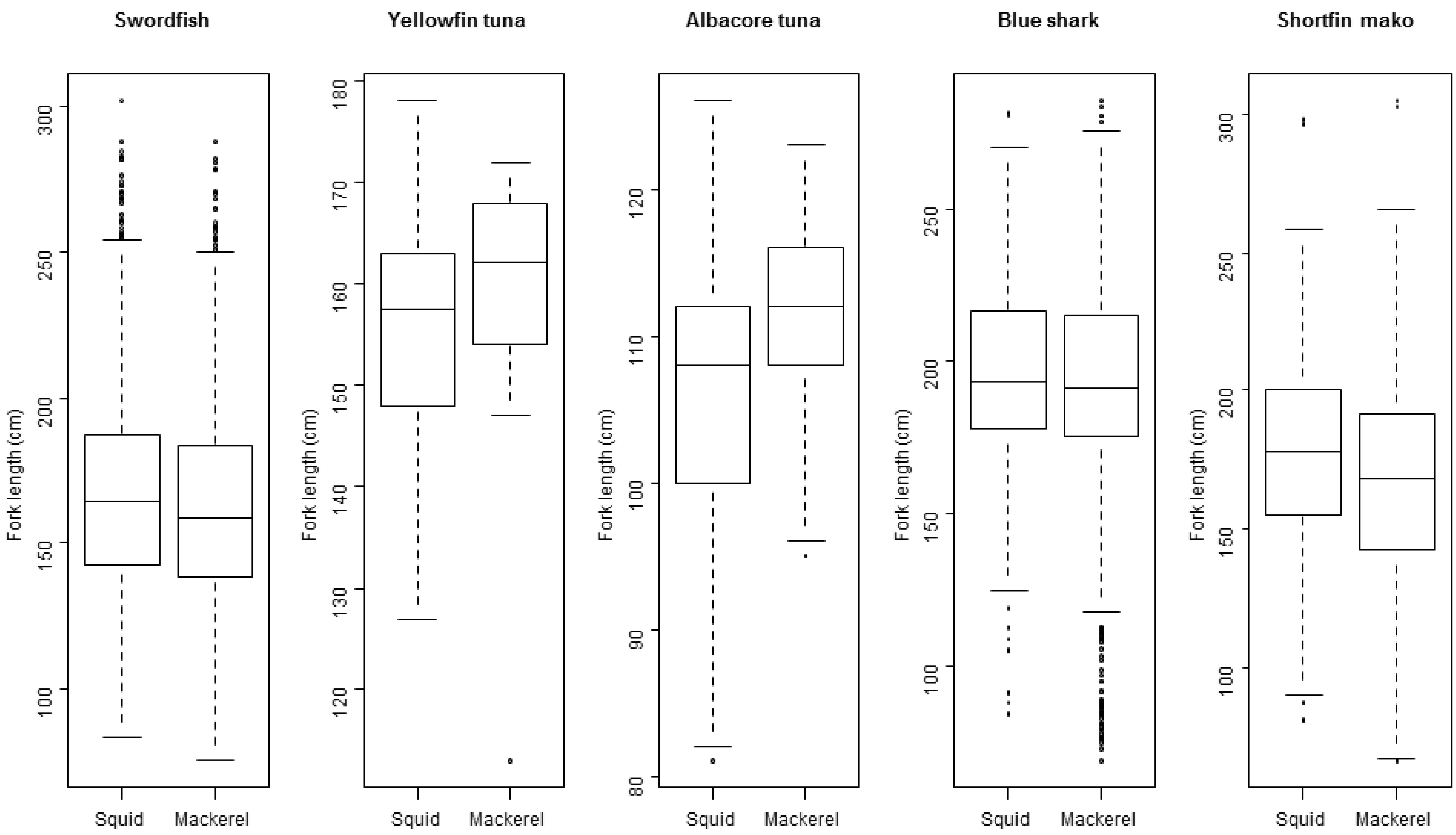

Figure 4.8 - Boxplots with the size distribution (median, inter-quartil range, non-outliers range and outliers) for the species swordfish (*Xiphias gladius*), yellowfin (*Thunnus albacares*), albacore (*Thunnus alalunga*), blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) for each bait type.

4.2.4. Catch rates and mortality of discarded species

In teleost discarded species no significant differences were observed on the catch rates when comparing hook styles, with exception for the snake mackerel *(Gempylus serpens*), as only for the lancetfish (*Alepisaurus ferox*) significant differences were detected in terms of bait type (Table 4.4). As observed with other large pelagic elasmobranches, the catch rates of bigeye thresher shark (*Alopias superciliosus*), hammerhead shark (*Sphyrna zygaena*) and manta rays (Myliobatidae) were higher when mackerel bait was used, but significant differences were only detected for the last two. For the hook style comparisons, significant difference was only detected for the pelagic stingray (*Pteroplatytrygon violacea*), which had the highest catch rates with J hooks (Table 4.4). For the species snake mackerel and pelagic stingray, results from the non-parametric multiple tests for all-pairs comparisons indicated that significant differences occurred between J hooks (higher catch rates) and circle hooks.

