Universidade de Aveiro Departamento de Biologia
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Ana Raquel Batista Aguiar

Trends in deep-water shark fisheries in the Azores.

Tendências da pesca de tubarões de profundidade nos Açores.

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Tendências na pesca de tubarões de profundidade nos Açores.

Dissertação apresentada à Universidade de Aveiro para cumprimento dos requisitos necessários à obtenção do grau de Mestre em Biologia Marinha, realizada sob a orientação científica da Doutora Ana Hilário, Investigadora Assistente do Departamento de Biologia da Universidade de Aveiro e do Doutor Telmo Morato, Investigador Auxiliar do Instituto do Mar, Departamento de Oceanografia e Pescas da Universidade dos Açores

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palavras-chave

Açores, elasmobrânquios, mar profundo, palangre, pesca, pesca acessória, sustentabilidade, tubarões.

resumo

Os recursos do mar profundo têm sido cada vez mais explorados, e devido a isso, vários ecossistemas e espécies têm sido gravemente afectados. As populações de tubarões de profundidade são das mais perturbadas, especialmente pelas práticas de pesca não seletivas, capturas acessórias e descarte, principalmente devido ao seu baixo valor comercial. Estas práticas tornam os tubarões de profundidade muito vulneráveis à sobre-pesca dadas as suas características de história de vida, aumentando assim o seu risco de extinção .

Com a proibição da pesca direta, e a implementação de quotas e TACs (Capturas Totais Admissíveis) na pesca de tubarões de profundidade, as capturas oficiais têm vindo a decrescer. No entanto, as capturas não reportadas têm vindo a aumentar exponencialmente.

Com a análise da captura por unidade de esforço (CPUE), da profundidade, e do peso médio dos indivíduos ao longo dos anos de cada umas das 9 espécies de tubarões mais pescadas nos Açores, conseguimos fazer uma análise descritiva do efeito das pescas nestas espécies.

Os resultados mostram que algumas destas espécies têm vindo a sofrer uma grande pressão por parte da pesca, e que as suas populações serão gravemente afetadas num futuro próximo se não forem tomadas medidas drásticas no que toca à gestão da sua sustentabilidade a longo prazo.

keywords

Azores, bycatch, deep-sea, elasmobranchs, fisheires, longline, sharks, sustainability.

abstract

Deep-sea resources have been increasingly exploited, and due to that, several ecosystems and species have been considerably affected. Deep-water sharks populations have been of the most disturbed by practices of unselected fisheries, bycatch and discard, mainly due to their low commercial value. Those practices make deep-water sharks very vulnerable to overfishing given their life-history traits, increasing their extinction risk.

With the prohibition of the direct fishery, and implementation of quotas and TACs (Total Allowable Catches) regarding the deep-sea shark landings, the official landings have dramatically decreased after the 1990s. However, the IUU (Illegal, unreported and unregulated) catch has exponentially increased.

With the analysis of catch per unit effort (CPUE), the depths, and the mean weight of the individuals over the years for each one of the nine most caught species in the Azores, we produced a descriptive analysis of the effect of fisheries in those species.

The results show that some of these species have been suffering from a great fishing pressure, and their populations will be greatly affected in the near future if drastic measures are not taken when it comes to managing their long term sustainability.

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LIST OF ACRONYMS

CFP	Common Fisheries Policy
CPUE	Catch per Unit Effort
DWS	Deep-water Sharks
FAO	Food and Agriculture Organization
ICES	International Council for the Exploration of the Sea
IUCN	International Union for Conservation of Nature
IUU	Illegar, Unreported and Unregulated
TACs	Total Allowable Catches

1. INTRODUCTION

Fishing is the economic activity with the greatest impacts on the marine environment, and due to that, the effects of fishing have generated great concern among scientists, the civil society in general, and the fishing industry. In result of the substantial world population growth, there is a higher demand for food, including fish protein (Turner, Thrush et al. 1999; Agardy 2000), and the Food and Agriculture Organisation of the United Nations (FAO) reported that, just to accommodate human needs, worldwide fisheries production in marine waters was of 79.7 million tonnes in 2012 (FAO, 2014). These fisheries affect not only the target species and resources, but also other marine species because of poor selectivity, and lead to practices such as bycatch and discard, which also disturb the surrounding environment and ecological processes at very large scales (Garcia, Zerbi et al. 2003). Bycatch of non-target species and their discard is today seen as a serious problem in all world's oceans.

1.1. Bycatch and discards

Bycatch can be defined as incidental catch of non target species, or target species with undesirable sizes or age, without any direct effort towards those species, while the discard is the portion of the catch that is not retained on board. Discard occurs mainly because of the lack of commercial value of bycatch and, depending on each fisherman and on the location of the fisheries, undesirable catches can be returned to the sea or thrown away (Gilman, Passfield et al. 2012). Even though they are related, these two concepts have different ecologic and economic impacts: bycatch affects several species but can be turned into profit and discarded species are a waste of valuable resources but can be useful to scavengers and seabirds (COFREPECHE and SCAPECHE, 2014; Sanchez, Demestre et al. 2004; Morandeau, Macher et al. 2014; Borges, Erzini et al. 2001).

The impacts of these practices not only affect directly the populations of captured species, but also indirectly disturb the structure and function of the ecosystems in which they thrive (Borges, Erzini et al. 2001; Monteiro, Araujo et al. 2001; Jennings and Kaiser, 2000). Indirect effects on trophic interactions, through the depletion of the top predators for example, can affect the entire community function (Stevens, Bonfil et al. 2000; Hall, Alverson et al. 2000). Discarding practices can also benefit the population of scavenging species and disrupt ecosystem processes (Garthe and Scherp, 2003). The populations of scavenging birds in the North Sea, for instance, have been growing exponentially due to the vast access to the fisheries waste, that can be a very important part of their diet, since they consume about 50% of the material that is returned to the sea (Catchpole, Frid et al. 2006). The proportion of consumed discard can vary, mainly due to factors such as discard types, season of the year, area and the scavenging species (Allain, Biseau et al. 2013; Clark, Althaus et al. 2015). Depending on the species and their life-stage, the fisheries waste can be essential for their survival and if the discard rates decreases in the future, some species can be seriously affected and suffer high mortality (Garthe, Camphuysen et al. 1996). Benthic fishes and invertebrates can also take advantage from discards arriving to the sea, making a considerable contribution to the species energy demand and allowing the existence of bigger populations (Catchpole, Frid et al. 2006).

In 1994 the annual landings reported to FAO were approximately 83 million tonnes (Alverson et al. 1994), and the amount discard by commercial fisheries was close to one third of this value (Moranta, Massuti et al. 2000). However, in the following decade (1994 to 2004) a decline on the discard rates in the main fisheries around the world was reported (Sanchez, Demestre et al. 2004). Since 1994, the global fish production has been growing steadily reaching about 91 million tonnes in 2012 (FAO, 2014). When comparing regions and fishing gears, Hall et al. (2000) estimated that the highest discard rates were found in the northwest Pacific Ocean, and the shrimp trawl fisheries were the gear that more contributed to those rates, in terms of weight, with about 9 million tonnes, when comparing with the global total fish discard provided by Alverson et al. (1994).

To ensure long-term sustainable environmental conditions, the Common Fisheries Policy (CFP) recently created a conservation proposal to minimize the negative impact of fishing activities in the European Union marine ecosystems, decrease the unwanted catches and therefore to end the practice of discard, through the monitoring of the fleets data and the implementation of a discard ban in combination with catch quotas (European Commission, 2011).

Although the impacts of bycatch and discards have been well studied for shallow coastal water ecosystems, much less information is available for deeper waters (Kelleher, 2005).

1.2. Deep-sea fisheries

Deep-water fisheries usually take place between 200 – 2000 m, on oceanic seamounts, continental slopes and oceanic ridge systems (FAO, 2009). Those fisheries started after Second World War, driven by major technological improvements and by the need to seek for new and unexploited resources that were previously out of range of traditional fishing methods (Koslow, Boehlert et al. 2000). Watson and Morato (2013) estimated that since 1950, the mean depth of fishing worldwide has increased by 350 m (Figure 1).

Among all human-related activities known to impact the deep sea, resource exploitation is the most preoccupying and can have serious future consequences such as significant environmental impacts on fragile habitats such as deep-sea coral beds and seamounts (Ramirez-Llodra, Tyler et al. 2011). It is only recently that scientists have raised concerns on the sustainability of deep-sea fishing suggesting dramatic consequences for deep-sea ecosystems (Benn, Weaver et al. 2010). Fishing impacts on the deep sea can affect many habitats and species on several levels, being bottom trawling, because of its habitat-destructive characteristics, one of the major threats (Pham, Diogo et al. 2014). Low selectivity, drifting and lost fishing gear can also greatly affect the whole ecosystem, as they can continuously catch and trap fishes, marine mammals, invertebrates or seabirds for a long period of time (Davies, Roberts et al. 2007).

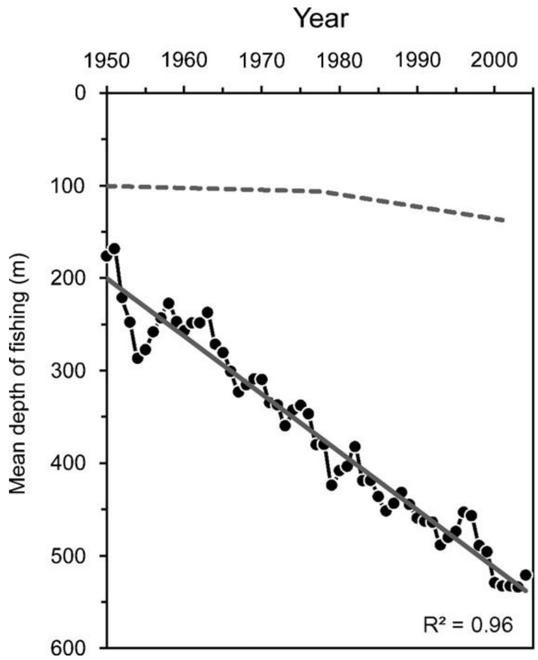

Figure 1. Depth of world marine bottom fisheries catches, 1950–2004, with the trend line (solid line), fitted using a simple linear regression model and taking account both within and between species changes in mean depth. The dashed line shows the trend line from Morato et al. (2006a), accounting only for between-species effects. (Source: Watson and Morato, 2013)

Although the concern for conservation and management is increasing, the knowledge on the deep-sea as an ecosystem is still in its infancy, and it is possible that drastic changes happen in the future but remains undetected due to the difficulty in assessing the full range of anthropogenic impacts in this vast and understudied ecosystem (Benn, Weaver et al. 2010).

The deep-water fishing industry has been described as economically unsustainable and deep-sea fish a non-renewable resource (Glover and Smith, 2003). It is expected that by 2025 all the existing deep-sea fisheries will be gravely affected, and by then new ones have been discovered, but they will not prevail more than 20 to 30 years (Glover and Smith, 2003). On top of the increasing fishing pressure, the deep sea is mainly exposed to unregulated fisheries (Clarke, Borges et al. 2005).

1.3. Bycatch and discard in deep-sea fisheries

Deep-sea fishing activities can destroy the seafloor, reducing the complexity of several habitats, destroying species refuges and disturbing population of deep-sea corals and sponges (Benn, Weaver et al. 2010; COFREPECHE and SCAPECHE, 2014), but it can also increase the bycatch and discard rates not only of deep-sea species, but also fishes and invertebrates from more superficial layers, and even sea birds (Norse, Brooke et al. 2012; Durán Muñoz, Murillo et al. 2010).

Bottom trawling has been known to be one of the most destroying types of fishing gears, being responsible for several fish stocks collapses in the world (Davies, Roberts et al. 2007; Clark, Althaus et al. 2015). Even though passive gears (e.g. longlines) have negative impacts on deep-sea coral reefs, these are much lower when compared with bottom trawling (Pham, Diogo et al. 2014). For example, in the Alaskan waters, between 1990-2002, fishermen have landed near 4182 tonnes of corals and sponges, and in the Orange roughy trawl fisheries, on the South Tasman Rise seamounts, corals represented approximately 25% of the fisheries bycatch (Norse, Brooke et al. 2012; Lewison, Crowder et al. 2004). For decades this problem has been neglected not only because of the ignorance of the existence of this issue but also because along all of the existing management priorities, the deep sea was not included.

Along with those practices, Illegal, Unreported and Unregulated (IUU) catches have also been declared to be a serious problem, as a result of a lack of effective flag State control. These IUU values are the portion of the catch that is not accounted for official statistics, contributing to the overexploitation and depletion of fish stocks while destroys marine habitats (Pham et al. 2013). It has been reported that IUU captures can range between 11 and 26 million tonnes annually (FAO, 2009; Agnew, Pearce et al. 2009).

Figure 2. Sponges, gorgonids and molluscans discarded by trawlers.
(Source: The Rufford Small Grants Foundation; Available in:
http://www.rufford.org/rsg/projects/raveendra_durgekar)

1.4 Deep-sea sharks

According to Compagno (1999), more than 60% of the described species of sharks are found in the deep sea, and almost 53% of them occur at depths greater than 600 m. However, research on bycatch and discards of deep-sea sharks has received little attention. Depending on the species, their size, the season of the year and their economic value, they can be either commercialized or discarded (Haedrich, Merrett et al. 2001; Coelho, Bentes et al. 2003). Many of the sharks are landed already dead or with serious injuries due to the fishing equipment or the changes of the temperature and pressure. The ones who are still alive can be returned to the sea, even though the injuries will affect their survival (Allain, Biseau et al. 2003; Coelho and Erzini, 2008). Other species, with high commercial value are commercialized especially for their livers that contain squalene and other elements with high value to the pharmaceutical market (Blackwell and Stevenson, 2003; Akhilesh, Ganga et al. 2011; Wetherbee, 2000).

Between 1940-1970 direct shark fisheries increased significantly due to the demand of the Vitamin A in their livers, but in the last years, a decreasing trend of the bycatch of deep-sea sharks has been noticed, along with the discard rates (Kyne and Simpfendorfer, 2007). With the increasing concern about the impact of fishing on shark populations, organizations such as the International Union for Conservation of Nature (IUCN) and FAO, have created groups towards the conservation and management of sharks (Stevens, Bonfil et al. 2000; Oliver, Braccini et al. 2015).

