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Tagging deepwater sharks in North Spanish waters

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Abstract

The present document summarizes different issues concerning tagging activities conducted on deep water sharks. Most of the results have been already published. Several aspects dealing with the type of tags used, fishing gears, species survival capacity, handling on board, etc. are discussed. Tagging surveys have been carried out in the North of Spain (Cantabrian Sea, NE Atlantic) during 2012-2022. Conventional tags and electronic archival tags (Mini PATs) have been used. The target species were *Centrophorus squamosus, Centrophorus granulosus, Centroscymus coelolepis, Deania calceus* and *D. profundorum*. Additionally other sharks such as *Galeus melastomus, Hexanchus griseus, Etmopterus spinax* or skates *Leucoraja circularis, Dipturus spp*. found in the study area were tagged. Results concerning horizontal and vertical movements for some deepwater sharks are presented.

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Tagging deepwater sharks in North Spanish waters

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ABSTRACT

The present document summarizes different issues concerning tagging activities conducted on deep water sharks. Most of the results have been already published. Several aspects dealing with the type of tags used, fishing gears, species survival capacity, handling on board, etc. are discussed. Tagging surveys have been carried out in the North of Spain (Cantabrian Sea, NE Atlantic) during 2012-2022. Conventional tags and electronic archival tags (Mini PATs) have been used. The target species were *Centrophorus squamosus, Centrophorus granulosus, Centroscymus coelolepis, Deania calceus* and *D. profundorum*. Additionally other sharks such as *Galeus melastomus, Hexanchus griseus, Etmopterus spinax* or skates *Leucoraja circularis, Dipturus spp*. found in the study area were tagged. Results concerning horizontal and vertical movements for some deepwater sharks are presented.

1.- INTRODUCTION

Deep-water sharks are considered highly vulnerable species due to their K-selected life-history characteristics and very low capacity for recovery from overfishing (Stevens *et al*., 2000). Limited information exists on some aspects of their biology and in particular about the survival capacity of these species when caught by different fishing gears and discarded, though survival capacity is assumed to be negligible.

The need for more research and dissemination of information about deep-water chondrichthyans has become imperative as fisheries worldwide continue to expand into deeper waters and exploit deep-water stocks, usually in the absence of data required for appropriate management (Morato *et al*., 2006; Kyne and Simpfendorfer, 2010).

Due to the relative environmental homogeneity (temperature, salinity, light levels, pressure) of the deep ocean, boundaries to species distribution are less pronounced than for shallower dwelling species. Therefore, many deep-water chondrichthyans have broad, often global, distributions, though species with limited geographic ranges, including endemics, are also commonly reported (Compagno, 1984).

Studies of population structure (Veríssimo *et al*., 2011, 2012) and species distributions (Moura *et al*., 2014) have demonstrated wide geographic ranges and high dispersal potential for some species. Such information can be used to inform fisheries management models as geographically limited fishing effort may have wide-ranging effects on deep-water species. In the absence of studies like these, it will be impossible to predict population growth trajectories or assess the full effect of fishing mortality on exploited species (Cotton and Grubss, 2015).

Extensive literature has been published on tagging pelagic sharks, both using conventional external tags (Kholer and Turner, 2001; Thorsteinsson, 2002) and using electronic tags (Arnold and Dewar, 2001; Hammerschlag *et al*., 2011), however, very few studies have been conducted on deepwater elasmobranchs. Most of these have been based on telemetry and acoustic tags

(Nelson, 1990; Carey and Clark, 1995; Andrews *et al*., 2009; Grubbs and Kraus, 2010, Daley *et al*., 2015).

Recent advances in satellite tagging technologies have provided scientists growing opportunities to resolve previously unknown spatial ecology of marine predators, including sharks. In particular, recent studies conducted on the deepwater shark *Centrophorus squamosus* have demonstrate that this shark is capable of making long migrations (Rodríguez-Cabello and Sánchez, 2014; Rodríguez-Cabello *et al.,* 2016).

The purpose of this study is to summarize the information collected from tagging surveys targeting deepwater sharks in North Spanish waters during the last decade. Questions addressed in this study included: which species have more survival capacity and thus are more suitable for tagging purposes, which factors can contribute to achieve good results and finally a brief review of the results obtained from satellite tags on leafscale gulper shark.

2.- MATERIAL AND METHODS

2.1. Study area

Tagging activities on deepwater sharks have been carried out in different locations along the continental shelf and slope of the Cantabrian Sea (North Spanish waters, NE Atlantic) since 2011 up to date. In this paper we are focusing on a particular area *Le Danois Bank* (Le Danois, 1948)*,* locally named *El Cachucho* fishing ground*,* were both conventional and electronic tagging had been conducted in a more extensively way. In 2008, El Cachucho was declared the first large off-shore marine protected area (MPA) in Spain by the Spanish Ministry of Environment (Heredia *et al*., 2008) and was included in the Natura 2000 network in the category of special area of conservation (SAC) following the principles established by the Habitat Directive of European Union (92/43/CEE). Since then, the consequences of the management measures applied in MPAs must be scientifically monitored, and noninvasive methods, such as acoustic, visual surveys or tagging activities must be used for their assessment and monitoring of MPAs.