Statistical analysis to the at-haulback mortality rates of the discarded species, detected significant differences between hook styles for lancetfish and bigeye tresher shark (Chi-square proportion tests: $p<0.05$, Table 4.5 in Annex I) with higher mortality rates in GT and G hook styles, respectively (Figure 4.9; Table 4.5 in Annex I). Regardless of the hook style used, most of the bigeye thresher sharks and lancetfish were dead at-haulback, while most of crocodile sharks (*Pseudocarcharias kamoharai*) were alive (Figure 4.9; Table 4.5 in Annex I). The statistical (Chi-square proportion test) analysis for the pelagic stingrays was not performed due to cells with zero values in the contingency table (100% alive at-haulback for every hook style). For all discarded species the Chi-square proportions tests (applying the Yates' continuity correction given that the contingency tables are of the 2x2 type), did not detect significant differences in the proportions of dead and alive specimens at-haulback with the two bait types (Chi-square proportion tests: $p>0.05$ on all cases).

Table 4.4 - Mean (standard deviation) catch per unit effort (CPUE, n/1000 hooks) of discarded species for the various hook-bait combinations. P-values refer to the Mann-Whitney tests comparing baits and the Kruskal-Wallis tests comparing hooks. J = 10º offset 9/0 hook; G = non-offset 17/0 circle hook; GT = 10° offset 17/0 circle hook. p<0.05 are in bold. NT = not tested.

FAO		**Squid**			**Mackerel**			**Comparisions (p-value)**	
code	**Species name**	**J**	**G**	**GT**	**J**	**G**	**GT**	**Bait**	**Hook**
ALX	*Alepisaurus ferox*	0,50 (±1.59)	0,16 (±0.77)	0,13 (±0.78)	0,73 (±2.83)	0,42 (±1.75)	0,56 (±1.80)	**<0,01**	0,08
CUP	*Cubiceps sp.*			0,03 (±0.33)				NT	NT
GSE	*Gempylus serpens*	0,09 (±0.55)		0,07 (±0.50)	0,34 (±1.39)	0,08 (±0.58)	0,05 (±0.47)	0,13	**0,01**
LAG	*Lampris guttatus*	0,05 (±0.33)	0,09 (±0.64)		0,08 (±0.58)	0,03 (±0.24)	0,01 (±0.17)	0,79	0,07
MOX	*Mola mola*		0,05 (±0.47)	0,01 (±0.17)			0,03 (±0.33)	0,32	0,37
Total teleosts discards		0,65 (±0.79)	0,31 (±0.5)	0,24 (±0.45)	1,14 (±1.46)	0,52 (±0.84)	0,66 (±0.87)	0,08	**<0,01**
ALV	*Alopias vulpinus*		0,01 (±0.17)			0,01 (±0.17)	0,01 (±0.17)	0,56	0,37
BTH	*Alopias superciliosus*	0,17 (±0.82)	0,26 (±0.99)	0,24 (±1.09)	0,43 (±2.22)	0,17 (±0.95)	0,46 (±1.37)	0,23	0,33
FAL	*Carcharhinus falciformis*		0,03 (±0.33)	0,03 (±0.33)			0,05 (±0.47)	1,00	0,17
ISB	*Isistius brasiliensis*		0,03 (±0.33)			0,08 (±1.00)		1,00	NT
MAN	Myliobatidae	0,04 (±0.37)			0,05 (±0.53)	0,04 (±0.37)	0,16 (±1.13)	**0,03**	0,52
OCS	*Carcharhinus longimanus*	0,03 (±0.24)	0,01 (±0.17)	0,03 (±0.33)	0,01 (±0.17)	0,05 (±0.41)	0,01 (±0.17)	0,74	0,71
PLS	*Pteroplatytrygon violacea*	0,55 (±1.5)	0,03 (±0.24)	0,12 (±0.68)	0,42 (±1.69)	0,2 (±1.11)	0,32(±1.39)	0,95	**<0,01**
PSK	*Pseudocarcharias Kamoharai*	0,3 (±1.27)	0,67 (±2.53)	0,52 (±1.80)	0,27 (±1.13)	0,67 (±2.53)	0,51 (±1.9)	0,89	0,3
SPZ	*Sphyrna zygaena*			0,01 (±0.17)	0,05 (±0.41)	0,05 (±0.41)	0,15 (±0.89)	**<0,01**	0,46
Total elasmobranch discards		1,09 (±0.75)	1,03 (±0.95)	0,95 (±0.77)	1,24 (±1.04)	1,29 (±1.07)	1,68 (±1.06)	0,09	0,17
Total discards		1,70 (±2.90)	1,30 (±3.01)	1,20 (±2.70)	2,38 (±4.58)	1,81 (±4.17)	2,34 (±3.90)	**0,02**	**0,02**