Using bathymetric categories, deep-sea sharks can be categorized into four divisions: Paraprofundic (< 200 m), Mesoprofundic (200 - 600 m), Holoprofundic (≤ 600 m) and Metaprofundic (greater than 600 m) (Martin and Treberg, 2002). For the purposes of this project, we will consider deep-sea sharks as those whose distribution is bellow 200 m and those with a life cycle characterized by high longevity (> 25 years), low growth rates, low fecundity, long gestation period and late maturity (Kyne and Simpfendorfer, 2007; Moura, Jones et al. 2014). Their life-history traits make these species highly vulnerable to overexploitation because they cannot overcome high mortality rates: once the population starts to decline, recovery will take decades or centuries (Ramos, Silva et al. 2013; ICES, 2013; García, Lucifora et al. 2008; Ferretti, Worm et al. 2010). Deep-sea chondrichtyans are considered 1.6 - 1.9 times more vulnerable to extinction than continental shelf chondrichtyans, and 2.4 - 2.9 times more than oceanic ones (García, Lucifora et al. 2008).

It has been shown by several authors that even the slightest mortality rates can quickly lead species with these life-history traits to overexploitation when exposed to multi-species fisheries (Barker and Schluessel, 2005; Clarke, Borges et al. 2005; Akhilesh, Ganga et al. 2011; Coelho and Erzini, 2008; Ferretti, Worm et al. 2010; García, Lucifora et al. 2008; Walker, 1998) or fisheries targeting shark resources world-wide (Walker, 1998). In collaboration with FAO, Castro (1999) determined that between 1989 and 1999, at least 26 shark species have severely declined and it is now known that other undocumented and unreported species followed the same pattern (Barker and Schluessel, 2005). Walker (1998) reported that chondrichtyans landings can exceed 700000 tons/year and the International Council for the Exploration of the Sea (ICES) revealed that since 1992, some commercial fishing boats catch up to 40 tonnes of deep water sharks per week due to the increasing of their economic value and the high levels of bycatch (ICES, 2013; Figueiredo, Bordalo-Machado et al. 2005).

Figure 3. Gulper shark (*Centrophorus granulosus*) landings in the deep sea shark fishery at Cochin. (Source: Akhilesh, Ganga et al. 2011)

It is currently recognized that there is still a lack of information on the biology of deep-sea sharks, including life history, feeding and migratory habitats, but also on catch data (ICES, 2013). The major problems that compromise our knowledge of the status of deep-sea shark population, as well as other marine species, are the inaccurate identification of the lesser-known species, illegal, unreported and unregulated (IUU) fishing and lack of information on discarding practices for most deep-sea fisheries. Therefore, it is currently challenging to provide a complete assessment on the fishing impacts on deep-water shark populations (Coelho and Erzini, 2008; Blackwell and Stevenson, 2003; Martin and Treberg, 2002; Leitão, Baptista et al. 2014).

Deep-water rays have been also widely affected by the bycatch resultant from commercial fisheries once they have life history traits very similar to deep-water sharks. The fishing pressure is showing to be a threat to these populations, and since the majority of these species (except *Raja clavata*) have no commercial value, they are usually discarded.

1.5. Deep-sea elasmobranchs in the Azores

The Azorean waters behold a high diversity of sharks and rays, constituting a valuable natural heritage that must be preserved. Until the present time, 8 orders, 21 families and 50 species of Elasmobranchs have been recorded in the Azores. The main deep-water shark and rays species captured in the Azores in terms of weight and numbers are:

Kitefin shark, *Dalatias licha*:

The kitefin is a relatively small shark (maximum length of 186 cm), found mostly on the continental shelf and slope and occurring mainly between 50 m and 1800 m depth (Bordalo-Machado, Pinho et al. 2002). It is characterized by not having spines in dorsal fins, a short and conical snout, and a greyish/dark-brown body. Feeds mainly on deep-water bony fish. Targeted mainly for liver oil extraction. Its skin and meat is also used, especially for fish food production (Barreiros and Gadig, 2011 ; Fishbase).

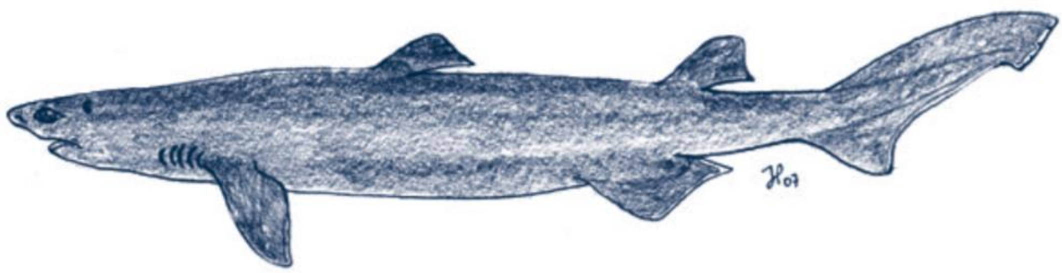

Figure 4. Kitefin shark, *Dalatias licha.* (Source: Barreiros and Gadig, 2011).

Leafscale gulper shark, *Centrophorus squamosus*:

A small sized shark (largest known male with 160 cm) found on or near the bottom of continental slopes between 229 m and 2359 m (Compagno, 1984). It has 2 dorsal spines and an elongated, almost cylindrical body, uniformly dark-grey or brown. Feeds on deep-water fish and cephalopods. It is commonly captured for human consumption: even though the fins and meat (mostly dried salted) have low value, the liver oil has a high commercial value (Barreiros and Gadig, 2011; Fishbase).

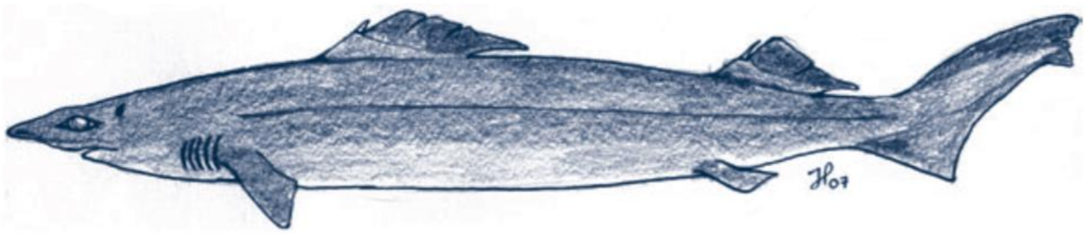

Figure 5. Leafscale gulper shark, *Centrophorus squamosus* (Source: Barreiros and Gadig, 2011).

Arrowhead dogfish, *Deania profundorum*:

A small shark (largest specimen with 79 cm) found in upper continental and insular slopes, ranging between 250 m and 1100 m (IUCN). It has 2 dorsal spines and a characteristic flattened head with a wide snout, and a uniformly brownish grey/dark grey body. Feed on small demersal and benthic fishes, cephalopods and crustaceans. Has no commercial value (Barreiros and Gadig, 2011; Fishbase).

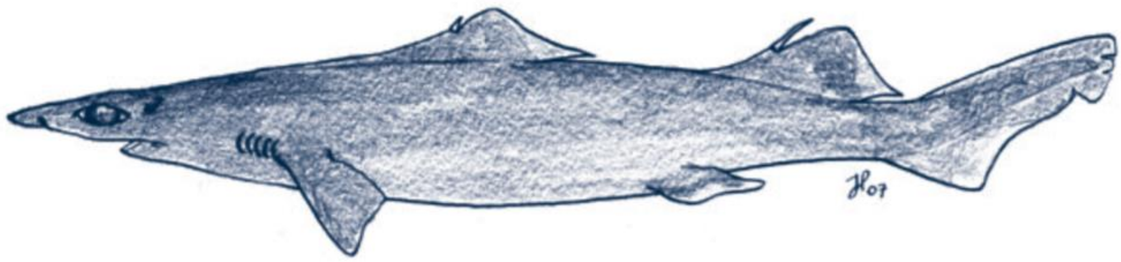

Figure 6. Arrowhead dogfish, *Deania profundorum* (Source: Barreiros and Gadig, 2011).

Velvet belly lanternshark, *Etmopterus spinax*:

A small sized shark (biggest known specimen with 60 cm) found on outer continental shelves and slopes and ranging between 200 m to 1200 m depth (Aranha, Menezes et al. 2009). It has a long snout and tail, with small gills and light-emitting photophores forming specific patterns. The body is brown, with black underside. Feeds on small fish, squids and crustaceans. Utilized for fishmeal and human consumption (dried salted) (Barreiros and Gadig, 2011; Fishbase).

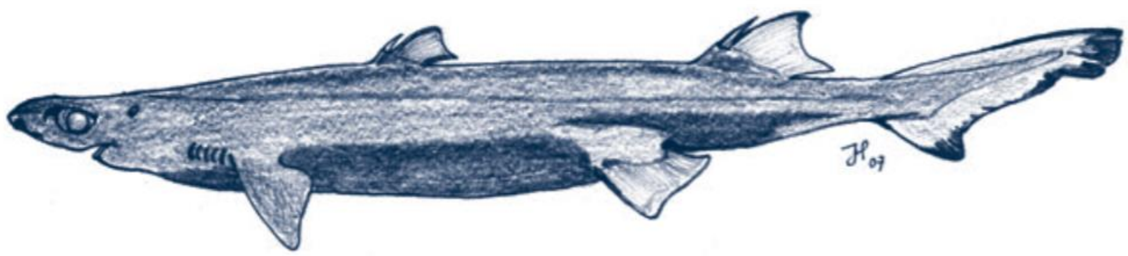

Figure 7. Velvet belly lanternshark, *Etmopterus spinax* (Source: Barreiros and Gadig, 2011).

Birdbeak dogfish, *Deania calcea*:

A small shark (largest male with 122 cm) found on outer continental and insular shelves and slopes, with recorded depths from 70 m to 1450 m (Last and Stevens, 1994). Has 2 dorsal spines, and a flattened head with a large snout with rounded edge. The body is uniformly grey to dark brown. Feeds on pelagic fish, cephalopods and shrimps. Liver oil with high commercial value, unlike their meat and fins (Barreiros and Gadig, 2011; Fishbase).

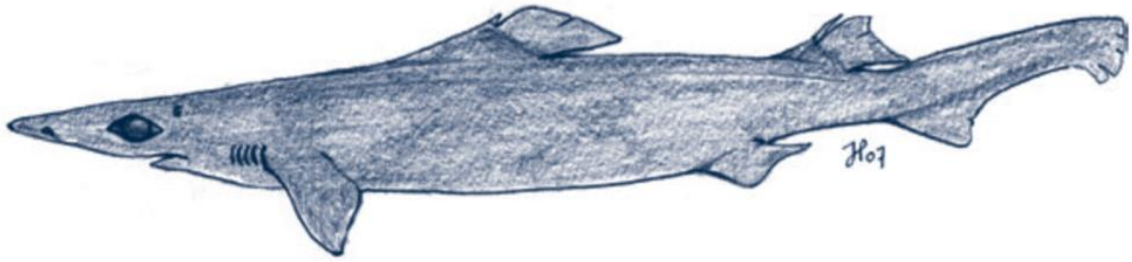

Figure 8. Birdbeak dogfish, *Deania calcea* (Source: Barreiros and Gadig, 2011).

Smooth lanternshark, *Etmopterus pusillus*:

A small sized shark (biggest specimen measuring 50 cm) found near the bottom of continental slopes at depths of 274 m to 1000 m (Whitehead et al. 1986). It has 2 dorsal spines and a rounded snout, with the nostrils closer to the tip. The body is dark brown, with a black belly, paler fin edges and specific photo marks. Feeds on small deep-water sharks, fish eggs, and lanternfish. Utilized dried salted for human consumption and for fish meat (Barreiros and Gadig, 2011; Fishbase).

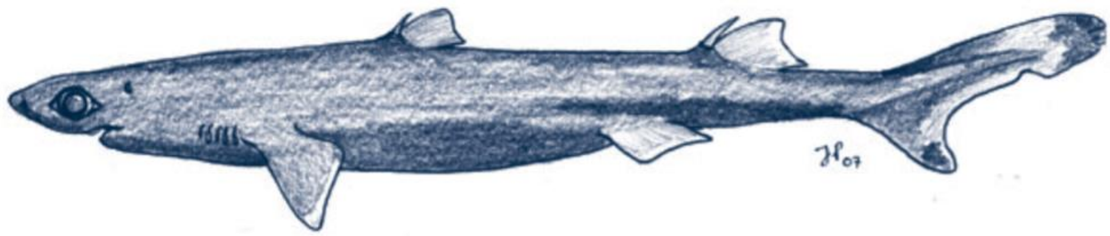

Figure 9. Smooth lanternshark, *Etmopterus pusillus* (Source: Barreiros and Gadig, 2011).

Longnose velvet dogfish, *Centroscymnus crepidater*:

A small shark (biggest specimen with 110cm) found on the continental slope and near the bottom, being common in depths of 270 m to 1300 m (IUCN). It has 2 dorsal spines, and an elongated snout. Dark-brown/gold-brown body, with paler fins. Feeds on several fish and cephalopods. It has low commercial value since their meat has a high content of mercury (Barreiros and Gadig, 2011; Fishbase).

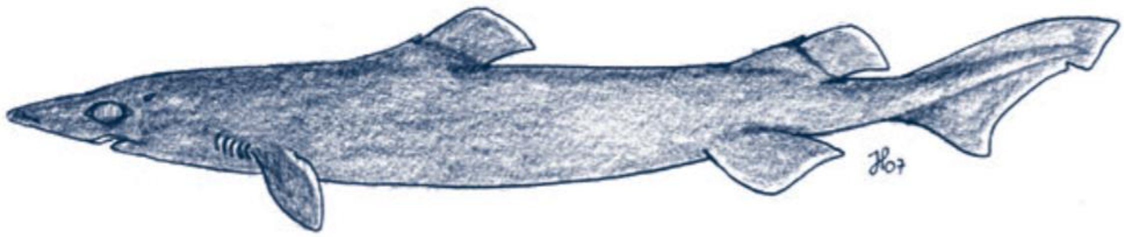

Figure 10. Longnose velvet dogfish, *Centroscymnus crepidater* (Source: Barreiros and Gadig, 2011).