The Bank is located in the Cantabrian Sea (NE Atlantic) 65 km from the Northern Spain coast. It is a marginal shelf—a seamount-like topographic feature nearby and partially connected to the continental shelf—. Depths on the top of the bank range between 450 and 600 m, whereas its intraslope basin exceed 850 m. Longlines were set in this area and on the basin floor between the bank and the continental shelf (Figure 1). More information about the biodiversity of this area or environmental characteristics be found in (Sánchez *et al*., 2008; Altuna, 2013; González-Pola *et al*., 2012 or www.ecomarg.com)

2.2. Tags

In this study several tags were used according to the shark species and size. Except those specimens dead or severely injured all the elasmobranchs caught were tagged and released. The majority of individuals were tagged using conventional tags either Rototags or T-bar anchor tags. A few sharks were tagged with electronic data storage tags (Mini PATs) from WildLife Computers. A special anchor tag was designed by IEO team to attach the electronic tags (Figure 2).

In some longline sets survivorship was semi-quantitatively evaluated according to the fish's health condition and response after the capture of the fish and subsequent release (see Rodríguez-Cabello and Sánchez, 2017). The survival criteria were based on the behavior of elasmobranchs after release (Hyatt *et al*., 2016). Four categories were chosen according to previous studies (Benoît *et al*., 2010; Braccini *et al*., 2012): 1) Good; 2) Moderate; 3) Poor and 4) Dead (Table 1).

2.3. Fishing gear

Surveys were carried out from a commercial longline vessel that was used to catch deep-water sharks in this area in the 1990's. The mainline was a leaded rope of approximately 4500 m length. The hooks used were size 10 circle hooks, and the mean number in each set was approximately 935 (Rodríguez-Cabello and Sánchez, 2014). Fishing was carried out at depths between 900 and 1100 m, with soaking time restricted to a maximum of 3 h. However, the time required for recovering all the hooks ranged between 3 and 7 h. In general, longline hauls were launched at dawn, and the haul speed to recover the gear was 0.4–0.5 $m.s^{-1}$, the standard one used in these artisanal commercial longliners.

3.- RESULTS

3.1. Species tagged and survival condition

Ten longlines have been conducted in the MPA of El Cachucho targeting deepwater sharks. Two more hauls were conducted in the top of the Bank (450-500 m) targeting blackspot seabream (*Pagellus bogaraveo*). Another haul, outside the area was used in the survival studies (Figure 1). Considering the ten longlines targeting deepwater sharks a total of 890 specimens were tagged corresponding to 15 species. However, nearly the 94 % of the elasmobranchs caught corresponded to 4 species (Figure 3). The most frequent species was the portuguese dogfish *Centroscymnus coleolepis* (28%) followed very closed by *Deania calceus* (27%), leafscale gulper shark *Centrophorus squamosus* (25%) and blackmouth catshark *Galeus melastomus* (14%) (Figure 3). In the two longline sets targeting blackspot seabream 4 sharks were caught as by catch. The most abundant was *Galeus melastomus* (n=158) followed by *Etmopterus spinax* (n=38), *Dasyatis violacea* (n=1) and blue shark *Prionace glauca* (n=1). It is remarkable that although *Centrophorus granulosus* was time ago usually found in the area, during these surveys only two individuals were caught.

Based on 6 longline sets and the information collected from tagging activities survivorship was qualitatively evaluated according to health condition and responses of individuals after capture and subsequent release. From the data recorded in these longlines the species with the highest vitality rate was *C. squamosus* (37.3% in good condition; 43.8% in moderate condition), followed by *D. calcea* (22.8% in good condition; 39.8% in moderate condition) and *C. coelolepis* (6.8% and 54.5%) Table 2. Post-release mortality (PRM) was examined using electronic tags (PSATs, n =14). Of the nine *C. squamosus* tagged successfully, three died within 5–10 weeks after release, whereas the other six survived for periods of at least 45–120 days, when tags were programmed to release). In the case of *C. coelolepis,* two of the four tagged specimens died almost immediately after release, whereas the other two tags indicated that the fish survived immediate release, but data were too limited to estimate survival due to tag failure Table 3. For more information see Rodriguez-Cabello et al., 2017. Recently, in august 2021 a Portuguese dogfish was tagged and programmed to record data for 5 months and a half (170 days). The shark survived during all this period releasing the tag on 24 of January 2022 close to the tagging location. Data has not been analyzed yet to check if the tag moved away during this period or remained in the study area.

