Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and contiguous Atlantic area, concluded under the auspices of the Convention on the Conservation of Migratory Species of Wild Animals (CMS)

Accord sur la Conservation des Cétacés de la Mer Noire, de la Méditerranée et de la zone Atlantique adjacente, conclu sous l'égide de la Convention sur la Conservation des Espèces Migratrices appartenant à la Faune Sauvage (CMS)

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MITIGATION MEASURES FOR PROTECTED SPECIES

Delegates are kindly invited to bring their own documents to the Meeting.
This document will be available only in electronic format during the Meeting.

MITIGATION MEASURES FOR PROTECTED SPECIES (before final editing)

Note of the Secretariat:

This review is aimed at compiling information on mitigation solutions and technics tested worldwide for the most impacting fisheries (static nets, longlines, trawls and purse seines), for each taxa of vulnerable species impacted by bycatch (or involved in depredation).

This report was prepared within the framework of the ACCOBAMS/GFCM Project on mitigating the interactions between endangered marine species and fishing activities supported by the MAVA Foundation.

It was reviewed by the ACCOBAMS Support Group on Interactions with fisheries and presented at the Twelfth Meeting of the ACCOBAMS Scientific Committee (Monaco, 5-8 November 2018). Peer-review was also organized by the GFCM Secretariat.

This report is currently being edited by GFCM in view of its publication in the GFCM Studies and Reviews series (in English and In French). The version of this report presented at the Seventh Meeting of the Parties to ACCOBAMS is before scientific editing and complete revision (currently ongoing). The final version will be published on the ACCOBAMS and GFCM websites as soon as available.

MITIGATION MEASURES FOR PROTECTED SPECIES

Document prepared by Jacques SACCHI

VERSION 16/07/2019 (before final editing)

Contents

I. INTRODUCTION

Highly migratory for the most part, occupying a wide distribution across the oceans, the marine megafauna undergo all possible forms of human pressure. Among them, bycatch fishery has increased exponentially in recent years and is now considered the most serious threat to these highly vulnerable species. Minimizing bycatch, is therefore a key component of sustainable fisheries management to maintain marine biodiversity and consequently to reduce negative effects on the resources (see Hall, 1996; Hall et al., 2000).

The aim of this document is to present various experimented approaches and strategies that could also serve as an example for fisheries facing the same problems. This review of the different mitigation measures draws on the analysis of the available literature, comprising scientific journal articles together with reports from international organisations and documents available on the internet.

The presentation adopted here is guided by the principle that it is not species that should be managed but fishing activities (metiers)[1] that should be the target of the technical or management measures that are required to reduce the negative impacts of interactions with fisheries. Consequently, for each of the main fishing gear groups (gill and trammel nets, longlines and lines, trawls, purse seines, trapnets and pots) the various solutions found in the documents consulted are classified by the four main groups of protected species (Cetaceans, Birds, Sharks and Sea turtles).

[1] https://datacollection.jrc.ec.europa.eu/wordef/fishing-activity-metier

II. .GILL & TRAMMEL NETS

The literature covers several descriptions of gillnets and trammels with their design and their different uses (Nedelec, 1975; Sainsbury, 1996; Gabriel et al. 2005; He, 2006) which are classified by FAO in nine main types according their setting modes (Nedelec , Prado, 1989).