Portuguese dogfish, *Centroscymnus coelolepis*:

A small sized shark (larger specimen with 120 cm) found in continental slopes and the abyssal plain, mainly between 500 m and 1700 m, even though it has been recorded at depths greater than 3000 m (Foster, 1973). It has 2 dorsal spines and a robust body, mostly dark-brown. Feeds on fish (sharks included), cephalopods, gastropods and even cetacean meat. Has a high squalene content in the liver (Barreiros and Gadig, 2011 ; Fishbase).

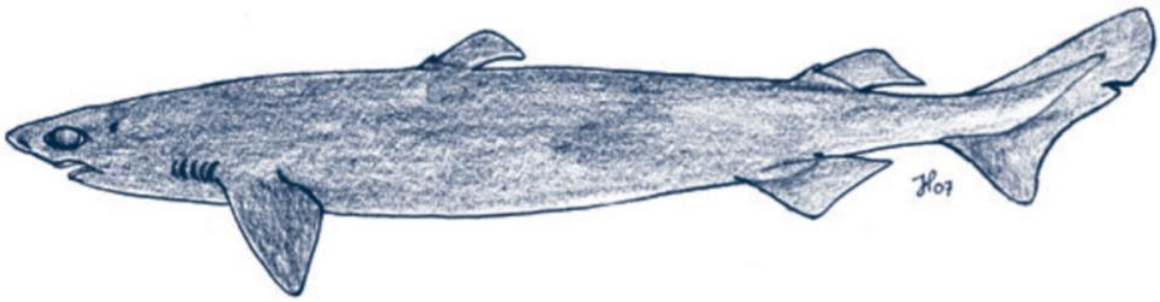

Figure 11. Portuguese dogfish, *Centroscymnus coelolepis* (Source: Barreiros and Gadig, 2011).

Gulper shark, *Centrophorus granulosus*:

It is a relatively big shark, reaching 170 cm. Found in outer continental shelves and upper slopes, ranging between 240 m and 2400 m (IUCN). It has 2 dorsal spines and an elongated body, with large, oval shaped eyes. The body is usually dark-grey or brownish-grey. Feeds mainly on bony fishes, squid and crustaceans. It is marketed smoked and dried salted for human consumption and is also processed into fishmeal. It is a high source of squalene (Barreiros and Gadig, 2011; Fishbase).

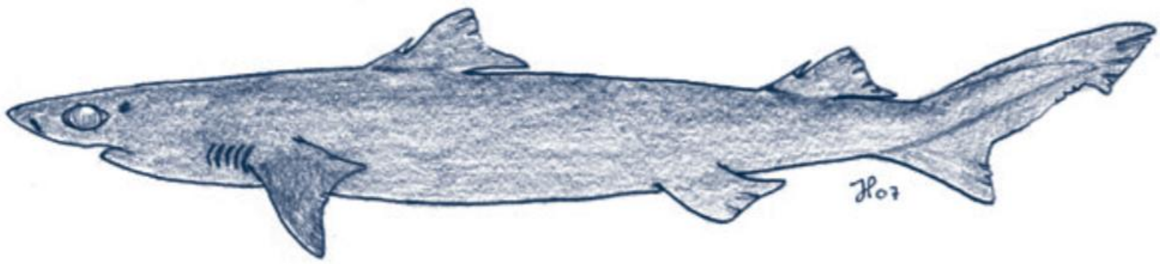

Figure 12. Gulper shark, *Centrophorus granulosus* (Source: Barreiros and Gadig, 2011).

Bluntose six-gill shark, *Hexanchus griseus*:

A large sized shark (usually 420 cm) usually found near the bottom, and occasionally pelagic, ranging from the surface to at least 2000 m (IUCN). It has no dorsal spines and the head is large with a short and flattened nose. It has six pairs of gill slits, and a dark-brown body with white edges in the fins. Feeds on a wide range of marine animals. In some areas their meat is commercialized frozen or dried, and their carcass is usually used to make fish food (Barreiros and Gadig, 2011; Fishbase).

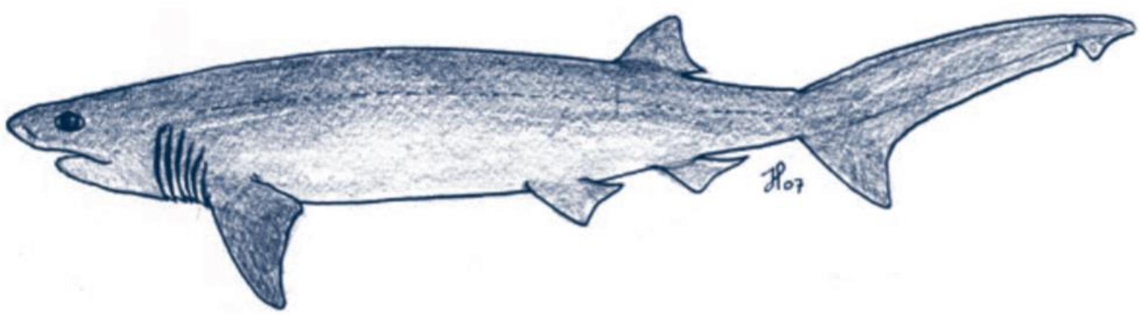

Figure 13. Bluntnose six-gill shark, *Hexanchus griseus* (Source: Barreiros and Gadig, 2011).

Shortnose velvet dogfish, *Centroscymnus cryptacanthus*:

A relatively small shark (biggest specimen measured 120 cm) found in upper continental shelves, on or near the bottom, ranging mainly between 274 m and 1000 m (IUCN). Robust body, usually dark-brown or black. Feeds on fish and cephalopods, and has low commercial value mainly due their high content in mercury (Barreiros and Gadig, 2011; Fishbase).

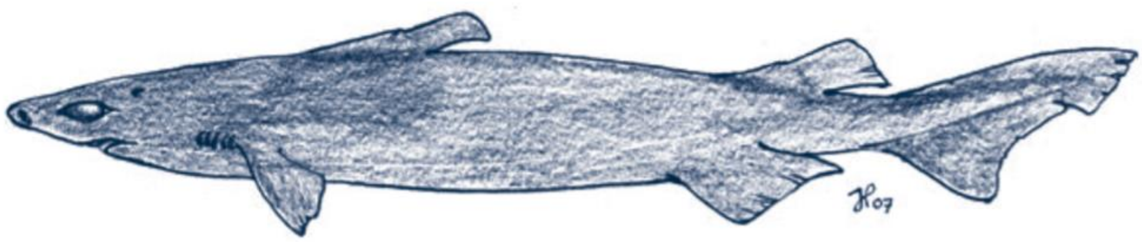

Figure 14. Shortnose velvet dogfish, *Centroscymnus cryptacanthus* (Source: Barreiros and Gadig, 2011).

Thornback Ray, *Raja clavata*:

Grows up to about 120 cm and inhabits shelf and upper slope waters, ranging from 10 m to about 300 m (Fishbase). It has a slightly protruding snout, has at least 30 irregular median thorns on the upper part of the tail, and the dorsal colour is highly variable. Feeds on several types of benthic organisms, but mainly crustaceans. It is the only ray with commercial value, being landed all year for human consumption, especially the pectoral fins (Barreiros and Gadig, 2011)

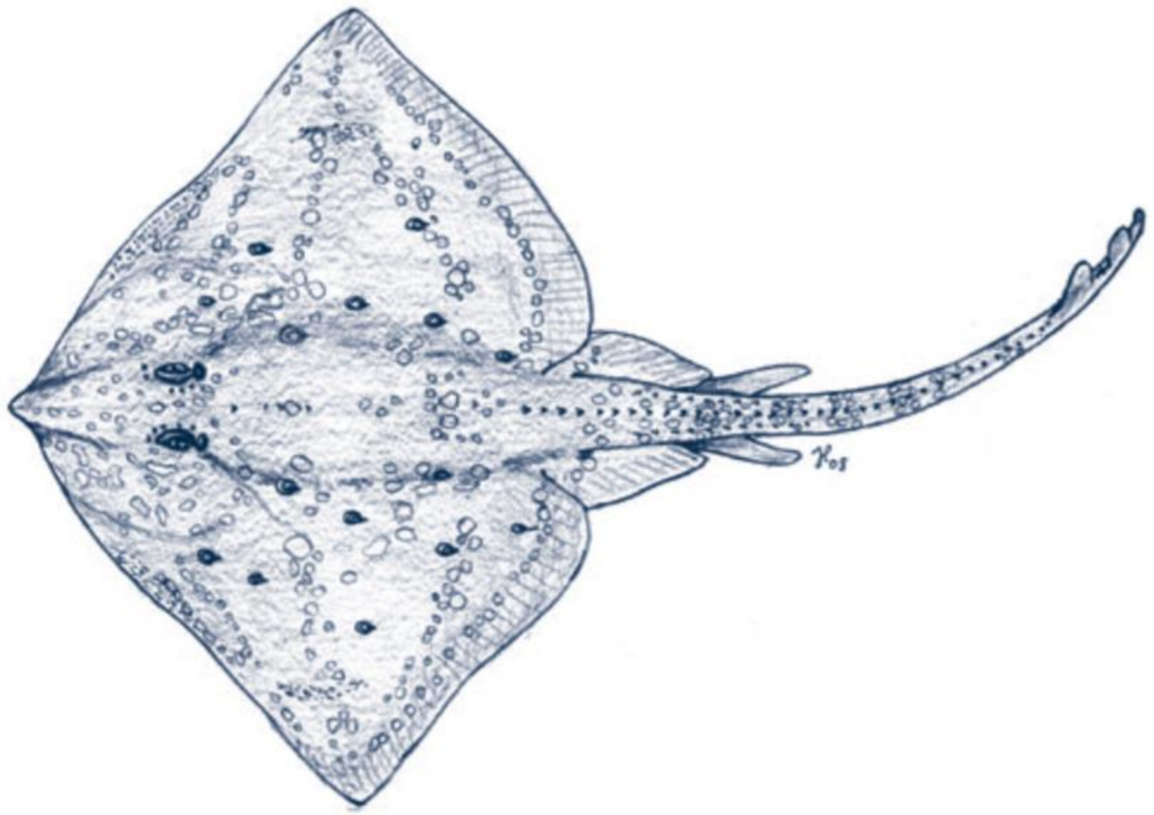

Figure 15. Thornback Ray, *Raja clavata* (Source: Barreiros and Gadig, 2011).

1.6. Objectives

The main objective of this work is to characterize the catch of the deep-water sharks in the Azores, a region where deep-water fisheries have a high economic and social importance, and at the same time harbours essential habitats for these species. Analyses of data from the last four decades provide the first account on deep-water shark bycatch in the Azores.

A short account on the diversity and distribution of deep-sea sharks in Azorean waters is given to support the interpretation of catch data. Since very little is known about discard rates and bycatch consequences in this region, a special focus is given to this subject, therefore, the potential impacts of these practices are acknowledged and discussed.

2. MATERIALS AND METHODS

2.1. Study Area

The archipelago of the Azores is located in the northeast Atlantic (36 to 40ºN, 24 to 32ºW) and is composed by 9 isolated volcanic islands distributed in 3 groups: the oriental group (São Miguel and Santa Maria), the central group (Faial, São Jorge, Pico, Terceira and Graciosa) and the occidental group (Flores and Corvo). Those islands together with other small islets define the size of the Azores Exclusive Economic Zone (EEZ) with almost 1 million km^2, and an average depth of approximately 3000 m (Morato, 2012). The Azores EEZ holds a great variety of deep-sea ecosystems and habitats, from seamounts to abyssal plains, island slopes and hydrothermal vents (Tempera, Pereira et al. 2012). The seafloor is tectonically active, irregular and rocky, therefore, the fishing grounds are highly limited to the shallow water bordering the islands and close to the seamounts and submarine banks (Menezes, Sigler et al. 2006).

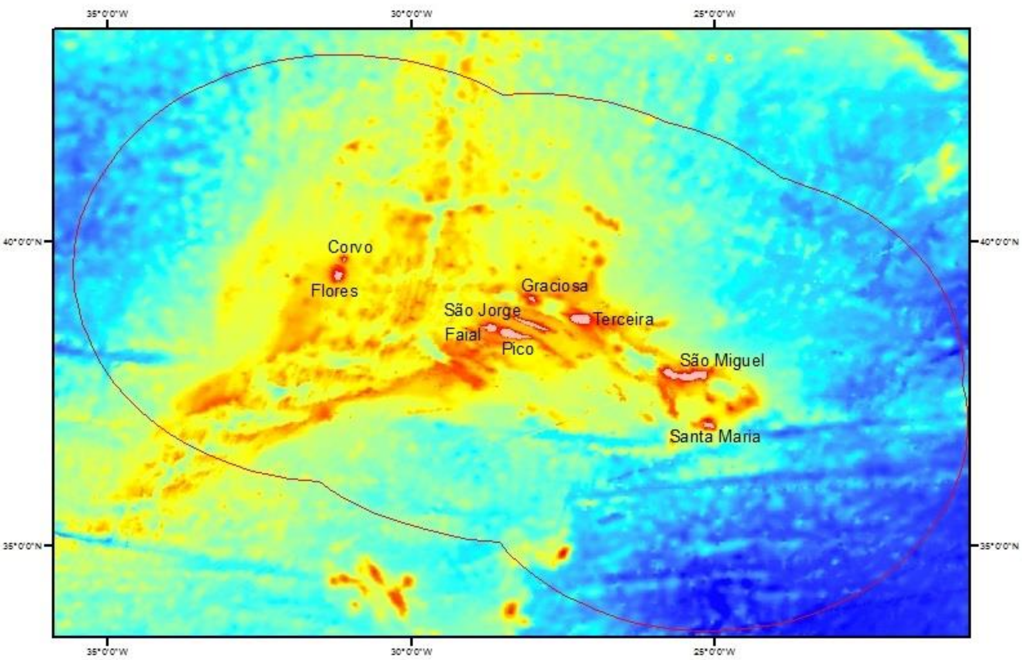

Figure 16. Geographic location of the archipelago of Azores, with the red line representing the EEZ limit.