3.2. Soaking time

Analysis based on 6 longline data in relation to the time after gear deployment (soak time and time spent in recovering the gear) did not show a clear significant relation for all the longlines combined (Kruskal-Wallis, $H(3, n=435) = 9.4606$, $p=0.024$; Figure 4A). For two deployments (L2; Figure 4B; $p < 0.001$) and (L6; Figure 4C; $p=0.005$) the vitality score differed with respect to the time spent in recovering the gear. In longline set 2, approximately 75% of the elasmobranchs caught in good or moderate vitality states were caught and brought onboard in less than 6 h, whilst nearly 75% of elasmobranchs considered in poor condition or dead were caught after that.

In longline set 6, most of the elasmobranchs caught in good state were caught and brought on-board in< 5 h.

3.3. Other issues: Type of tags, Handling and release, environmental conditions

Regarding type of tags our experience indicates that T-bar tags are suitable for several species, particularly small and medium size sharks such as *Galeus melastomus*, *Etmopterus spp* and even *Deania spp*. They are relative easy to attach and produce less damage compare to other tags, the main difficulty is that in some cases the dermal denticles are strong and do not allow to introduce properly the tagging gun and the tag is rejected. Rototags were mainly used for Centrophoridae species (*Centrophorus* and *Deania*) however caution must be paid on its attachment. This family have a larger dorsal fin compare to other deepwater sharks but the fins are not as hard as the ones of pelagic sharks. If the tag is attach close to the tip or near the border it can tear the tissue and break it when removing the tag applicator. Thus careful must be taken when inserting the rototags.

Handling should be done as quickly as possible to reduce the time sharks spent out of the water. In some cases the sharks arrive on board with a lot of water swallowed due to the process of hauling. In those cases it might help to put the shark upside down and try to get it rid of the water before releasing back to the sea.

The main problem we have observed after shark release is its buoyancy. Due to the large livers these species possess and the fact that these species are not conceived to be at surface water the sharks have positive buoyancy. If the shark is strong enough it can swim down to deep waters after recover, however in many cases it is unlikely and probably it will die.

Water temperature is also an important factor to be considered. These species are known to live at cold water temperature around 9-10 ºC. Therefore is surface temperature is relative high and the sharks spent some time on the surface this can have a very negative effect on its physiology and even produce damage on the internal organs like the liver.

Deepwater sharks, mainly *Centrophorus* species and Portuguese dogfish are caught with specific longline targeting these species (forbidden since 2011). In the study area very few are caught as bycatch using other fishing gears such as trawl or gillnets. In the case of other deepwater sharks that are frequently caught as by catch with bottom trawl gears such as *Galeus melastomu*s the survival rate of this shark is considerably lower than with longline. Likewise other deepwater sharks such as *Etmopterus spinax*, *Centroselachus crepidate*r or *Scymnodon ringens,* have a high survival rate when caught as bycatch on longline fisheries targeting commercial species (*Merluccius merluccius, Phycis blennoides, Pagellus bogaraveo*). These species are almost dead when they come on board in trawl fisheries or gillnets.

3.4. Horizontal and vertical movements of *Centrophorus squamosus*

Conventional and electronic tagging data have revealed that this shark can make long migrations. There has been only one recapture from conventional tag. The shark was tagged in the Cantabrian Sea and was recovered 3 years later in the south of Faroe Islands. The shark, a female, measured 116 cm when it was released and after nearly 3 years at liberty had increase 3 cm in length and 954 g in weight. The distance covered in straight line had been approximately 1900 km (Table 4).

Electronic tags have confirmed this shark can make long displacements. In this study 9 satellite tags were analyzed. Data collected from Argo floats in the study area have been used to devise a simple geolocation algorithm to infer the probable routes followed by this species. Tag release points revealed that *C. squamosus* moved both to the west (Galician waters) and to the north (Porcupine Bank) from the tagging area, suggesting well defined preferred path ways (Figure 5).

The inferred trajectories indicated that sharks alternate periods constrained to specific geographical regions with quick and prompt movements covering large distances. Regarding vertical movements differences were observe among individuals. Some sharks made conspicuous diurnal vertical migrations being at shallower depths around midnight and at maximum depths at midday, while other sharks did not make vertical migrations. Vertical movements were done smoothly and independently of the fish swimming long distances or resting in the area. On Figure 6 two examples of vertical movements obtained from electronic tags. This species is highly migratory, supporting speeds of 20 nautical miles.day^{-1} and well capable to swim and make vertical migrations well above the abyssal plain

4.- DISCUSSION

Deep-water sharks are considered highly vulnerable species due to their K-selected life-history characteristics and very low capacity for recovery from overfishing (Stevens et al., 2000). For improved understanding of deep-sea ecosystems, data on animal movements in space and time and the scales over which those movements occur is required (Cotton and Grubbs, 2015).

By catch is a common practice in many fisheries and frequently not accounted for in fisheries statistics. Improving data collection both on shark by catch and retained is essential to understand changes in the populations or their trends through time and help to provide advice. Previous survival studies have outlined several factors that could affect survival of discards, particularly from longline fishing, such as type of vessel, depth of capture, type and size of hooks, soak time, hauling speed and handling (Broadhurst *et al*., 2006; Davis, 2002; Musyl *et al*., 2009).