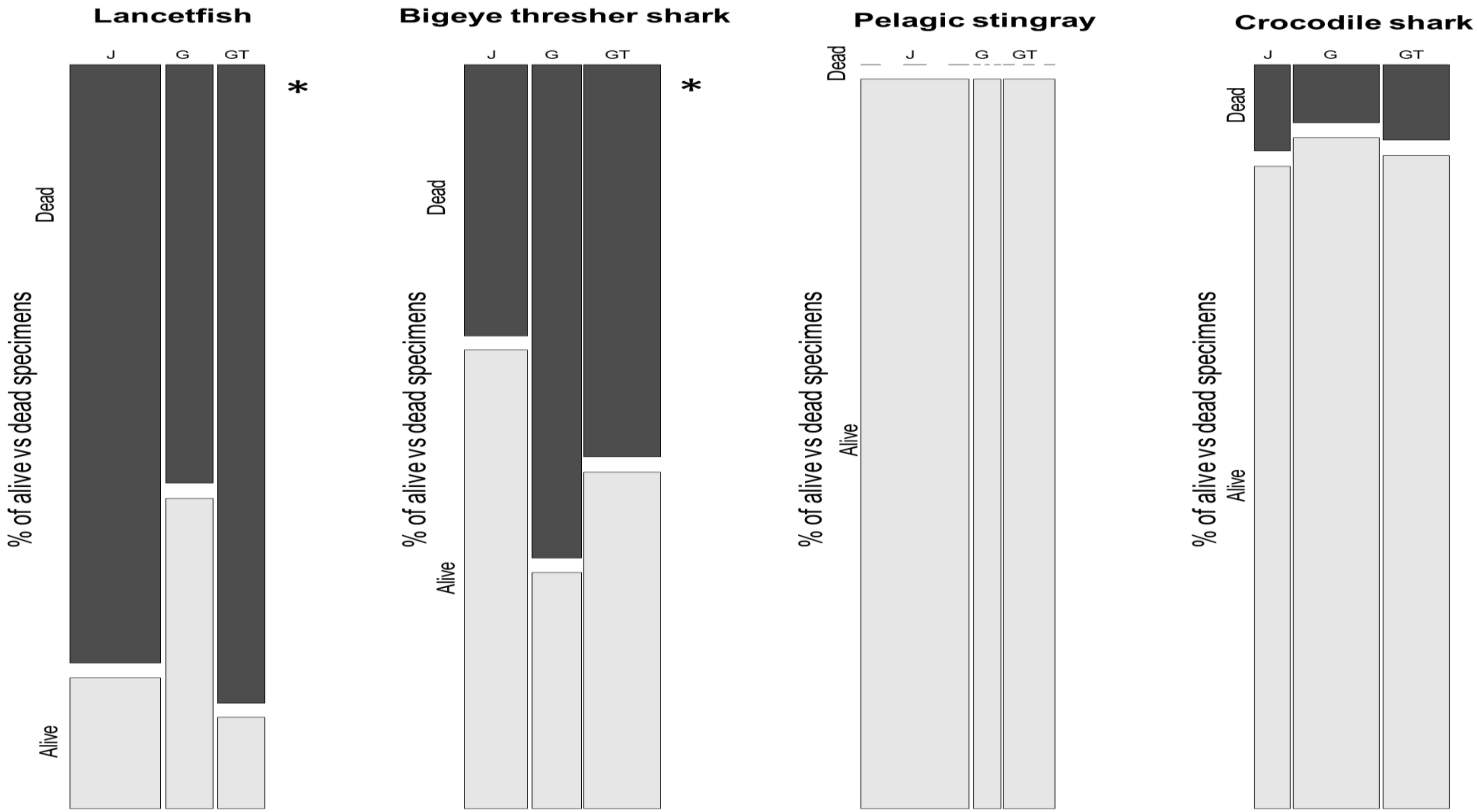

Figure 4.9 – Mosaicplot of the percentage of alive *versus* dead specimens at-haulback for the most frequently discarded species: lancetfish (*A. ferox*), bigeye thresher shark (*A. superciliosus*), pelagic stingray (*P. violacea*), and crocodile shark (*P. kamoharai*). Hook effect was significant (*) for lancetfish and bigeye thresher shark.

4.3. Discussion

The catch composition observed in this study was similar to those reported by other author´s for the same area of study (Anon., 2008; Sales *et al*., 2010; Domingos *et al*., 2012), where swordfish and blue shark comprised most of the retained catch. Significant higher swordfish CPUEs were found in western longitudes near the seamount chain "Rio Grande Rise". There is limited information on physical characteristics of seamounts (e.g. minimum summit depth) that affect the abundance of pelagic fish, however depending on their physical characteristics and location, seamounts are an obstacle to flow, creating local currents and increasing upwelling around the seamount (White *et al*., 2007). Upwelling around seamounts can bring nutrients from the deeper ocean to enhance primary productivity, supporting a variety of life (White *et al*., 2007). Grubbs *et al*. 2002 hypothesized that pelagic fish aggregate at seamounts due to this enhanced primary productivity. In addition to more prey availability, pelagic species may aggregate at seamounts for spawning and nursery habitat (Allain *et al*., 2006). The results of increased catches within these longitudes may be explained not only by seamounts but also by other oceanographic considerations (e.g. SST, Subtropical Convergence, etc). For blue shark a significant increase catch rate was detected in eastern longitudes but no significant differences were detected within the range of latitude. Bigelow *et al*. (2009) in a research study addressed to analyze environmental effects on swordfish and blue shark catch rates, found that higher catch rates for blue shark were obtained in lower SST. In addition, the increased CPUEs of blue shark in eastern longitudes may also be related to other oceanographic factors (eg. thermal fronts and chlorophyll). The effects of environmental factors in the catches were not explored in the present study. Although, environmental influences on the distribution of fishery resources are important factors that should be used in fisheries management models (Carruthers *et al*., 2011).