2.2. Description of the commercial fisheries

Fisheries in the Azores are multi-segmented, targeting multiple species inhabiting a wide range of habitats, and can be divided in four main categories: coastal fleet targeting mainly small pelagic fishes with nets, pole-and-line targeting tunas, the pelagic longline fleet targeting primarily swordfish and the bottom longline fleet targeting various demersal fishes.

The small-scale fishery (using fishing boats smaller than 12 meters in length) in spite of being considered inefficient when compared with the large-scale fishery, is responsible for almost 52% of the total catches in the region (Carvalho and Isidro, 2011). This fleet usually operate in shelf slopes and continental shelf breaks, accessible to fishermen with small boats, and use mainly hand-operate nets, lift nets, purse seine or drop lines that are later collected by hand or with electric or hydraulic reels, targeting small pelagic fishes like *Trachurus picturatus* (Blue jack mackrel), *Scomber japonicus* (mackerel) and *Sardina pilchardus* (sardine) and having annual landings of about 1.4 million tonnes per year (Pham, Diogo et al. 2014 ; Morato, 2012 ; Carvalho and Isidro, 2011).

The pole-and-line fishery is responsible for the majority of the catch occurring within the Azores EEZ. Total catch of tuna fluctuates between 3500 and 14000 tonnes per year (Pham et al. 2013). Pole-and line is considered to be selective practice, having limited levels of bycatch. This technique relies on two stages: 1) catching small pelagic fishes that will later be used as bait and 2) fishing for the tuna. The fishing gear generally is a pole and a line, with a hook on it, and the bait depends on the morphology and behaviour of the target species. The main species caught in those fisheries are *Thunnus obesus* (big eye tuna), *Katsuwonus pelamis* (skipjack tuna) and to a lesser extent *Thunnus alalunga* (albacore), *Thunnus albacares* (yellowfin tuna) and *Thunnus thynnus* (Atlantic bluefin tuna) (Morato, 2012).

The large pelagic vessels are also widely used in the Azores, they are in average 18 m long, host different gear types and have a high catch capacity, using more effective fishing techniques (Carvalho and Isidro, 2011; Ruttan, Gayanilo Jr. et al. 2000). They are used to catch swordfish and to a lesser extent blue sharks.

This fishing gear was first introduced in 1987, with official landings ranging between 25 to 450 tonnes per year (Pham et al. 2013).

Lastly, the fourth and second most important component of the Azorean fishing industry in terms of landed weight and value is the demersal fleet, which uses bottom longline and handline, since bottom trawling has been prohibited (EC1568/2005, 2005; Carvalho and Isidro, 2011). Total catches of this component ranges between 3500 and 4500 tonnes per year. The bottom longline is a fishing gear that is comprised of a main line, with several branch lines attached and hooks placed on the end of them. This device has many alternative buoys and weights placed in constant intervals of the main line, and it can range from depths from 800 to 1450 m (Figure 17) (Ramos, Silva et al. 2013; Morato, 2012). The same happens with the handlines, but the main gear type consists in a line with several hooks attached.

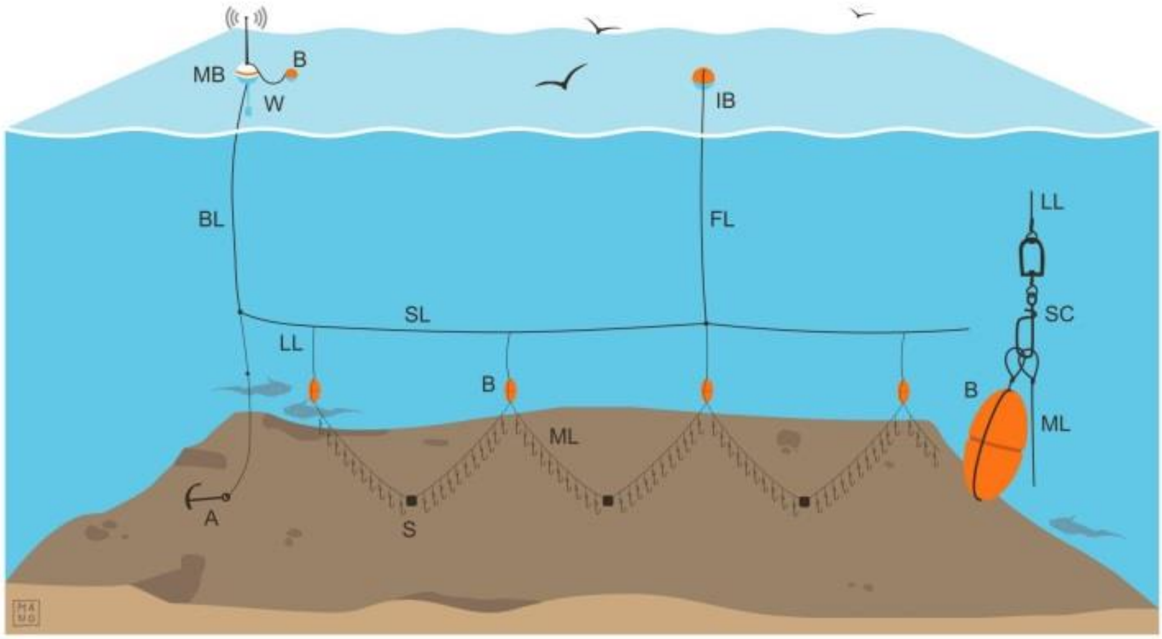

Figure 17 - Schematic representation of the bottom longline fishing method. In the figure: **MB** – Marker buoy; **B** – Small Buoys; **W** – Weight; **BL** – Buoy line Multifilament; **A** – Anchor; **LL** – Link line multifilament; **SL** – Safety line; **S** – Sinkers; **ML** – Mainline Multifilament; **FL** – Free line Multifilament; **IB** – Intermediate buoy; **SC** – Clip; **LL** – Link line multifilament. Ilustration: Nuno Brito ©ImagDOP.

Recently, the exploitation of a new resource, black scabbard fish (*Aphanopus carbo*) has begun in Azorean waters using drifting bottom longline. It is a selective fishing gear and it can range from depths between 1000 m to 1900 m (Besugo, 2013). It is comprised of a main line, connected with other secondary, vertical lines (free lines), with hooks placed on the lower end, and buoys on the upper end (Figure 18). The size of the gear, hooks and the material, depends mainly on the target species, but also on the vessels and the fishermen (Machete, Morato et al. 2011; Domingo, Forselledo et al. 2014). At present, official statistics suggest catches are relatively low, ranging from 50 to 450 tonnes per year.

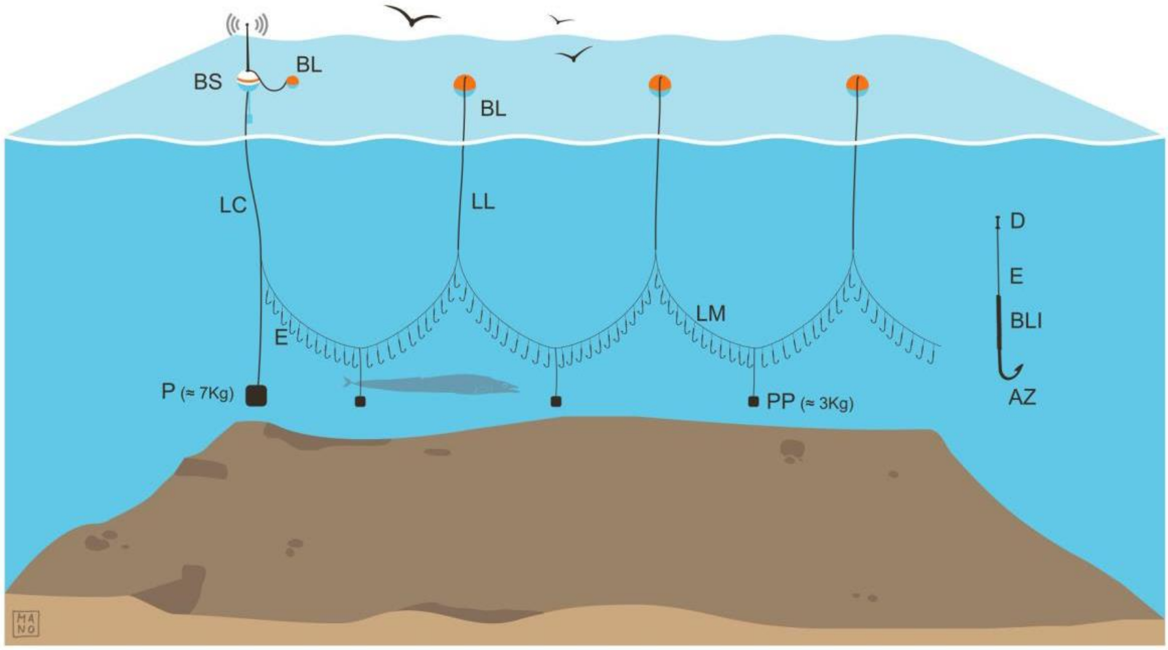

Figure 18 - Schematic representation of the drifting bottom longline fishing method. In the figure: **BS** – Marker buoy; **BL** – Small buoys; **LC** – Buoy line Multifilament; **P** - Weight; **E** – "Estralhos"; **LL** - Free line Multifilament; **LM** – Main line Multifilaments; **PP** – Small weights; **D** – "Destorcedores" ; **BLI** – "Belisqueiro" ; **AZ** – Hook. Ilustration: Nuno Brito ©ImagDOP.

2.3 Fisheries catch data

Official and "illegal, unreported and unregulated" (IUU) catch data were used to characterize the catch of deep-water sharks in the Azores. Both of the data sets were compiled and estimated by Pham et al. (2013). The official data were obtained from several landing databases recorded by regional and national authorities from 1950 to 2014, but for this study only the last 4 decades (1974 to 2014) were analysed. The data from 2010 to 2014 is derivative from unpublished work.

Estimation of IUU catch for the demersal fleet was based on data collected by fishery observers, according to a stratified random sampling scheme, based on fishing gear and the fleets by a Observer Programme for the Discards in Azorean fisheries, PORPESCA (Pham et al. 2013). In the Azores, the IUU catches of the demersal fleet consists primarily of bycatch and discards since very little illegal fishing activities currently exist. From the 24 elasmobranchs identified in the catches, 17 were deep-water sharks. Catches were analysed in detail for the most caught 9 species in terms of weight.

2.4 Fishing surveys data

In addition, and to complement this work, data from scientific fishing surveys was used to further describe the deep-water shark diversity and distribution in the Azores.

These surveys were carried out between 1996 and 2011, however no data is available for 1998 and 2006, and in 2009 only a few sets were performed. Therefore the data sets from these years were excluded from the analyses. In total 481 longline sets were analysed. These were performed mainly around the nine islands and in the main seamounts and banks (Figure 19) using the R/V “Arquipélago”, with a mean depth of 525 m and a minimum and maximum depth of 16 m and 2476 m, respectively. The bottom longline surveys followed a standardized methodology designed to monitor Azorean demersal and deep-water fish species (Menezes, Sigler et al. 2006).

During gear deployment, the start and end of each 50 m depth stratum was registered. For all the depth intervals, we recorded the initial and final position of the stratum, and the total fish catch (total weight and number of individuals), as well as the effort associated (except for 2010). For the 9 most caught deep-water species the number of individuals landed was also registered. Since the fishing sets, locations, depth and effort, were not constant every year, the analysis of the variation of the total weight per year would not be completely accurate (Table 1). Catch per unit effort (CPUE), in this case the number of individuals caught by 1000 hooks, where the fishing effort was distributed through the years, mainly from March to November, was also computed.

A Kruskal-Wallis test was performed to investigate annual differences in the mean weight of the captured species; the null hypothesis was that the species mean weight was not significantly different through the years. This test was combined to the Bonferroni–Dunn test to allow multiple comparisons. Dunn's test is a not parametric analog where we can highlight where are the significant differences using multiple, stepdown comparisons.

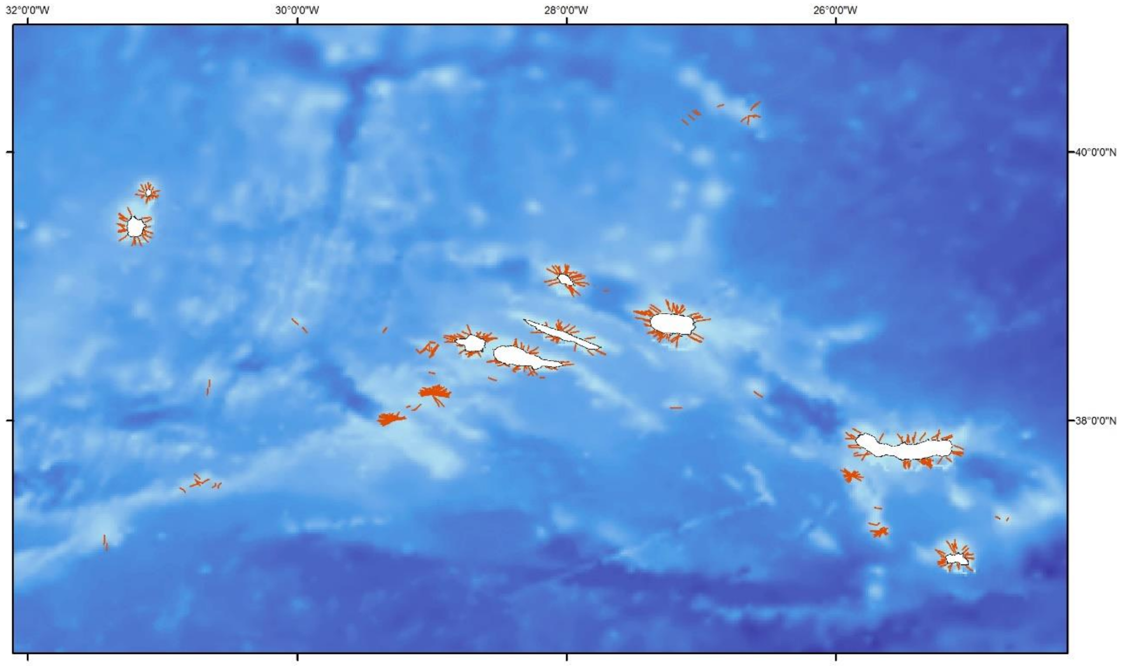

Figure 19 - Representation of the sets performed (red lines) in the Azores between 1996 and 2011.