The health score criterion has the inconvenience that it is a subjective method to assess the survival capacity of a fish. Nevertheless, it allows evaluation of a large number of fish relatively quickly and cheaply, and it can be done aboard fishing vessels where other methods are not feasible (Braccini *et al*., 2012). It does provide good estimates of capture mortality (AVM), but does not inform on post release mortality (Skomal, 2007).

At-vessel mortality (AVM) differs among shark species. For the species explored in this study it was not as high as expected nevertheless in these longline surveys analyzed soaking time did not exceed 3 hours and times spent in recovering the fishing gear never exceed 6 hours. Therefore, some sharks arrived alive and in moderate condition and consequently could be tagged. In commercial fisheries soaking time can range from 24 h to 72 h thus the chance to recover a shark in good vitality stage is likely very low.

Post-release mortality, over both short and relatively long periods, could be high and further studies should be performed. Electronic tags (PSAT) are useful tools to estimate long-term survival. A recently study carried out in Bahamas reported AVM for *Centroscymnus owstoni* and *Centrophorus* spp. of 80% and 29% respectively (Brooks *et al*., 2015). In Australia, an acoustic tracking study carried out on *Centrophorus zeehaani* showed that it had potentially high survivorship rates. Sixty-one sharks from seventy-one acoustic tagged were detected repeatedly over an average period of 408 days (Daley *et al*., 2014). These fish were caught at depths of 300–600 m, but not under commercial fishing operations.

One of clearest post-release effects observed is on their buoyancy. Deep-water sharks possess enlarged livers with high accumulations of lipids that serve both as a hydrostatic buoyancy organ and as a lipid nutrient deposit and which can also be sensitive to pressure changes (Wetherbee and Nichols, 2000; Pethybridge *et al*., 2010; Treberg and Speers-Roesch,2016;). This particular feature likely reduces the capacity of captured sharks to dive after release, as we have observed during this study.

Environmental variables such as sea water temperature can have a significant effect as well on post release mortality (Gale *et al*., 2013). Deep-water species usually live at colder temperatures than they are brought into at the surface; therefore the amount of time exposed at warmer temperatures could increase the stress of capture and finally lead to mortality as we have observed during tagging surveys (Davis, 2002; Weltersbach and Strehlow, 2013).

Conventional tagging relies on the ability to recapture previously tagged individuals to make inferences about their locations. Tags are cost-effectively and easier to use however it requires a large number of tags to be employed to make these efforts valuable. In addition if the species are not target or are forbidden the probability to receive information from fish recaptured is rather low. Satellite technology can provide data on behavioral, spatial and population ecology of fishes which can be used to inform managers (Greene *et al*., 2009; Sims, 2010).

Pop-up archival satellite tags (PATs) have been used successfully to track the movements of large pelagic sharks. Nevertheless for its application on deepwater species several difficulties arise. One of this is that up to date electronic tags are designed to support depths up to 1800 m, therefore it could be a limitation for some deepwater sharks that are known to live at great depth. In addition satellite tags require light level data for estimation of geolocation and infer fish trajectories, but for most deep-water species that reside below the photic zone, light level data required for geolocation is not recorded. Therefore horizontal displacements of deepwater species have been limited to the point of capture and release pop off location (Peklova *et al*., 2012, 2014; Comfort and Weng, 2015; Rodriguez-Cabello and Sanchez, 2014).

Different approaches have integrated diverse parameters such as bottom topography, swim speeds, tidal cycles and vertical temperature profiles in conjunction with archival tag data to retrospectively estimate horizontal locations (Hunter *et al*., 2003, 2004; Skomal *et al*., 2009; Chittenden *et al*., 2013). Most recent geolocation model frameworks have been based on non-parametric state-space models, such as the Hidden Markov Model (HMM) (Nielsen et al., 2019). A simple devised geolocation algorithm based on comparing, for a given time frame, each single shark pressure-temperature record against all available pressure-temperature profiles in the domain (Argos floats) has recently been applied. This approach has helped to infer shark trajectories for the leafscale gulper shark (Rodriguez-Cabello *et al*., 2016). The inferred trajectories indicated that in the study area (NE Atlantic) *Centrophorus squamosus* is a highly migratory species that alternates periods constrained to specific geographical regions with quick and prompt movements covering large distances.

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TABLES

Table 1. Description of the criteria used to estimate at vessel mortality (dead) and score the vitality of deepwater sharks after catch and release for specimens alive.

Good	Moderate	Poor	Dead
Strong and lively. Swims down quickly and with energy	Lively. Swims on the surface trying to go down but not immediately going deep	Lively but weaker movement. Floats on the surface. Slight movements of fins	No response or badly injured

Table 2. Species and number of sharks caught and released following the criteria for behavioral release condition score (BCRS) for either good/moderate/poor. Dead was considered AVM. Analysis based on 6 longlines sets (L1-L6).