The main results, demonstrated that both hook style and bait type effects on the catch rates are species-specific, and that, the bait appears to be more important than hook style. For the swordfish, the primary target species of the Portuguese pelagic longline fishery, the results presented a significant decrease in catch rates, when switching from the traditional combination (J hooks baited with squid) to other combinations. Comparing the baseline reference level covariate J hook baited with squid, to the other levels of covariates, the catchability decreased, which is similar to the results reported by other authors (e.g. Watson *et al*., 2005; Anon., 2008; Sales *et al*., 2010; Coelho *et al*., 2012; Foster *et al*., 2012) for the Atlantic waters. Our results may be explained by the morphology of the circle hooks, with the point on circle hooks turned in towards to the hook shank, so the gap width (distance between the point and the shank) being smaller than on J hooks, decreasing the efficiency of capture. The higher catchability of swordfish may also be related to its diet. When analyzing the effect of mackerel as bait type, significant lower catches were observed which is similar to those detected by Coelho *et al*. (2012). However, other authors (Watson *et al*., 2005; Foster *et al*., 2012) reported distinct results, with no significant differences in catch rates of swordfish or even increased catches, when hooks were baited with mackerel. The importance of squid in the swordfish diet was highlighted by Stillwell and Kohler (1985) and Guilherme *et al*. (2012) for the Northwest and South Atlantic Ocean, respectively. These authors when analyzing the stomach contents of swordfishes found that the predominant food item was cephalopod mollusks which may enlighten the increased catches obtained in our results, when using squid as bait.

For *Thunnus* spp., caught as bycatch by this fishery, significant higher catch rates were obtained with squid. Catches with circle hooks increased in relation to J hooks; however the hook effect was only significant for albacore tuna (*Thunnus alalunga*). Working in the South Atlantic Ocean, Domingo *et al*. (2012) compared circle hooks (18/0 10° offset) with J hooks (9/0 10° offset) and as in our study, concluded that the catch rates of albacore tuna with circle hooks was over twice the catch of J hooks. For the same area, Sales *et al*. (2010) comparing 18/0 10° offset circle hooks against J hook 9/0 0° offset obtained similar results. The reasons for the significant increase of albacore catch rate in the circle hook may be related to anatomical or behavioral strategies relative to hook shapes, however at this stage it is not clear. Further studies on anatomical strategies relative to hook shapes and its interaction with the bait, particularly filming the interaction of the tuna with the baited hooks, as proposed by Pacheco *et al*. (2011) are necessary to assess this issue. All *Thunnus* spp. showed a reduction in CPUE with mackerel bait. These results may relate to the relative size of the mackerel bait as compared to the squid. The mackerel bait used in the experiment was 35.1±1.19 cm fork length as compared to the 27.8±0.97 cm mantle length of squid. A study by Ménard *et al*. (2006) indicated that bigeye and yellowfin tunas feed on small prey relative to body size and that small preys make up a large proportion of the diet.

For the other teleosts (bony fishes) bycatch, bait type seemed far more important for differences in catches than hook style, the exception being escolar (*Lepidocybium flavobrunneum*). For the billfishes, blue marlin and white marlin, circle hooks decreased the catches, although none of these results were statistically significant. These results are consistent with the studies performed in the Equatorial Atlantic pelagic longline fishery by Coelho *et al*. (2012), but opposite to those found by Pacheco *et al*. (2011) for the same area.

For the elasmobranches bycatch, catch rates tended to be much higher when circle hooks baited with mackerel were used, but these differences were only statistically significant for blue shark (*Prionace glauca*). With respect to reducing sea turtle and shark interactions, Foster *et al*. (2012) in a study conducted in the western North Atlantic Ocean evaluated the effectiveness of 18/0–20/0 circle hooks and 10/0 Japanese tuna hooks against the standard combination 9/0 J hooks baited with squid and concluded that blue shark catches increased with circle hooks (compared to J hooks) which is similar to our results. Higher shark catch rates with circle hooks were also reported in other studies (Watson *et al*., 2005; Anon., 2008; Sales *et al*., 2010; Afonso *et al*., 2011; Coelho *et al.,* 2012) and less frequently, a lower shark catch rate on circle hooks have also been reported for specific species of sharks (Gilman *et al*., 2007a; Curran and Bigelow, 2011). In a review to elucidate the overall differences between circle and J hooks on shark catchability rates, Godin *et al*. (2012) completed a meta-analysis on data of shark species and concluded that using circle hooks on pelagic longlines do not have a major effect on shark catch rates. Besides hook style comparisons, these author´s concluded that, bait type, taxonomic family and study area seems to be significant factors that affect catch rates on pelagic longlines fisheries. Gilman *et al*. (2008) based on interviews conducted with pelagic longline fisherman's also suggested that hook style may not have a large effect on shark catch rates, while bait type appears to contribute most to shark catchability. Results from Watson *et al*. (2005), Gilman *et al*. (2007b) and Yokota *et al*. (2009) showed a reduction in catch rates of sharks when squid was replaced with fish (usually mackerel spp.) while Coelho *et al*. *(*2012) found opposite results (significant increase), mainly for blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*) which is similar to our results. For the same area (South Atlantic Ocean), Anon. (2008) in a field study to assess mitigation measures to reduce bycatch of marine turtles in surface longline fisheries also obtained an increase in catch of blue shark, however non-significant differences were found.