Data organization and assemblage as well as statistical analyses to represent the average CPUE per year, the depth ranges and the species mean weight through the years were performed using Microsoft Office Excel (Microsoft Office © 2007). This software and SigmaPlot (version 11.0) were used to create all graphs. The program ArcMap 10.0 © ESRI was used for the construction of the maps and the visual representation of the sets performed on the experimental surveys. The Kruskal-Wallis and Bonferroni–Dunn tests were performed on the software GrapPad Prism 6 © 2015.

Years	Nº of Sets	Total Weight (kg)
1996	24	201,29
1997	28	190,90
1999	46	276,48
2000	31	447,09
2001	32	414,50
2002	32	728,01
2003	37	721,56
2004	44	987,12
2005	37	864,45
2007	32	1740,23
2008	38	778,852
2009	7	123,34
2010	50	1277,74
2011	50	579,24

Table 1 - Number of sets performed each year, and the corresponding total weight of deep-sea sharks.

3. RESULTS

3.1. Official Landings and IUU catch

Table 2 presents a summary of the differences between the reported and IUU catch of deep-sea sharks (orders Carcharhiniformes, Hexanchiformes and Squaliformes) and rays (orders Myliobatiformes, Rajiformes and Torpediniformes) in the last 4 decades. The total weight of the reported catches, approximately 13428 tonnes, greatly exceeded that of IUU ones (~ 8400 tonnes). However, this value (13428 tonnes) is almost completely due to the catch of only two species, *Dalatias licha* and *Raja clavata*.

Dalatias licha represents almost 53% of the total catches and about 98% of the sharks reported values. The second deep-water shark with the highest reported catch is *Centrophorus lusitanicus*, even though it is known that this species does not dwell in Azorean waters (Correia, 2009) suggesting that other species were landed and identified as *Centrophorus lusitanicus*, as its fishing is allowed.

The IUU catches are mainly represented by seven different species, the most caught being *Centrophorus squamosus*, which contributes to almost 40% of the deep-water sharks IUU catches.

Regarding rays, *Raja clavata* shows the highest values both on the official and IUU catches, while other species have only been recorded in IUU data.

It is worth noting that from the 23 species of elasmobranchs, only 11 of them are landed, while 20 are usually discarded.

Table 2. Reported and IUU catches of deep-water elasmobranchs in the Azores between 1974 and 2014.

Species		Reported (tonnes)	IUU (tonnes)	Total
Family	**Sharks**			
Dalatiidae	*Dalatias licha*	10590,13	1009,78	11599,92
Centrophoridae	*Centrophorus squamosus*	0,00	2789,78	2789,78
Centrophoridae	*Centrophorus granulosus*	23,58	1169,32	1192,90
Centrophoridae	*Deania profundorum*	5,43	654,13	659,56
Hexanchidae	*Hexanchus griseus*	36,46	500,04	536,50
Etmopteridae	*Etmopterus spinax*	0,01	447,37	447,38
Centrophoridae	*Deania calcea*	6,66	226,86	233,52
Centrophoridae	*Centrophorus lusitanicus*	117,94	0,00	117,94
Etmopteridae	*Etmopterus pusillus*	0,00	96,28	96,28
Dalatiidae	*Somniosus microcephalus*	0,00	5,53	5,53
Hexanchidae	*Heptranchias perlo*	2,22	0,00	2,22
Somniosidae	*Centroscymnus crepidater*	1,04	0,92	1,96
Somniosidae	*Centroscymnus cryptacanthus*	1,59	0,00	1,59
Somniosidae	*Centroscymnus coelolepsis*	0,00	1,00	1,00
Pseudotriakidae	*Pseudotriakis microdon*	0,00	0,89	0,89
Etmopteridae	*Etmopterus princeps*	0,00	0,46	0,46
Somniosidae	*Scymnodon obscurus*	0,00	0,04	0,04
	Total Sharks	10785,07	6902,39	17687,46
	Rays			
Rajidae	*Raja clavata*	2643,09	846,07	3489,17
Rajidae	*Dipturus batis*	0,00	590,73	590,73
Rajidae	*Leucoraja fullonica*	0,00	49,00	49,00
Dasyatidae	*Pteroplatytrygon violacea*	0,00	4,96	4,96
Rajidae	*Raja brachyura*	0,00	5,28	5,28
Torpedinidae	*Torpedo nobiliana*	0,00	3,86	3,86
	Total Rays	2643,09	1499,91	4143,00
	Total	13428,16	8402,30	21830,46

The patterns in total catch of deep-water sharks (Figure 20) reflect key events in the Azorean fisheries. The increase in deep-water sharks caught from the late seventies until the early 1990´s can be mainly attributed to the *Dalatias licha* direct fishery. Together with the introduction of the bottom longline in 1984, the total annual catches in that year and the following show a dramatic increase, but it was only between 1987 and 1991 that the annual values increase steadily until they reach its peak in 1991 with almost 1200 tonnes. Since then, the values started to gradually decline and in the last 15 years they remained relatively stable at about 200 tonnes per year.

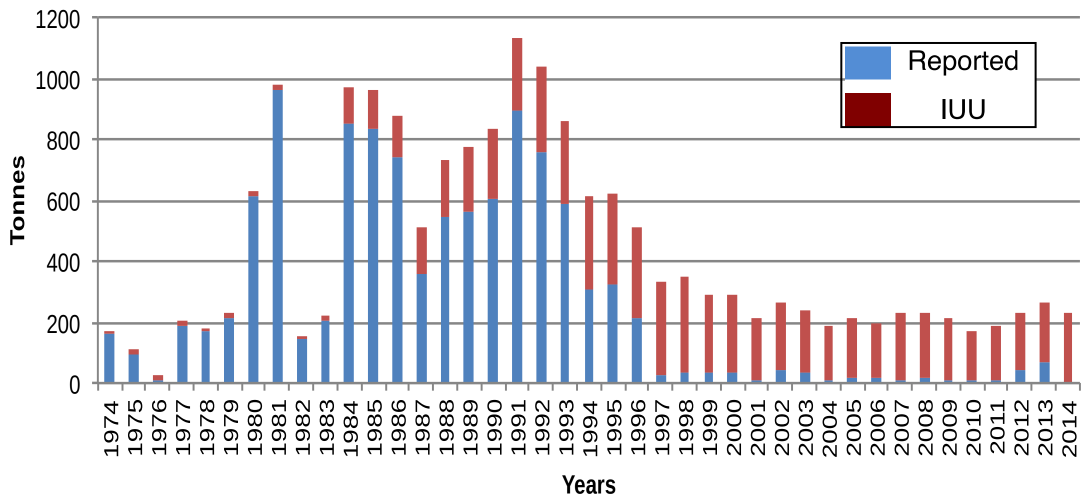

Figure 20. Annual catches of deep-water sharks, divided into reported and IUU catches from 1974 to 2014.

The proportion of deep-water sharks (%DWS) in relation to other species captured by bottom fishing methods [(1)], such as bottom trawling, bottom handline and drifting pelagic longline, follows a trend similar to that presented in Figure 20, with the exception that the higher values occurred in 1981, with almost 35% of the total catches (Figure 21).

It can be observed an increase until the mid-80s, followed by a decrease and then a stabilization from 1997 until the end of the study in 2014, with a mean proportion of 4.5%.

1) Within the 178 species caught by those gear types, 17 of them were deep-water sharks.

When comparing the reported and IUU catches per year, the official component of fisheries dominates between 1974 and 1995 (Figure 20) reaching its highest value in 1981 with about 966 tonnes. In 1991 another peak on official landings was observed (896 tonnes) and since then it started to decline. By the year 1996, the unreported values exceed the reported ones, a trend that was observed until the end of the study in 2014. IUU catches reached their peak in 1998, with 319 tonnes. Even though the IUU values only surpassed the reported values in 1996, they have been relatively stable at a mean of 232 tonnes per year since 1989.

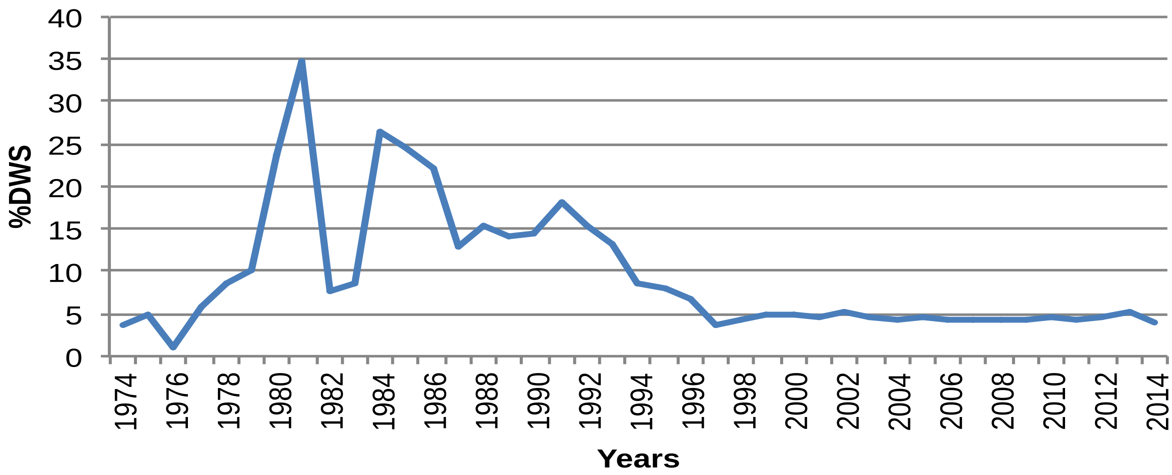

Figure 21. Proportion of deep-water sharks (%DWS) in relation to total catch by bottom fishing methods.

Trend analyses of the percentage of IUU catches show that these values have been high during most of the studied time (Figure 22). Only between 1977 and 1995 they have maintained values below 50%. In the year 2014 the values have reached the highest percentages, close to 100%. Regression analyses show a linear relation between time and the % of IUU catches ($r=0.892$; $p= <0.0001$).

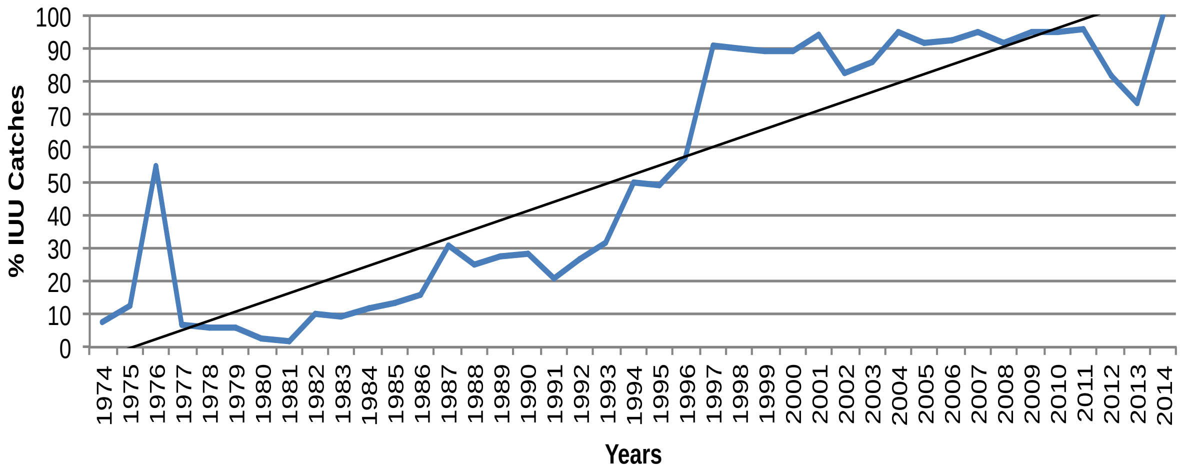

Figure 22. Percentage of the IUU catches through the years, with the line representing the linear regression.

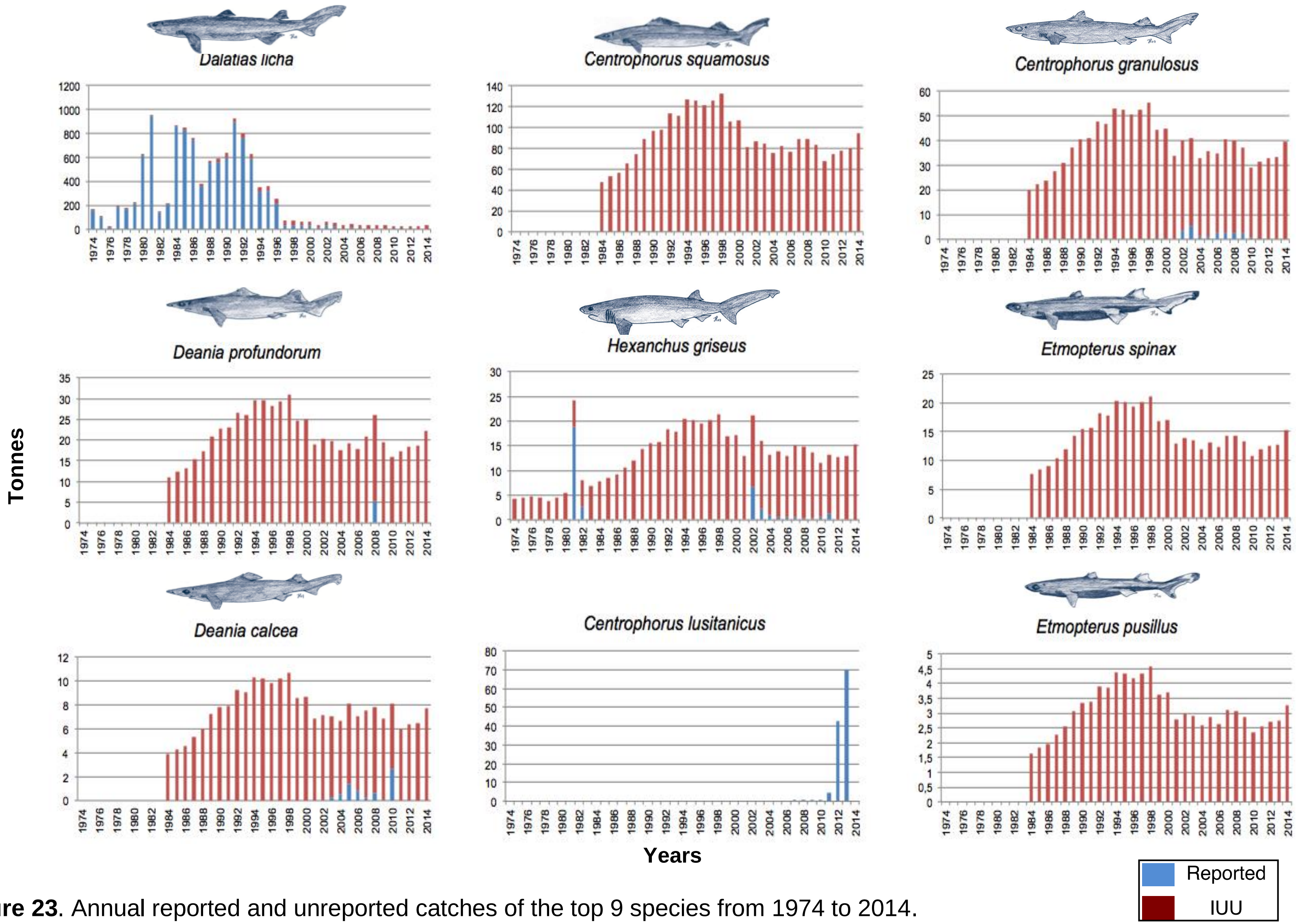

Figure 23. Annual reported and unreported catches of the top 9 species from 1974 to 2014.