Species	Good	(%)	Moderate	(%)	Poor	(%)	Dead	(%)	TOTAL
Centrophorus granulosus	1	*33.3*	1	*33.3*	1	*33.3*			3
Centrophorus squamosus	63	*37.3*	74	*43.8*	30	*17.8*	2	1.2	169
Centroscymnus coelolepis	3	*6.8*	24	*54.5*	15	*34.1*	2	4.5	44
Centroscymnus crepidater	1	*100*							1
Dalatias licha	3	*75.0*	1	*25.0*					4
Deania calceus	39	*22.8*	68	*39.8*	49	*28.7*	15	8.8	171
Deania profundorum	1	*14.3*	4	*57.1*	1	*14.3*	1	14.3	7
Dipturus nidarosiensis	1	*50.0*	1	*50.0*					2
Dipturus oxyrhinchus	1	*100*							1
Etmopterus pusillus	1	*25.0*	1	*25.0*	2	*50.0*			4
Galeus melastomus	1	*4.8*	4	*19.0*	8	*38.1*	8	38.1	21
Hexanchus griseus	1	*50.0*	1	*50.0*					2
Leucoraja circularis	1	*100*							1
Prionace glauca	1	*100*							1
Scymnodon ringens	2	*100*							2

Table 3. Summary of species, health score and electronic tags released. Numbers of days initially programmed (Prog.) and achieved. Weight* has been estimated from the length-weight relationship (Casas *et al.*, 2001). Mature State codes correspond to: I= immature. D= developing. M =mature. P= pregnant. (from Rodriguez-Cabello and Sánchez, 2017).

Shark Code	Species	Health score	Mini PAT Code	Length (cm)	Weight* (g)	Sex	Mature State	Tagging Date	Days Progr.	Days Real	Premature released	Fate	Cause Notes
S1	*C. squamosus*	*Good*	PT 119541	104	4744	M	D	10/12/2012	120	45	Yes	Survive	Excced Depth
S2	*C. squamosus*	*Good*	PT 119537	93	3152	M	---	10/12/2012	120	116	No	Uncertain	Uncertain Dead
S3	*C. squamosus*	*Good*	PT 119540	107	5264	M	M	10/12/2012	130	----	------	Uncertain	Tag Failed
S4	*C. squamosus*	*Good*	PT 122977	118	7492	M	M	13/06/2013	90	90	No	Survive	
S5	*C. squamosus*	*Good*	PT 119539	99	3943	F	---	13/06/2013	120	120	No	Uncertain	Uncertain Dead
S6	*C. squamosus*	*Good*	PT 122978	122	8463	F	---	01/07/2013	90	90	No	Survive	
S7	*C. squamosus*	*Good*	PT 122979	108	5420	M	M	20/09/2013	80	80	No	Survive	
S8	*C. squamosus*	*Good*	PT 122980	107	5239	M	M	20/09/2013	90	90	No	Survive	
S9	*C. squamosus*	*Good*	PT 119538	110	5796	M	M	20/09/2013	120	120	No	Survive	
S10	*C. squamosus*	*Moderate*	PT131056	116	7038	F	M	23/12/2014	105	0	Yes	Uncertain	Atachment failed
S11	*C. coelolepis*	*Moderate*	PT131057	106	10846	F	P	23/12/2014	90	4	Yes	Dead	
S12	*C. coelolepis*	*Moderate*	PT131055	92	6315	M	M	15/09/2014	90	4	Yes	Survive	Tag Failed
S13	*C. coelolepis*	*Good*	PT131054	108	11648	F	M	15/09/2014	60	4	Yes	Survive	Tag Failed
S14	*C. squamosus*	*Good*	PT145082	111	5991	M	M	08/07/2015	105	75	Yes	Dead	
S15	*D. calcea*	*Moderate*	PT145083	100	4750	F	M	08/07/2015	80	6	Yes	Dead	
S16	*C. coelolepis*	*Moderate*	PT 142312	112	13384	F	M	08/07/2015	150	6	Yes	Dead	

Table 4. Tagged and recaptured data of *Centrophorus squamosus* obtained from conventional tags.