Heterogeneous catch rates between hook styles could be ascribed to post-hooking processes, further complicating the association between hook types and catch rates (Afonso *et al*. 2012). For example, if nylon is used (as opposed to wire leaders) in the terminal tackle of branch lines, then J and circle hooks may exhibit different probabilities of allowing a hooked shark to escape by biting through the leader (bit-off), since gut hooked individuals, which are more common with J hooks, would have greater access to the nylon leader (Watson *et al*., 2005). In our study no information of bit-offs was collected so this issue could not be addressed. As a consequence catch rates of sharks for the different hook styles used in our study may have led to differing levels of underestimation.

The tweedie GLM is an appropriate method to model continuous positive data with an added mass of zeros and has been used previously with success to model CPUE data (e.g. Candy, 2004; Shono, 2008; Coelho *et al*., 2012). We explored the influence of important covariates on swordfish and blue shark catch rates, which in our study, were hook style and bait type, but no residual analysis was performed after model fitting. Thus, we did not explore diagnostics such as the goodness-of-fit of the model, the adequacy of the link function, and the presence of outliers. Our results for swordfish and blue shark corroborate what was observed with non-parametric statistical tests (Mann-Whitney and Kruskal-Wallis), however it should be noted that we did not present a complete tweedie GLM. Previous research studies (Watson *et al*. 2005; Anon., 2008; Ward *et al*. 2009; Curran and Bigelow, 2011) had highlighted important covariates on the catch rates beside hook and bait types, such as sea surface temperature (SST), soak time, set depth, moon phase, season (3-month quarter), etc. Some of these factors strongly influenced the probability of catch and had dramatic effects on their results. We did not analyzed the effects of these additional factors on the catch rates due to the fact that our experimental trials were specifically designed only to infer the effect of the explanatory variables, hook style and bait type.

The influence of hook and bait types on catches is an important consideration with respect to species conservation. However, the size of fish caught and the overall change in catch weight resulting from a gear modification must also be considered, in order to determine the viability of this mitigation measures to the fishing industry. Thus, the effects of bait and hook types on the size of the fish caught were explored. Significant differences between hook styles were detected for bigeye tuna (with smaller specimens caught on circle hooks) and yellowfin tuna (smaller specimens caught on J hooks) mirroring the previous study of Coelho *et al*. (2012). Higher mean sizes (although non-significantly) of blue shark with circle hooks were identified, a difference that could be related to the location of the hook. Watson *et al*. (2004) and Pacheco *et al*. (2011) suggested that the differences in the mean FL of sharks caught (bigger specimens caught in circle hooks) may be related to J hooks lodging internally more often than the circle hooks, so larger sharks would then be able to bite and cut off the line more frequently than in circle hooks (which tend to lodge more often in the corner of the mouth). Previous studies (Yokota *et al*., 2006, Ward *et al*., 2009 and Pacheco *et al.,* 2011) also analyzed the mean sizes for several species but found no significant differences regarding size selectivity within the range of hook style. Significant differences on length-frequency distribution between bait types were obtained. While for yellowfin and albacore, lower mean size specimens were captured with squid, for swordfish, blue shark and shortfin mako it was observed the opposite (higher mean size using squid has bait) which is coincident with the results from Coelho *et al.* (2012). However the differences in mean sizes were small, on the order of a few cm FL.

Most of the discarded species of this fishery corresponded to elasmobranchs that are either discarded due to their insignificant commercial value (e.g. pelagic stingray and crocodile shark) or due to current management regulations requiring their release (e.g. ICCAT recommendation 2009-07 and 2010-08 for thresher and hammerhead sharks, respectively). When circles hooks were used, significantly smaller catch rates were found for smaller-mouthed species such as pelagic stingray and snake mackerel. Particularly for the pelagic stingray, similar findings were obtained by other authors (Kerstetter and Graves, 2006; Piovano *et al*., 2010; Pacheco *et al*., 2011; Coelho *et al.,* 2012). Although numerous sizes and shapes of hooks are used within longline fisheries, the minimum width is probably the primary measure influencing catchability rather than straight total length or gap. In our study, the maximum width of 17/0 circle hooks probably resulted in a smaller probability of ingestion and consequently a reduced catchability of small-mouth species. In terms of bait, significantly higher catches with mackerel were obtained for lancetfish (*Alepisaurus ferox*), hammerhead sharks (*Sphyrna zygaena*) and manta rays (Myliobatidae). For the other discarded species, low sample sizes were recorded, which precluded further analysis.

Mortality rates and therefore opportunities to reduce post-release mortality differed among the four more frequently discarded species. For pelagic stingray all specimens were alive at-haulback independently of the hook style used. Similar results were presented by Coelho *et al*. (2012) for the pelagic stingray and crocodile shark, who also observed that most specimens were hauled alive independently of the hook style, showing that the mortality rates for the above species were taxon-specific and independent of the hook style. However, contrary to our results, Carruthers *et al*. (2009) in the Canadian longline fishery operating in the northwest Atlantic Ocean, reported that the odds of survival for the pelagic stingray was approximately 5 times more on circle hooks than on J hooks and found no significant difference in the odds of survival for lancetfish (*Alepisaurus ferox)*. In our study significant differences in hooking survival of lancetfish were detected, with higher percentage of dead specimens at-haulback for the offset hooks (J and GT). Rice *et al*. (2012) in a study comparing the performance of 18/0 non-offset and 10º offset circle hooks, found that offset circle hooks had a higher incidence of deep hooking events and that non-offset had a significantly higher incidence of hooking in the corner of the mouth, increasing the percentage of alive specimens at-haulback. From our results we suggest that mitigation strategies for pelagic stingray should include careful handling and release, whereas strategies to reduce lancetfish mortalities would have to focus earlier in the capture process.