Analyses of the catch trend of the nine most caught deep-water elasmobranch species (Figure 23) show that six of these species (*Centrophorus squamosus*, *Centrophorus granulosus*, *Deania profundorum*, *Deania calcea Etmopterus spinax*, and *Etmopterus pusillus*) have a similar pattern: the harvesting data begin in 1984, there is a peak in 1988 and the unreported values always predominate over the reported ones. From 1988, the values slowly decline, with a few irregular high peaks, but from 2011 to 2014 they raise again in all the six species, even though with different landing weights. *Etmopterus pusillus* and *Centrophorus squamosus* are the only species that have never been officially landed. The other four species have been reported but the captures never surpassed 6 tonnes per year.

The deep-water shark *Hexanchus griseus* also shows a similar trend to these six species, but with the exception that it started being caught in 1974. In addition, there was an unusual peak of reported catches in 1981.

Dalatias licha is the only species with more reported landings than unreported catches. From 1987 to 1992 the capture values tend to increase, and from there they start to slowly decrease. A marked difference was observed between the years 1996 and 1997 when the values dropped dramatically. From 1997, the decrease is gradual until 2011, the last year with reported catches. Concerning the IUU, from 1974 to 1997 the values were relatively low but show a steady increase. From there, the IUU catches were fairly stable, even though they gradually decreased.

Finally, *Centrophorus lusitanicus* is the only species with only reported catches and those only began in 2007 and continued until 2013. Those values started below 1 tonne and increased to almost 70 tonnes in 2013.

3.2. Fishing Surveys

The fishing surveys performed in the Azores between 1996 and 2011 resulted in the identification of 28 deep-water elasmobranchs, including 20 sharks of 8 different families (Table 3) that accounted for 66 % (9.2 tonnes) of the total weight of elasmobranchs captured. The top 3 species captured in terms of weight were *Deania profundorum*, *Deania calcea* and *Dalatias licha*, but in terms of number of individuals were *Etmopterus spinax*, *Deania profundorum* and *Deania calcea*.

These species were captured at a mean depth ranging from 208 m to 1085 m. The widest depth ranges were observed in *Etmopterus spinax* (from 112 m to 1200 m), *Etmopterus pusillus* (from 112 m to 1195 m) and *Deania calcea* (from 335 m to 1296 m). Species caught in the greater mean depth were *Centroscymnus coelolepis* (1085 m), *Etmopterus princeps* (1064 m) and *Centroscymnus crepidater* (1049 m). Some of the species with a shallower mean depth were also the ones with the lower number of individuals caught (*Heptranchias perlo*, *Charcarias taurus* and *Hexanchus griseus*).

The capture depth range of the nine most frequent deep-water sharks is represented in Figure 24. The relatively small boxplots of the species *Etmopterus spinax*, *Dalatias licha*, *Deania profundorum* and *Centroscymnus crepidater* indicate a high level of aggregation between their respective depths. The boxplot of the species *Etmopterus pusillus* and *Centroscymnus cryptacanthus* are comparatively taller, showing that they have a higher depth range and are more disperse. There are 3 distinctive groups where 50% of the individuals form aggregations at similar depth ranges: *Etmopterus spinax* and *Dalatias licha* form aggregations at about 600 m, *Etmopterus pusillus* and *Deania profundorum* form aggregations at 700 m, and the remaining species (*Censtroscymnus cryptacanthus*, *Centrophorus squamosus*, *Deania calcea*, *Centroscymnus crepidater* and *Centroscymnus coelepis*) assemble between 1000 m and 1100 m.

Table 3. Total catch amount, numbers and depth ranges of deep-sea elasmobranchs captured during the fishing surveys in the Azores from 1996 to 2011

Species				Depth (m)		
Family	**Sharks**	**Total Weight (kg)**	**Total Numbers**	**Mean**	**Min**	**Max**
Etmopteridae	*Etmopterus spinax*	439,05	2241	558	112	1200
Centrophoridae	*Deania profundorum*	3060,86	1866	724	254	1201
Centrophoridae	*Deania calcea*	3117,59	1154	982	335	1296
Etmopteridae	*Etmopterus pusillus*	197,98	854	721	112	1195
Somniosidae	*Centroscymnus crepidater*	282,35	169	1049	657	1249
Somniosidae	*Centroscymnus coelolepis*	547,98	88	1085	705	1251
Dalatiidae	*Dalatias licha*	574,35	71	571	246	1091
Centrophoridae	*Centrophorus squamosus*	384,09	50	965	335	1188
Somniosidae	*Centroscymnus cryptacanthus*	127,00	33	962	406	1250
Scyliorhinidae	*Galeus murinus*	11,50	26	933	570	1208
Dalatiidae	*Squaliolus laticaudus*	1,41	15	702	401	950
Somniosidae	*Scymnodon obscurus*	57,44	12	983	551	1171
Centrophoridae	*Centrophorus granulosus*	114,38	11	951	550	1170
Etmopteridae	*Etmopterus princeps*	12,73	10	1064	823	1150
Hexanchidae	*Heptranchias perlo*	19,19	6	208	103	331
Pseudotriakidae	*Pseudotriakis microdon*	39,76	6	977	703	1198
Centrophoridae	*Deania hystricosa*	13,86	4	996	953	1050
Hexanchidae	*Hexanchus griseus*	180,00	2	475	312	636
Odontaspididae	*Carcharias taurus*	19,18	1	382	367	396
Somniosidae	*Somniosus rostratus*	6,76	1	929	926	931
	Total Sharks	9207,45	6620			
	Rays					
Rajidae	*Raja clavata*	3755,07	2074	163	30	572
Rajidae	*Dipturus cf. intermedia*	883,433	123	432	57	841
Rajidae	*Leucoraja fullonica*	71,997	28	431	251	650
Dasyatidae	*Dasyatis pastinaca*	13,81	10	89	47	148
Dasyatidae	*Pteroplatytrygon violacea*	43,00	6	81	34	150
Rajidae	*Dipturus oxyrinchus*	21,80	2	720	702	738
Rajidae	*Raja brachyura*	2,74	2	492	402	579
Torpedinidae	*Torpedo nobiliana*	16,00	1	473	452	493
	Total Rays	4807,85	2246			
	Total	14015,30	8866			

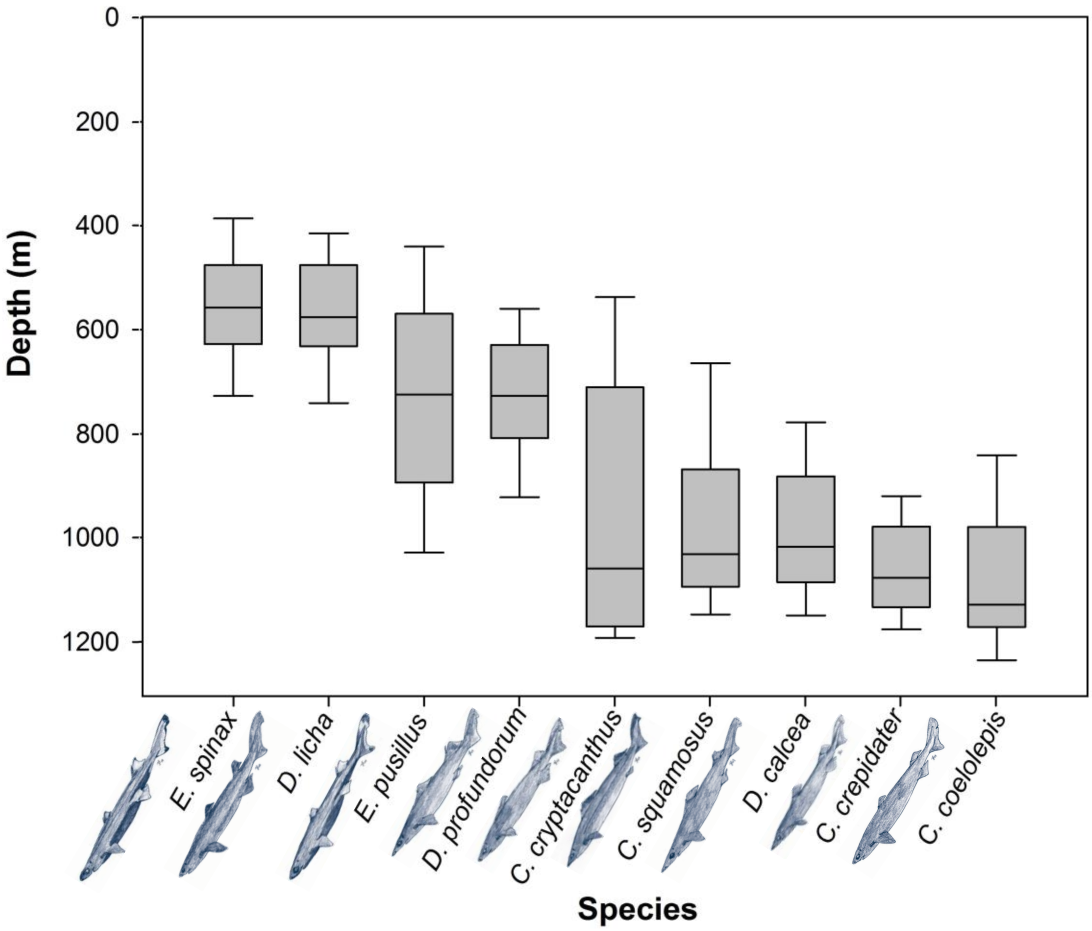

Figure 24. Boxplot of the depth at which deep-water sharks were captured during experimental longline surveys performed in the Azores between 1996 and 2011 (the black line represents the median and the error bars are represent in the 90th and 10th percentile)

In the species *Etmopterus spinax*, *Etmopterus pusillus* and *Deania profundorum* we can see a symetrical distribution of the species.

Even thought *Etmopterus spinax* have a relatively low median value when compared with their depth range, with the representation of the 90th percentile, it is possible to see that 40% of the individuals range between the median and almost 700 m. The same happens with *Etmopterus pusillus*, with 40% of the individuals ranging between 700 m and 1000 m.

Regarding the deep-water rays, they represented about 34% of the elasmobranchs catches, with the species *Raja clavata* contributing for 78% of those values.

Ten species of deep-water sharks were caught in relatively low numbers, and therefore it can be assumed that those species are not very common in Azorean waters and/or do not have a similar distribution to the other species. Interestingly, the species with the greatest importance to commercial fisheries, *Centrophorus squamosus* and *Centroscymnus coelolepis*, commonly called as "siki", were not captured in large numbers. Of these two species, only 138 individuals were caught, representing only 10% of the deep-water shark fishery in terms of weight (0.93 tonnes).

Analyses of catch per unit effort (CPUE) (Figure 25) show that the species with higher CPUE were *Etmopterus spinax* (5 ± 2 individuals per 1000 hooks), *Deania profundorum* (4 ± 1 individuals per 1000 hooks) and *Deania calcea* (2.2 ± 0.25 individuals per 1000 hooks). *Deania calcea* presented an increasing trend in the average CPUE from 1999 to 2004. From there, the values dropped and remain lower. The same did not happen with *Deania profundorum* and *Etmopterus spinax* that show irregular high and low CPUE within the study period, with the exception that *Etmopterus spinax* shows a decrease from 2003 to 2011.

The CPUE of *Etmopterus pusillus* showed 3 increasing periods: between 1999 and 2001, 2003 to 2005, and then from 2007 to 2011, reaching the higher value in 2001 with an average of 1.4 (± 0.4) individuals per 1000 hooks, but each of those increase periods are less accentuated than the other. The CPUE for both *Centroscymnus crepidater* and *Centroscymnus cryptacanthus* showed high inter-annual variability, increasing and decreasing every other year, but *Centroscymnus crepidater* presented generally higher values and a stabilization of the values between 2004 and 2008.

Centrophorus squamosus presented the lower CPUE, showing the highest average CPUE of 0.11 (± 0.05) individuals per 1000 hooks in 2002. CPUE for *Centroscymnus coelolepis* was 0 during 5 years, and presented relatively low values, but with large error bars in the remaining years. In 2011 it reached its highest CPUE, when normally the other species presented one of their lower catch rates.

CPUE of *Dalatias licha* showed two visible trends: an increase from the beginning of the study to 2005 (except from 2000 to 2001), and a decrease from then onwards, having a value near to 0 in 2011.

For almost all the species, the first two years present the lower average CPUE values.