	TAGGING DATA							RECAPTURE DATA					
Species	Tag	Sex	Lm	Weight*	Date	Situation	Depth	Date	Situation	Depth	Lr	Wr	Gear
Centrophorus squamosus	IEO 589	Female	116.0	7500	24/12/2014	43º40'31 N - 4º24'07 W	1060	08/09/2017	60°55 N - 10°02 W	900	119.3	8454	Trawl

* Approximately

FIGURES

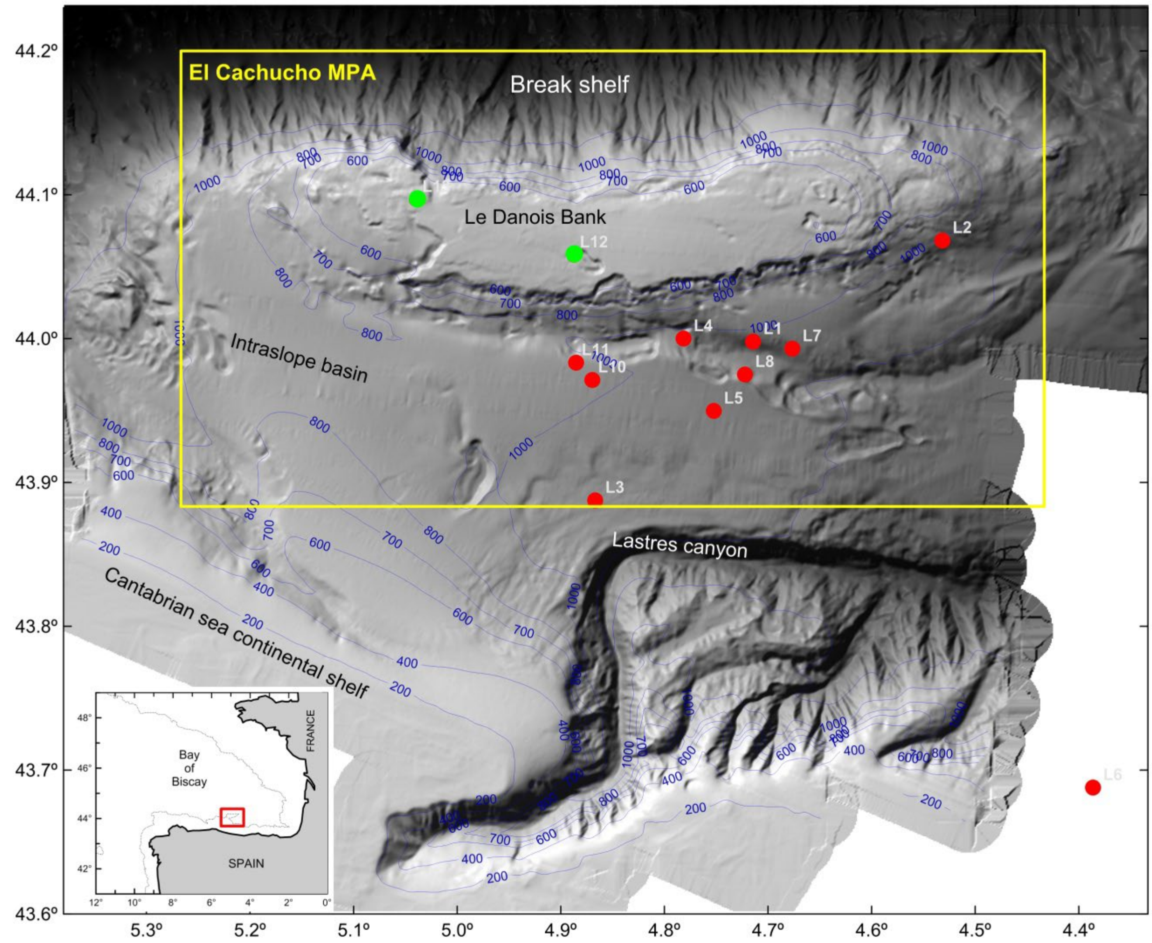
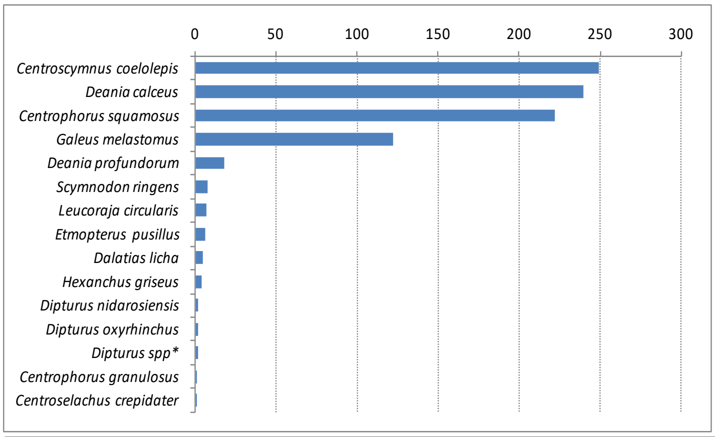


Figure 1. Location of the study area and longlines carried out for tagging deepwater sharks. Red circles longlines targeting deepwater sharks and green circles targeting blackspot seabream.

Figure 2. A) Types of conventional tags used in this study B) Electronic archival tag (Mini PATs) and C) Anchor tag designed for electronic tags.