For the bigeye thresher shark significant differences were found between circle hooks and J hooks, with lower percentage of dead specimens at-haulback in J hooks. Opposite results were found by other authors such as Curran and Bigelow (2011) and Coelho *et al*. (2012) where most species had an equal probability of being alive independently of the hook style used. Pelagic thresher sharks are often hooked by the tail (Compagno, 2001; Amorim, 2012, pers. observ.) and die soon afterwards, probably due to increased fight when tail-hooked. We have not record hook location for the captured specimens, and therefore caution should be taken when analyzing these results. From a management perspective, a reduction in shark bycatch rates, as opposed to a reduction in hooking mortality is preferred, because even sharks that are retrieved alive can still be potentially finned in unregulated fisheries where no-retention policies or non-finning regulations exists.

Several authors have evaluated the effect of hook styles in the mortality rates and reported circle hooks to have a lower gut-hooking rate than J hooks, and consequently a higher survival rate observed at boat-side (Gilman *et al*., 2006; Sales *et al*., 2010). Watson *et al*. (2005) and Epperly *et al*. (2012) in experiments conducted on the Grand Banks of the North Atlantic Ocean reported that the probability of boating a dead bigeye tuna, swordfish or blue shark increased if the animal was captured on a J hook. For the sharks in particular, Godin *et al*. (2012) combining data from 15 published and eight gray literature studies examining mortality rates (meta-analysis study) also supported the hypothesis of reduced at-haulback mortality on circle hooks due to being more frequently hooked in the mouth or jaw rather than internally. Other studies (Kerstetter and Graves, 2006; Diaz *et al*., 2008) also addressed the effect of different hooks in mortality for other fishes, such as blue and white marlins and found that the use of circle hooks increases the number of fish boated alive. Circle hooks seems that will not prevent the capture of billfishes, but their use may increase the rate of survival for these species and thereby reduce overall fishing mortality on the overfished blue marlin and white marlin stocks. Even though we just found significant differences in the proportions of at-haulback mortality in two discarded species for the different hook styles, it is possible that circle hooks lead to lower post-release mortalities due to differences in hooking locations. In general, deeply hooked specimens will die more often than jaw-hooked specimens, mainly due to tissue damage and possible perforation of the internal organs (Watson *et al.,* 2005). Application of methods such as pop-up satellite archival tag to estimate post-release survival which has been successfully applied to billfishes (e.g., Horodysky and Graves, 2005) and sharks (Campana *et al.,* 2009) should be encourage. Furthermore, the importance of anatomical hooking location in predicting haulback mortality, and likely effect on post-release mortality suggests that fisheries observer programs should include information about hooking location among the data collected for scientific analysis (Ryder *et al.,* 2006).

GENERAL CONCLUSIONS

This study represents advancement in knowledge of the use of circle hook styles and bait types as a mitigation measure in the reduction of the incidental bycatch of sea turtles in the Atlantic Ocean, particularly in the South hemisphere. It also contributed to the increase knowledge of the effect of hook-bait combinations on the catch of target and non-target species caught by the Portuguese swordfish pelagic longline fishery.

The results obtained, showed that by changing the traditional configuration J hook baited with squid to circle hooks baited with mackerel, resulted in a reduction of BPUE on both species of sea turtles (Loggerhead and Leatherback). However, bait seems to have more influence on the bycatch reduction then the hook style (significant differences only occurred changing from J-style to one of the circle hooks when using squid bait).

Hooking location was species-specific, with most leatherbacks hooked by the flippers or entangled, while loggerheads were mostly hooked by the mouth and esophagus. Mortality was also species-specific and reflected the hooking location, with most of the specimens caught by the flippers being alive, while the specimens hooked in the mouth and esophagus having higher percentages of dead specimens. The urgent need to address the bycatch of sea turtles, make of the technical measures, like the use of circle hooks and mackerel bait a very attractive management strategy. However, the behavior of the species caught, can be different from region to region, even when dealing with the same species, thus caution must be taken when interpreting these results.

Technological changes with the aim of reducing the catch of undesirable species also affect the capture of target species in ways that vary depending on the region. Longline management strategies must not only be effective in reducing bycatch, but also be commercially viable. Our results indicate that hook and bait modifications (changing from J to circle hooks and from squid to mackerel) reduce bycatch of vulnerable sea turtles, but simultaneously result in lower catch rates of swordfish, the main target species of this fishery. However an increase catch of other marketable species (blue shark and shortfin mako) was observed. In this study no economic analysis were addressed so it was not possible to infer if the highest catches of elasmobranchs balanced the losses of swordfish lower catches. It should be noted that shark populations resilience to fishery exploitation, due to low fecundity and late age at maturity, is much lower than high fecundity species such as swordfish and *Thunnus* spp. Thus, predicting the effects of a gear change (circle hooks baited with mackerel) on shark populations is urgent because any irrational exploitation can lead to the eventual collapse of these populations.