Figure 26 shows the mean weight variation of the 9 most captured species through the years. Statistical analysis (Kruskal-wallis test) showed that there were no significant annual differences in the mean weights of the species *Dalatias licha* (P=0.7661), *Centroscymnus cryptacanthus* (P=0.4093) and *Centroscymnus crepidater* (P=0.0664). However, in the species *Centrophorus squamosus* (P=0.0353), *Deania calcea* (P=<0,0001), *Centroscymnus coelolepis* (P=0.0217), *Deania profundorum* (P=<0,0001), *Etmopterus pusillus* (P=<0,0001) and *Etmopterus spinax* (P=<0,0001) significant annual differences were detected. Results of a Dunn's test show the years with significant differences (Table 4).

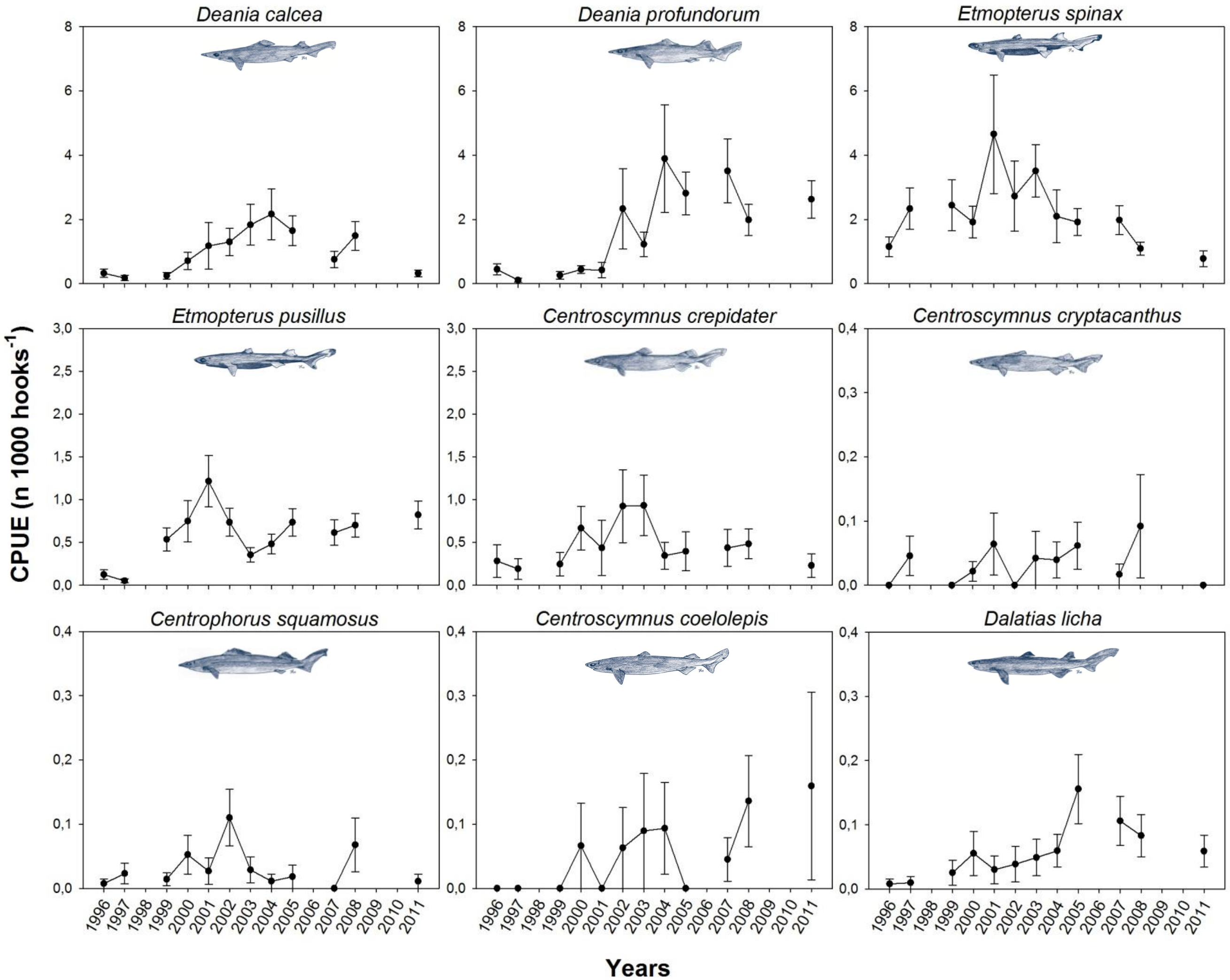

Figure 25. Average CPUE per year of the 9 most captured species of deep-water.

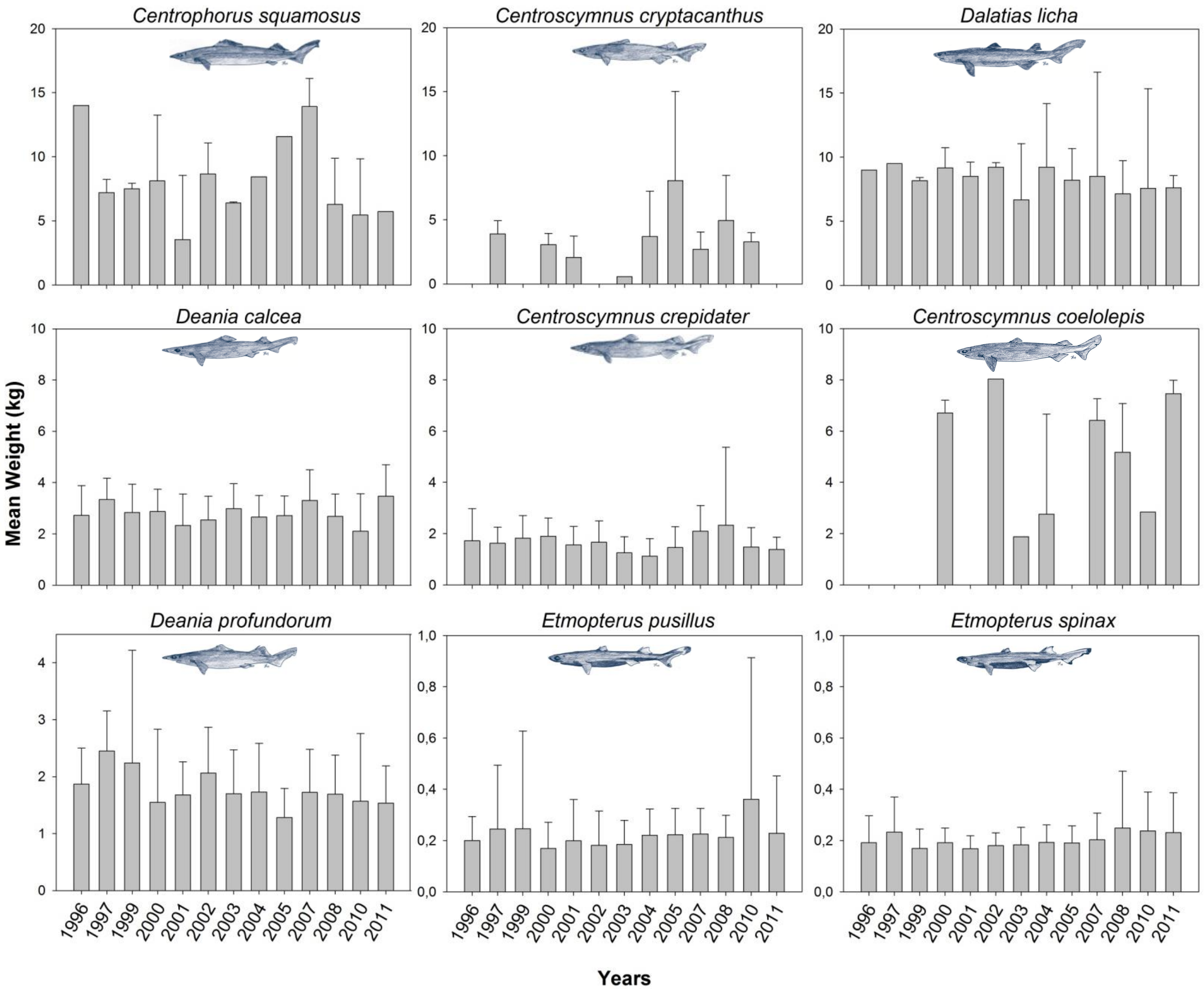

Figure 26. Mean weight per year of the 9 most captured species and its standard deviation.

Table 4. Representation of the years with significant differences in the mean weigh through de years.

Species	Years with significant differences
C. squamosus	2007 x 2010
C. coelolepis	2004 x 2011
D. calcea	1997 x 2001
	1997 x 2004
	1997 x 2010
	2001 x 2007
	2001 x 2011
	2002 x 2007
	2002 x 2011
	2003 x 2004
	2003 x 2010
	2004 x 2007
	2004 x 2011
	2005 x 2007
	2007 x 2008
	2007 x 2010
	2010 x 2011
D. profundorum	1996 x 2005
	1997 x 2000
	1997 x 2005
	1999 x 2005
	2001 x 2005
	2002 x 2004
	2002 x 2005
	2002 x 2007
	2002 x 2008
	2002 x 2010
	2002 x 2011
	2003 x 2005
	2004 x 2005
	2005 x 2007
	2005 x 2008
	2005 x 2010
	2005 x 2011

Species	Years with significant differences
E. pusillus	1996 x 2005
	1997 x 2000
	1997 x 2005
	1999 x 2005
	2000 x 2002
	2001 x 2005
	2002 x 2004
	2002 x 2005
	2002 x 2007
	2002 x 2008
	2002 x 2010
	2002 x 2011
	2003 x 2005
	2004 x 2005
	2005 x 2007
	2005 x 2008
	2005 x 2010
	2005 x 2011
E. spinax	1996 x 2008
	1997 x 1999
	1997 x 2001
	1999 x 2000
	1999 x 2007
	1999 x 2008
	1999 x 2010
	1999 x 2011
	2000 x 2001
	2001 x 2005
	2001 x 2007
	2001 x 2008
	2001 x 2010
	2001 x 2011
	2002 x 2008
	2003 x 2008

4. DISCUSSION

Total catch estimates in the Azores suggest that 203 different species have been landed between 1974 and 2014 (ICES, 2013). These include a wide variety of groups, such as algae, cephalopods, fishes, marine mammals and crustaceans, having a total weight of about 272294 tonnes. The reported landings of the identified species have a total weight of about 213883 tonnes, while the IUU catch have a total weight of 58411 tonnes. When analysing our group of interest, the deep-sea elasmobranchs - 17 species of deep-sea sharks and 6 species of deep-sea rays - they contribute to 6.28% of reported catches, and 14.38% of the IUU catch, concluding that this group suffers a great pressure from the IUU fishing.

As shown in Table 2, reported catches (13428 tonnes) are higher than IUU catches (~ 8400 tonnes). It is important to note that catches of the kitefin shark, *Dalatias licha*, comprise about 79% of this amount, which can be explained by the fact that the direct fisheries of this species were permitted until the middle of 1990s.

The small catch values (both official and IUU) observed between 1997 and 2014 (Figure 20) reflect the implementation of fishing regulations including Total Allowable Catches (TACs) that limit the amount of fishes that can be caught, over a given period of time, in a specific stock. Therefore, from the 23 species of elasmobranchs caught, only 11 were officially landed, with relatively low values, whilst 20 have IUU values, indicating that they are mostly discarded.

TACs are set annually, based on the ICES scientific advice (ICES, 2013). For example, TACs for deep-water shark species in the EU were set to 0 in 2010, and since then, reported values were relatively low ranging from about 70 tonnes in 2013 to about 0.2 tonnes in 2014. Those catches (70 tonnes) are mostly composed of *Centrophorus lusitanicus* a species that doesn’t dwell in Azorean waters and that is not subject to the TACs regulations. Therefore, the report of *Centrophorus lusitanicus* landings must result from misidentification problems. Ramos et al., (2013) reported that in 2010, 93% of *Centrophorus squamosus* individuals were marked as *Centrophorus lusitanicus*.

For other species (*Centrophorus granulosus*, *Centroscymnus crepidater*, *Centroscymnus cryptacanthus*, *Dalatias licha*, *Deania calcea*, *Deania profundorum*, *Heptranchias perlo* and *Hexanchus griseus*), the reported values since 2010 never surpassed 2.7 tonnes per year. This value (2.7 tonnes) is mainly derivative from the catches of *Deania calcea* in 2010, the last year with reported landings; the landing values of the other species barely surpass one tonne per year. Due to the implementation of the TACs, the IUU values tend to raise every year and it is believed that the discard rates in mixed deep-water fisheries has significantly increased. The values derived from the period 2010 to 2014 are similar to those observed from 2001 forward, and this can be explained with the implementation of quotas for the deep-water species. As a result, it is believed that some vessels may have logged some deep-water sharks as other species. *Centrophorus squamosus* was the species with the highest IUU value, contributing with almost 40% of the deep-water shark IUU catches. It has been previously reported (Machete and Santos, 2007) that this species represents a large share in the bycatch resultant of the black scabbard fish fisheries in the Azores, along with two other shark species: *Etmopterus spinax* and *Centroscymnus cryptacanthus*. Although *Etmopterus spinax* represents about 7% of the IUU catches, *Centroscymnus cryptacanthus* does not contribute to a significant share of the landings, both reported and IUU.

The fisheries of the kitefin shark, *Dalatias licha*, in the Azores began around the 1970s resulting in high official catches until the end of the 1990s, when it stopped in result of low profit margins. Catch values changed every other year, due to the fluctuation of the market, having high peaks in 1981 and 1991. Since 2000, the reported values dramatically decreased, ranging from 35 tonnes in 2002 to about one tonne in 2011, the last year with reported values. This species has always been present as bycatch in other fisheries, and since 2010 the IUU values remained relatively stable at a mean of approximately 27 tonnes per year, mainly to management restrictions.

The remaining species have low reported landings, due to the implementations of TACs as it was mentioned before. In 2010, TACs were reduced to 0 with an allowance for bycatch of 10% of 2009 TACs, and by 2011 it was reduced to 3%. By 2012, no allowance for bycatch was authorized (ICES, 2013). Consequently, the IUU values tend to rise as a result of the restricted quotas implemented, and other measures such as minimum mesh sizes, minimum sizes and weights, bans of specific gear types (EC1568/2005, 2005), along with the bycatch of the mixed fisheries, especially since 1984 with the introduction of the bottom longline in the Azorean fisheries.