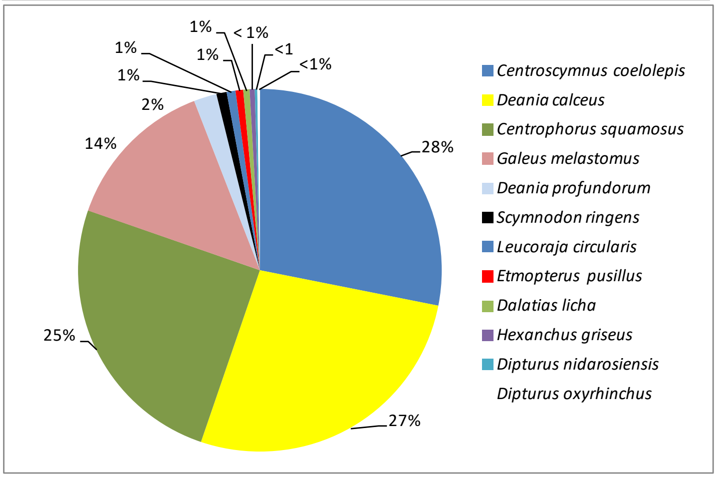


Figure 3. List of elasmobranchs caught in the longline tagging surveys targeting deepwater sharks. On the top the number of specimens tagged and on the bottom the catch proportion.

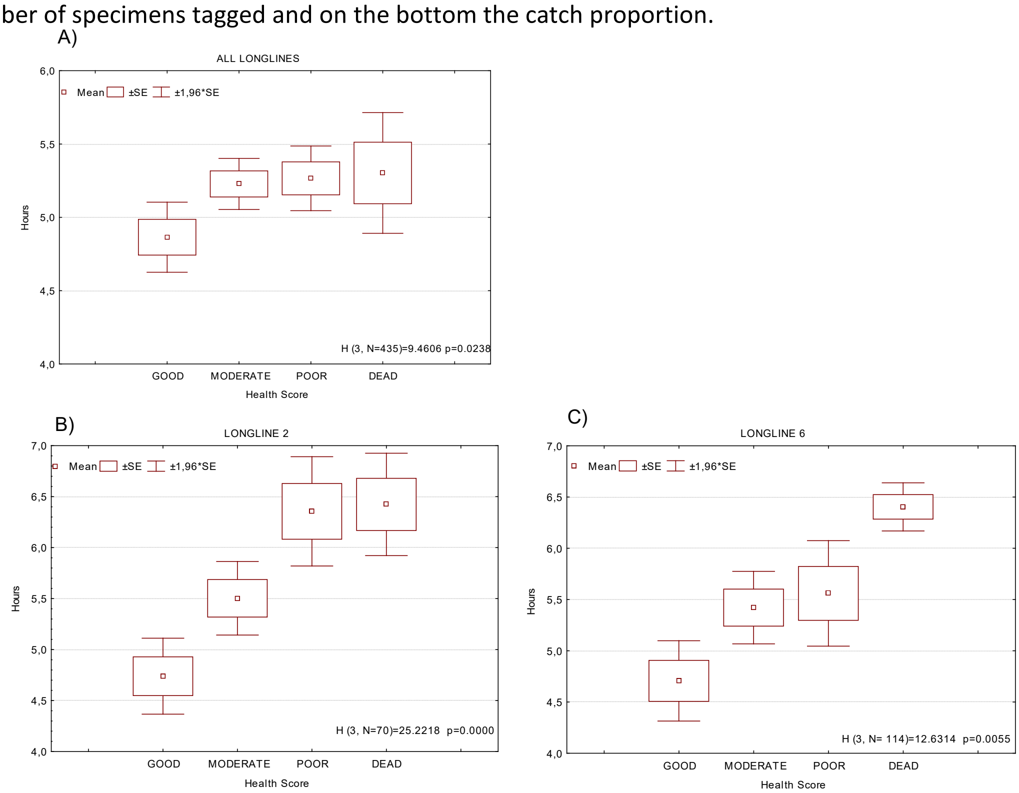


Figure 4. Box plot of mean values and SE obtained for each survival category and time spent in recovering the gear, including the soaking time A) All longlines combined B) Longline L2 C) Longline L6 (Rodríguez-Cabello and Sánchez, 2017).