The differences in mean size between hook style and bait type for the seven most caught species were of a few cm FL. However when comparing hook styles significant differences were detected for bigeye (larger specimens with J hooks) and yellowfin tuna (larger specimens with circle hooks). In relation to bait type significant differences were found in swordfish, blue shark and shortfin mako, with larger specimens caught in squid bait and yellowfin and albacore tuna with larger specimens in mackerel bait. For the discarded species mortality at time of fishing gear retrieval was species-specific with the proportions of alive *versus* dead varying significantly by hook style for the lancetfish and bigeye thresher shark.

In order to promote a sustainable management of the pelagic longline fisheries, complementary studies must be undertaken in the near future. Although the present study provided new knowledge on the effect of different hook styles and bait types in sea turtle's bycatch and target and non-target species in the South Atlantic Ocean, unanswered questions persist, such as the influence of environmental parameters in bycatch rates, therefore requiring further studies. Different results on the use of circle hooks have been reported, which mean that the effectiveness of each mitigation measure may be fishery-specific, thus successful management will require a combination of alternative measures. The cooperation of stakeholders is essential to the biological, economic, and social success of fisheries management and regulation, and such is the case with the use of circle hooks. The most effective means of transferring the technology to date is not through management measures that are difficult to enforce, but through direct outreach to the fishermen´s in their fishing operations. Therefore, the expansion of mechanisms to engage stakeholders in circle hook education as well as participation in decision making processes has great potential to enhance effective and efficient incorporation of the technology. A holistic approach to bycatch reducing technology that engages social scientists as research collaborators should develop. This will increase compliance with management measures and ultimately increase the conservation benefits of circle hook use in pelagic fisheries.

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ANNEXES

Annex I – Tables

Table 1.1 – General parameters and measurements of the Portuguese pelagic longline fishing gear (American-style).

Gear Characteristics	Swordfish Pelagic Longline (“American-style”)
Mainline material	Nylon monofilament (3.2 – 3.6 mm Ø)
Mainline lenght	35 - 60 nautical miles (~ 60 - 110 km)
Mainline deployment	Shooter
Distance between buoys	400 - 700 m
Distance from buoy to mainline (floatline length)	12 – 18 m
Branch line length	8 - 20 m
Branch line material	Nylon monofilament (1.8 - 2,0 mm Ǿ)
Wire leader (trace) used on branch lines?	No when targeting swordfish and tuna Yes when targeting sharks
Number of hooks per set	800 - 1500
Hooks per basket (between buoys)	4 – 8
Maximum depth of mainline when set	50 m
Typical min depth of hooks	20 m
Typical max depth of hooks	70 m
Common mainline sink rate	40 m in 8 seconds
Common timing of set, soak, and haul	Set: 5 PM (for 7 hours) Soak: 7 hours Haul: 6 AM (for 10 hours)
Lightstick use	Battery
Hook setting interval	8 - 16 seconds (70-100 m)
Radio beacons buoys	Yes
Hook type	“Stell” 10/0 - ref. 39960 J16/0 Ancora (no offset) - ref. 722 J17/0 Ancora (no offset) - ref. 722 J18/0 Ancora (no offset or 10º offset) - ref. 722 J Mustad 9 (10º offset)
Weight size and location	60 - 80 g. at connection of mainline with float line. 65 - 75 g. swivel at top of leader
Clip size and type	320 - 350S
Bait type	Squid (*Ilex* spp.) and mackerel (*Scomber* spp.)

Table 4.3 - Mean (standard deviation) size (LJFL and FL, in cm) for the species swordfish (*Xiphias gladius*), bigeye (*Thunnus obesus*), yellowfin (*Thunnus albacares*), albacore (*Thunnus alalunga*), blue marlin (*Makaira nigricans*), blue shark (*Prionace glauca*) and shortfin mako (*Isurus oxyrinchus*). P-values refer to the Mann-Whitney tests comparing sizes with different baits and the Kruskal-Wallis tests comparing sizes with different hooks. J = 10º offset 9/0 hook; G = non-offset 17/0 circle hook; GT = 10° offset 17/0 circle hook. p<0.05 are in bold.

	Bait type		Hook style			Comparisions (p-value)	
Species name	Squid	Mackerel	J	G	GT	Bait	Hook
Xiphias gladius	166,5 (±35,0)	162,2 (±36,1)	165,0 (±36,7)	163,7 (±34,5)	164,9 (±35,1)	**<0,01**	0,42
Thunnus obesus	124,2 (±30,6)	126,2 (±35,8)	144,5 (±26,6)	128,7 (±30,1)	110,5 (±30,6)	0,59	**<0,01**[a]
Thunnus albacares	155,3 (±10,1)	158,6 (±12,3)	154,4 (±9,1)	159,2 (±9,1)	155,0 (±12,3)	**0,01**	**0,01**[b]
Thunnus alalunga	105,7 (±9,4)	111,7 (±5,9)	106,6 (±9,6)	108,0 (±8,3)	109,0 (±8,7)	**0,01**	0,13
Makaira nigricans	229,1 (±36,8)	223,0 (±28,3)	222,8 (±29,3)	231,9 (±35,8)	224,1 (±34,4)	0,86	0,15
Prionace glauca	197,8 (±26,5)	194,8 (±30,6)	195,1 (±29,8)	196,9 (±29,3)	195,4 (±28,7)	**<0,01**	0,08
Isurus oxyrinchus	176,8 (±35,6)	167,7 (±38,1)	175,2 (±33,6)	168,5 (±38,6)	171,4 (±38,3)	**<0,01**	0,10

[a] Non-parametric multiple tests for all-pairs comparisons. Significant difference between all hooks.
[b] Non-parametric multiple tests for all-pairs comparisons. Significant differences between G and the other two style of hooks (J and GT).