The deep-water rays are also included in the EU TACs for "*Skates and Rays Rajidae*", given that some of these species have high commercial value, especially *Raja clavata*.

Within the shark species landed, the IUCN red list assessments classifies as:

- Data deficient: *Etmopterus princeps*; *Scymnodon obscurus*.
- Least Concern: *Deania profundorum*; *Etmopterus spinax*; *Deania calcea*; *Etmopterus pusillus*; *Centroscymnus crepidater*; *Centroscymnus cryptacanthus*; *Pseudotriakis microdon*.
- Near Threatened: *Dalatias licha*; *Hexanchus griseus*; *Somniosus microcephalus*; *Heptranchias perlo*; *Centroscymnus coelolepis*.
- Vulnerable: *Centrophorus squamosus*; *Centrophorus granulosus*; *Centrophorus lusitanicus*.

Centrophorus squamosus and *Centrophorus granulosus*, classified as vulnerable (high risk of endangerment in the wild), are two of the three species with the highest landings, especially regarding IUU values, which gives them a very uncertain and worrying future. The near threatened species (likely to become endangered in the near future), mainly *Dalatias licha* and *Hexanchus griseus*, should also become a priority in the fisheries management.

When it comes to the proportion of deep water sharks (%DWS) captured in relation to other species by bottom fishing methods (Figure 21), since 1997 the values tend to stay stable at a mean of 4.5%, but it's still a high value to ensure the sustainability of long-term fisheries, and the survival of these species, especially the ones referred as vulnerable and near threatened.

With the implementation of the quotas, the IUU catches tend to rise (Figure 22). The low values of IUU landings between 1977 and 1995 can be explained by the low commercial value of some species, and the permission of the direct fisheries in some species, especially *Dalatias licha*. After that, the IUU values increased every other year, reaching almost 100%. The results herein presented together with those reported by Pham et al. (2013) clearly demonstrate that with the implementations of TACs, the discard rates greatly increased without decreasing the catch levels.

In the fisheries surveys performed in the Azores between 1996 and 2011, 34 species of elasmobranchs were captured. The deep-water sharks accounted for about 50% of the total weight. *Deania calcea*, *Deania profundorum* and *Dalatias licha* were the top 3 species captured in terms of weight, but when it comes to numbers, *Etmopterus spinax* replaced *Dalatias licha* in the top. From these species, *Dalatias licha* was the only one that entered the top 3 of the official landings.

Regarding the capture depth ranges (Figure 24), it is important to refer that the recorded depths belong to the depth stratum where the fishery occurs, not corresponding to the actual structure of deep-sea shark populations analyzed. However, the survey results were consistent with those published for all studied species except *Etmopterus pusillus* and *Centroscymnus cryptacanthus* that have been captured at greater depths than previously reported (presented in the Introduction).

The species belonging to the family Etmopteridae (*Etmopterus spinax* and *Etmopterus pusillus*), are among the ones with the highest number of individuals caught, but they are also the ones that dwell at the lower depths, suggesting that species that inhabit in lower depths are more susceptible to the fishing gears targeting demersal and deep-water species, and therefore more vulnerable. *Dalatias licha* is also mostly caught at similar depths, but was not as abundant compared to other species. *Deania calcea*, *Centroscymnus crepidater* and *Centroscymnus coelolepis* were caught at deeper waters than the other species, but *Centroscymnus crepidater* and *Centroscymnus coelolepis* have lower landing numbers when compared with *Deania calcea*, which could be explained by their depth range. *Centroscymnus crepidater* and *Centroscymnus coelolepis* form aggregates at higher depths and are not as dispersed in shallower depths as *Deania calcea*, being therefore less susceptible to the fishing gears. The occurrence of *Centroscymnus coelolepis* in these type of fisheries can be explained by its primarily scavenging behaviour (Menezes et al. 2009). Some authors have also suggested that *Centroscymnus coelolepis* may be less vulnerable to over fishing given their widespread depth distribution. The same may happen with *Centroscymnus cryptacanthus* that although it has a large depth range, 50% of the individuals assemble at about 1100 m, explaining their low captures in numbers. These depth aggregates can be a result of various conditions, including sex, maturity stage, size, different prey preferences and even avoidance of feeding competition with larger specimens (Clarke et al. 2001; Ramos, Silva et al. 2013).

The analyses of the average CPUE of the top 9 deep-water shark species (Figure 25) showed that the species with higher CPUE were *Etmopterus spinax*, *Deania profundorum* and *Deania calcea*. CPUE values for *Deania calcea* showed an increasing trend from 1999 to 2004, which demonstrate a high fishing pressure leading to a presumed decreased of the population size, with a decrease in the average CPUE in the following years. *Deania profundorum* showed low CPUE in the first years, and a large increase in 2002. Since then, the values showed great variations, which could indicate fluctuations in the population size every other year. The species with the higher CPUE average, *Etmopterus spinax*, showed high captures up until 2003, even though those values present fluctuations. From 2003 until the end of the study the values tended to decrease, suggesting that this species abundance have been previously disturbed and exposed to possible overexploitation. *Etmopterus pusillus* showed three increasing periods, which means that there were two periods where the species abundance declined: between 2002 and 2004, and 2005 to 2007. Since there is no available data for 2006, it is not possible to conclude what happened during that period. Although *Centroscymnus crepidater* CPUE values had 3 high peaks (2000, 2002 and 2003), the rest of the years appear to be relatively stable, with low fluctuations every other year, with a visible stabilization between 2004 and 2008, which could mean sustainable harvesting of this species. *Centroscymnus cryptacanthus* also showed variations in the average CPUE, having 4 years with 0 CPUE, which suggests that this species is more rarely caught than the others. The species *Centrophorus squamosus* and *Centroscymnus coelolepis*, also presented fluctuations in the average CPUE, but *Centroscymnus coelolepis* showed 5 years with 0 CPUE which may mean that this species has a different distribution then the others or its population has decreased. Finally, *Dalatias licha* showed an increase in the average CPUE up until 2005, and then a decrease, until the end of the study. Since it was a very popular species until the end of the 1990s, it is possible that this decrease is related with the prohibition of its direct fishery.

Generally, the CPUE analysis always shows increasing and decreasing trends that accompany the declines and recovery of populations. This monitoring should be maintained in the future to ensure suitable management of the resources.

There is not enough information avalailable regarding deep-sea sharks and their biology, specially regarding their mean weight. Therefore, the mean weight per year analyses performed in this study have almost no data for comparison. The only species with information available are *Dalatias licha*, with a mean weight of 8 kg (eol.org), *Etmopterus spinax*, with a maximum published weight of 850 g (Fishbase), *Centroscymnus coelolepis*, with a mean weight of 20 kg (Parker and Francis, 2012) and *Deania calcea* with a recorded mean weigh of 2.61 kg (Clarke, 2000).

Although the mean weight per year of the 9 most caught species does not seem to present high variations with time, the results of a Kruskal-Wallis test showed that only three species (*Centroscymnus cryptacanthus*, *Dalatias licha* and *Centroscymnus crepidater*) do not present significant differences in their mean weight though the years which could mean that they are less influenced by fishing practices, maintaining their mean weight stable over the years. Based on a relationship between the average CPUE and mean weight we suggest that in some cases, when values are varying in opposite directions (for example, the decrease of the CPUE values and increase of the mean weight), they are correlated. The mean weight of *Dalatias licha* obtained in this study was similar to the one reported in the literature (8 kg; eol.org). This may suggest that fishing has not reduced the species average size. Their mean individual size can be related with their average CPUE: when the mean CPUE start to decline (mainly in 2007 and 2008), this species recovers, having a higher mean weight in those years. Therefore we can conclude that the decreasing CPUE in the last years is not related to a decreasing abundance of the population but a decrease in the catches. Regarding the other 2 species (*Centroscymnus cryptacanthus* and *Centroscymnus crepidater*), and relating the mean weight values with the average CPUE, it can be observed that *Centroscymnus cryptacanthus* shows an increase in the mean weight when the average CPUE stabilized, between 2003 and 2004. In the case of *Centroscymnus crepidater*, the years with the lowest mean weight (2003 and 2004) may result from the high peaks of CPUE from 2002 and 2003. However, these differences were not significant.

Significant differences were detected for the remaining species. In *Centrophorus squamosus*, the only years with significant differences detected were 2007 and 2010, were the species suffer a difference of nearly 5 kg in the mean weight. *Deania calcea* showed several years with significant differences, as well as *Deania profundorum*, *Etmopterus pusillus* and *Etmopterus spinax*. In *Etmopterus pusillus*, 2002 was the year with the most significant differences, when compared with the other years, and in *Deania profundorum*, 2002 and 2005. Finally, for *Etmopterus spinax*, 1999 and 2001 were the years with the higher significant differences, recording two of the years with the lowest mean recorded weight. The weight differences in *Centroscymnus coelolepis* are particularly evident between 2004 and 2011.

Centrophorus squamosus showed one of the higher mean weights in 2007, were the CPUE is close to 0. From 2003 to 2007 it presented an increase in the mean weight and low CPUE values, suggesting that the species were recovering from the higher landings in the past years.

In *Deania calcea*, the mean weight tend to fluctuate between the different years and in 2007 it presented the highest mean weight, also corresponding to one of the lowest CPUE values, showing a recovery. The mean weight reported in the northeast Atlantic (2.61 kg; Clarke, 2000), match the ones registered by these experimental surveys, so we can conclude that this species can more easily recover from the fishing pressure when compared to other species.

The mean weight of *Centroscymnus coelolepis* drastically decreases with the increase of the CPUE, meaning that this species is very vulnerable to fishing. It is also important to refer that this species is not caught in the surveys every year, and when it is, the mean weight never surpass the 8 kg. When compared to the mean weight reported by Parker and Francis (2012) of 20 kg, it could mean that *Centroscymnus coelolepis* landings are mainly composed by juveniles and that they are more vulnerable to fishing than adults, or they have different distributions. It has been reported that this species have preferential distribution of young specimens at greater depths and of pregnant females in the upper strata (Clarke, 2000). To complement the current study, an evaluation of the size and maturity stage of the caught individuals would be very important. The constant low weight of *Centroscymnus coelolepis* may also explain the decrease in “siki” landings: this species was very popular in the past commercial fisheries, but since the populations started to decline and being severely affected, it has become much less common in present commercial fisheries.

Deania profundorum showed one of the higher mean weights in the beginning of the study up until 2001, where the CPUE values were close to 0 and this species was rarely caught. Since then, the mean weight has been slowly decreasing, and in 2005 shows the lowest mean weight. In 2004 high CPUE values were recorded, suggesting that the species suffered from high fishing pressure that year and remained affected until the next year, demonstrating their low capability of recovery.

Etmopterus pusillus showed weight fluctuations throughout the years that cannot be entirely correlated to the CPUE values, which could mean that this species is not being greatly affected by fishing practices.

Statistical analyses showed that *Etmopterus spinax* weight was lowest in 1999 and 2001 when compared to other years. The low value registered in 2001 can be correlated with the high CPUE value, affecting the species up to 2008, when the mean weight increased and the average CPUE decreased. *Etmopterus spinax* has been described as having a mean weight of 0,85 kg (Fishbase), which is a lot higher that the weight registered in the fishing surveys. Assuming that the individuals caught are mainly juvenils and that this species can not easily recover when target of fishing practices, it is possible to define *Etmopterus spinax* is particularly susceptible to overexploitation. Both *Etmopterus spinax* and *Deania calcea* have one of the greatest average CPUE values, and both of them show decreasing patterns from 2004 until the end of the study, suggesting that both these species are the ones that are most affected and vulnerable to overexploitation, especially *Etmopterus spinax*, since, as referred before, the landed individuals may all be juveniles.

The combination of the results of the landing, IUU and survey data show that some species may be more vulnerable to fishing practices than others, and than those take more time to recover. If these particular species continue to be affected by fishing, they can easily be lead to extinction, especially the ones already registered as Near Threatned or Vulnerable by the IUCN.

This study shows an increasing trend of the IUU catches. Although it has been reported that bycatch rates have been slowly declining all over the world, this decrease may have been a result from the decline of the global catch rate, indicating a decrease of the total availability of fish, rather than a more cauticioness managament of the unselective fishing practices and gears (Zeller and Pauly, 2005). The same maybe happening with deep-sea sharks: results show a declining in the landings, but are the fisheries being adapted to these species or have the population sizes decreased over time?

It is well known that even small changes in species populations can change the whole ecosystem. At species level, a high fishing pressure can result in changes in species abundance and population size, but when taken in account the consequences at a higher level, it can affect trophic interactions and the whole community function (Stevens, Bonfil et al. 2000). Concerning deep-sea sharks, attention needs to be focused on these poorly studied species, particularly in the context of the entire ecosystem for a better understanding of the consequences of population changes in the trophic interactions, and to be able to avoid negative impacts in the future.

5. CONCLUSION

As already pointed out in this study, there is a large lack of information regarding deep-sea species, in particular, deep-water sharks. Herein we identify a need for more accurate taxonomic identification and collection of data regarding the species landed, as well as a more descriptive study of those species, especially the ones that are less-known. It is important to understand species biological traits, such as growth for further comparison with future works in the same field and update of fishing statistics. Also, a better knowledge of their reprodutive ecology, as well as behaviour, such as spatial movement patterns and locations of parturition is of great importance, and would be a major improvement, to prevent high rates of bycath in sensitive areas (Parker and Francis, 2012). There is also a clear need to better quantify bycatch and discard practices through the implementation of observer programs.

The study of deep-sea sharks fisheries, bycatch and discard is still in its infancy and is particularly challenging since there are many problems that can be masked and difficult to control. Fisheries management and long term sustainability are of utmost importance and therefore, research to understand the effects and consequences of bycatch is essential. The establishment of precautionary quotas and size limits to avoid overfishing should be considerate a priority. Further, other problems such as the waste derivative from finning practices as finning should be taken in consideration in the near future: it is recommended that once the species are landed the carcass should have full utilization (Kjerstad, Fossen et al. 2003).

Finally, one of the top priorities should be the research of effective practices such as fishing gears modifications and balanced harvesting methods that can decrease the high rates of deep-sea species bycatch, and promote an effective system of control, enforcement and inspection, including the fighting against IUU fishing activities, while encouraging the sustainability of long-term fisheries (Musick, Burgess et al. 2000).

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