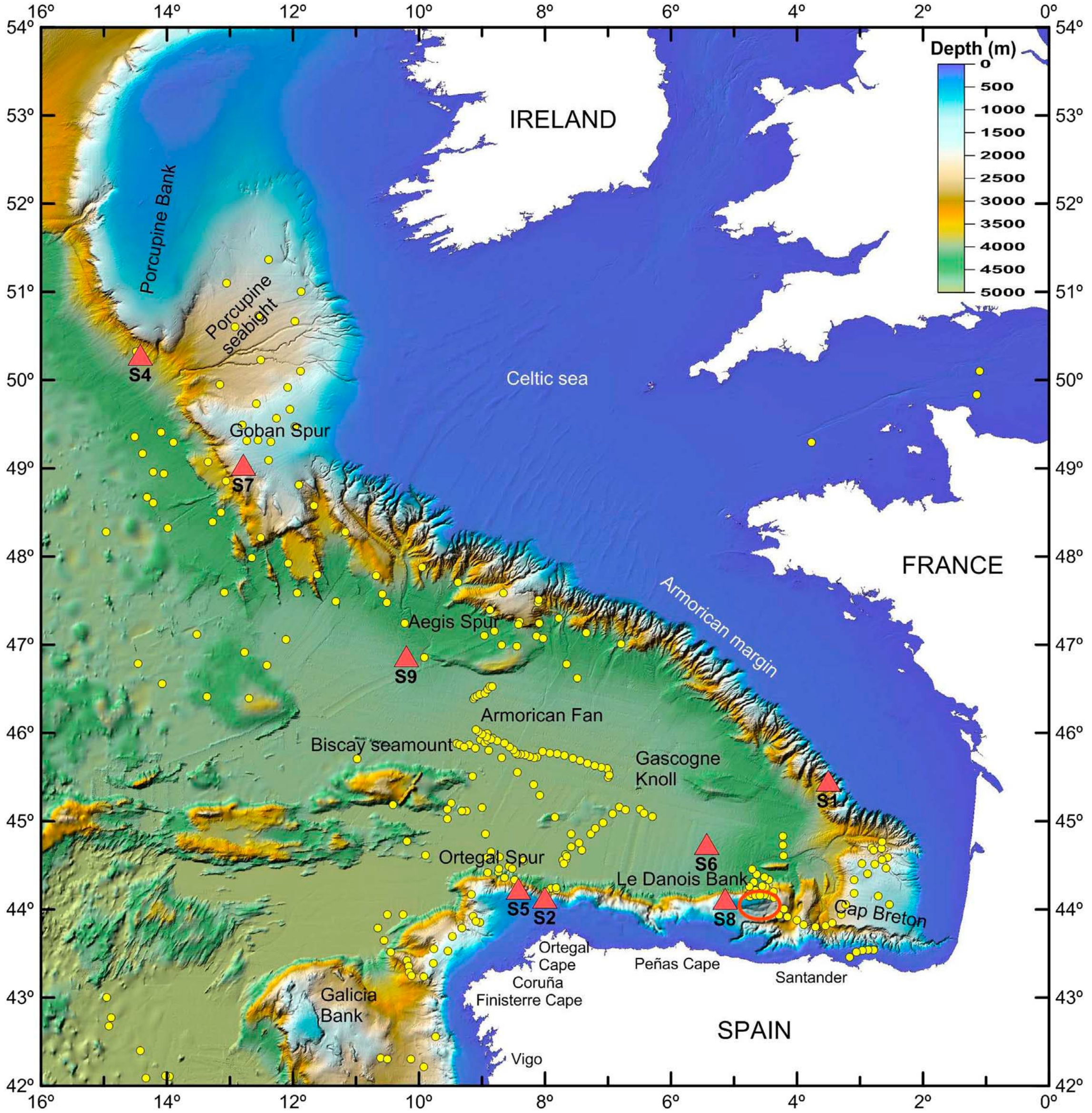


Figure 5. The study area showing the tagging area in red circle, El Cachucho MPA, the continental shelf, the slope and some bathymetrical features. The red triangles indicate the detachment and surfacing locations of eight pop-up tags (PSATs) from sharks S1 to S9 (S3 never detached). Yellow circles indicate the position of Argos floats used in this study (more information on Rodriguez-Cabello *et al.*, 2016).

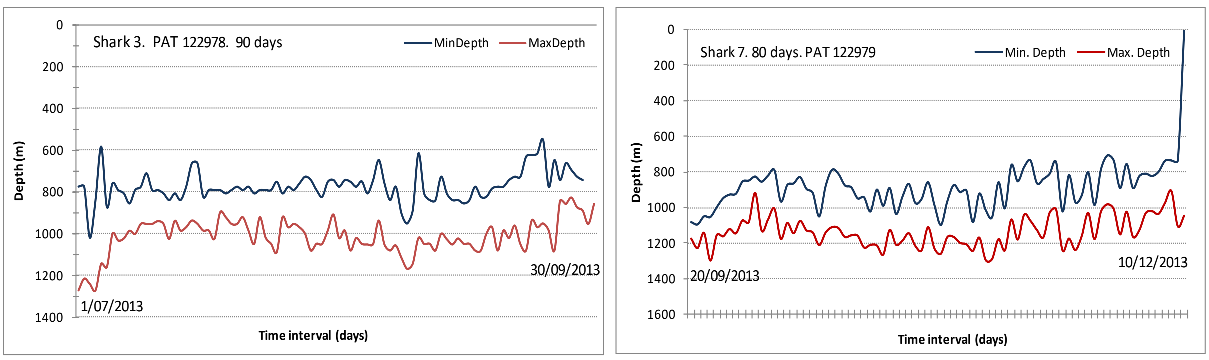


Figure 6. Example of depth profile of two sharks *Centrophorus squamosus* tagged.