Table 4.5 – Percentage of alive *versus* dead specimens at-haulback for the most frequently discarded species: lancetfish (*A. ferox*), bigeye thresher shark (*A. superciliosus*), pelagic stingray (*P. violacea*), and crocodile shark (*P. kamoharai*). The statistical comparisons refer to Chi-square tests for contingency tables. J = 10º offset 9/0 hook, G = non-offset 17/0 circle hook, GT = 10° offset 17/0 circle hook. p<0.05 are in bold. NT= not tested

	J			G			GT			Comparisions	
Species name	n	% dead	% alive	n	% dead	% alive	n	% dead	% alive	Chi-square	p-value
Alepisaurus ferox	89	82,02	17,98	47	57,45	42,55	48	87,50	12,50	14,48	**<0,01**
Alopias superciliosus	43	37,21	62,79	34	67,65	32,35	52	53,85	46,15	7,17	**0,03**
Pteroplatytrygon violacea	72	0,00	100,00	17	0,00	100,00	33	0,00	100,00	NT	NT
Pseudocarcharias kamoharai	42	11,90	88,10	100,00	8,00	92,00	77	10,39	89,61	0,61	0,74

Annex II – List of fish species

Table 2.2 – List of fish species, with FAO codes, common names, scientific names (with authority) and category. In the category, T-B refers to targeted bony fish species; BC-B to bony fish bycatch; BC-E to elasmobranch bycatch; D-B to bony fish discards and D-E to elasmobranch discards

FAO Code	Category	Common name	Scientific name (Authority)
SWO	T-B	Swordfish	*Xiphias gladius (Linnaeus, 1758)*
BET	BC-B	Bigeye tuna	*Thunnus obesus (Lowe, 1839)*
YFT	BC-B	Yellowfin tuna	*Thunnus albacares (Bonnaterre, 1788)*
ALB	BC-B	Albacore	*Thunnus alalunga (Bonnaterre, 1788)*
AMB	BC-B	Greater amberjack	*Seriola dumerili (Risso, 1810)*
BUM	BC-B	Blue marlin	*Makaira nigricans (Lacepède, 1802)*
DOL	BC-B	Dolphinfish	*Coryphaena hippurus (Linnaeus, 1758)*
LEC	BC-B	Escolar	*Lepidocybium flavobrunneum (Smith, 1843)*
OIL	BC-B	Oilfish	*Ruvettus pretiosus (Cocco, 1833)*
POA	BC-B	Atlantic pomfret	*Brama brama (Bonnaterre, 1788)*
SAI	BC-B	Sailfish	*Istiophorus platypterus (Shaw 1792)*
SPF	BC-B	Longbill spearfish	*Tetrapturus pfluegeri (Robins & de Sylva, 1963)*
TAS	BC-B	Rough pomfret	*Taractes asper (Lowe, 1843)*
WAH	BC-B	Wahoo	*Acanthocybium solandri (Cuvier, 1832)*
WHM	BC-B	White marlin	*Kajikia albida (Poey, 1860)*
BSH	BC-E	Blue shark	*Prionace glauca (Linnaeus, 1758)*
CCA	BC-E	Bignose shark	*Carcharhinus altimus (Springer, 1950)*
LMA	BC-E	Longfin mako	*Isurus paucus (Guitart, 1966)*
POR	BC-E	Porbeagle	*Lamna nasus (Bonnaterre, 1788)*
SMA	BC-E	Shortfin mako	*Isurus oxyrinchus (Rafinesque, 1810)*
ALX	D-B	Lancetfish	*Alepisaurus ferox (Lowe, 1833)*
CUP	D-B		*Cubiceps* sp
GSE	D-B	Snake mackerel	*Gempylus serpens (Cuvier, 1829)*
LAG	D-B	Opah	*Lampris guttatus (Brünnich, 1788)*
MOX	D-B	Sunfish	*Mola mola (Linnaeus, 1758)*
ALV	D-E	Common thresher	*Alopias vulpinus (Bonnaterre, 1788)*
BTH	D-E	Bigeye thresher	*Alopias superciliosus (Lowe, 1841)*
FAL	D-E	Silky shark	*Carcharhinus falciformis (Müller & Henle, 1839)*
ISB	D-E	Cookie cutter shark	*Isistius brasiliensis (Quoy & Gaimard, 1824)*
MAN	D-E	Devil and manta rays	Myliobatidae (family) (Bonaparte, 1838)
OCS	D-E	Oceanic whitetip	*Carcharhinus longimanus (Poey, 1861)*
PLS	D-E	Pelagic stingray	*Pteroplatytrygon violacea (Bonaparte, 1832*
PSK	D-E	Crocodile shark	*Pseudocarcharias kamoharai (Matsubara, 1936)*
SPZ	D-E	Smooth hammerhead	*Sphyrna zygaena (Linnaeus, 1758)*