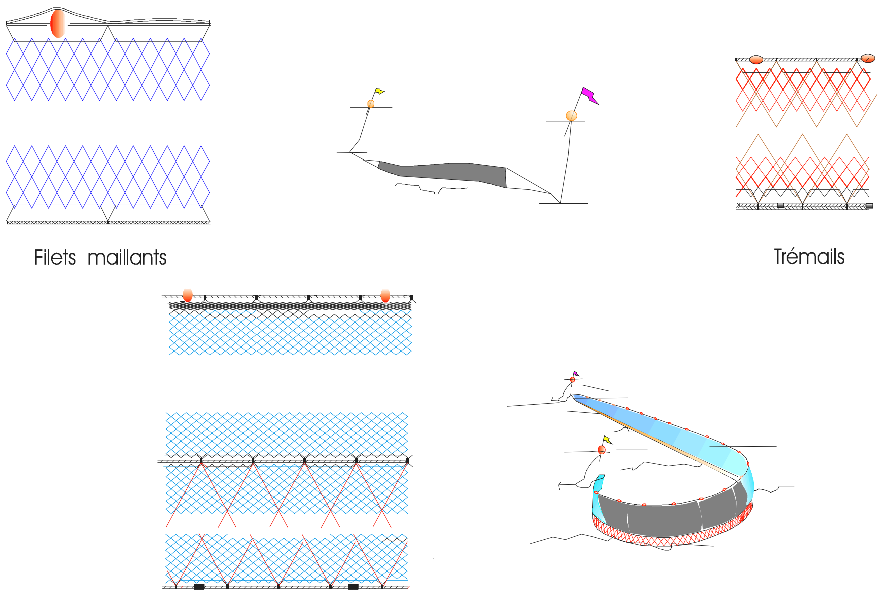

Figure 1 Main bottom set nets: gillnet, trammel, combined net

Gillnets are highly size selective but have limited interspecies selectivity and can catch birds; cetaceans, turtles, and sharks (He., 2006). Set on the bottom or drifting in surface, these are one the most common fishing techniques used by artisanal fisheries in the World. They generally consist of a single rectangular layer of net (gillnet) or framed by one or two panels of larger mesh (trammel net). (fig.1); they are mounted vertically between a float headline and a weighted bottom line. Some Mediterranean fisheries use combined nets consisting of trammel nets topped with gillnets. The webbing is hung to the headline and the bottom line by a hanging twine (staple) which is stitched to the headrope at regular intervals.

Several studies and documents, dealing in particular on selectivity (Baranov, 1948, Hamley, 1975; Hovgard, 2000, Sacchi, 2001, etc.) show that a fish can be caught either enmeshed in a mesh of the net (wedged or gilled) or entangled (snagged, hooked or wrapped into the net panel).

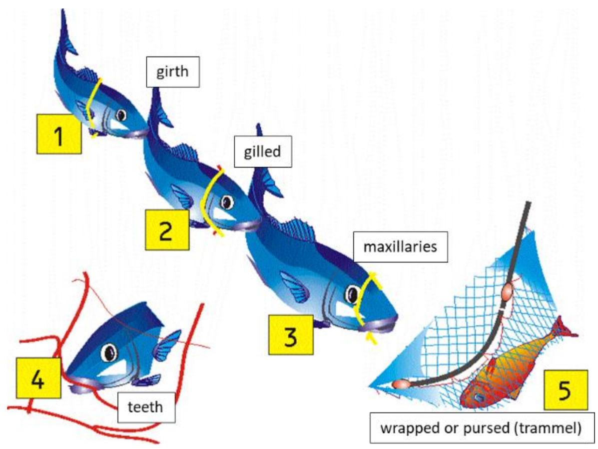

Figure 2 different mechanisms of fish capture : 1 - wedged; 2 - gilled; 3 - snagged; 4 - hooked; 5 - wrapped or pursed

Depending on the type of species targeted, the fisherman will favour one of the two mechanisms for the construction of his fishing gear, , for example by using preferably an entangling net for flatfish, large individuals or crustaceans.

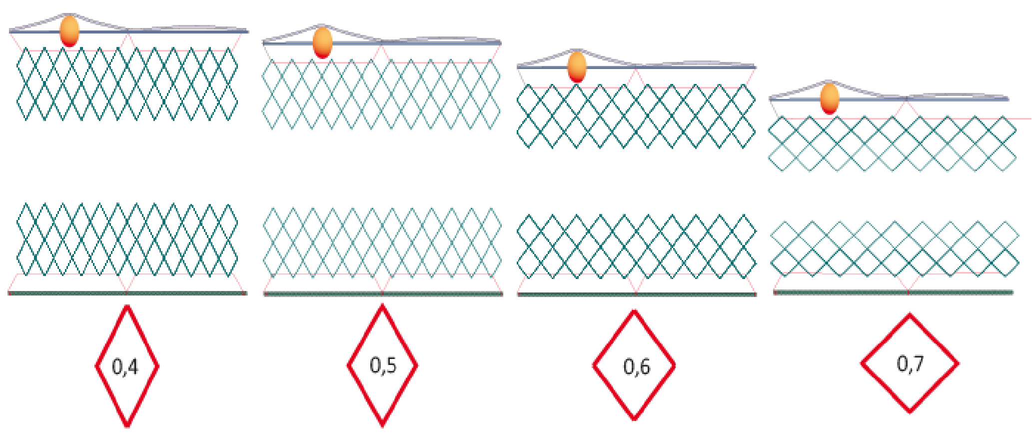

Figure 3 Effect of the Hanging ratio on mesh opening and on net drop (from FA0, 1978)

The net Depth (D), or stretched height of net panel should not be confused with the drop (d) which is the vertical distance between the headrope (headline, float-line) and the footrope (lead-line) determines the theoretical fishing height of a set net (i.e. headline height). The drop depends in first of the Depth and the Hanging ratio (E), then of buoyancy and other external factors as catch and water dynamics (tide, currents, etc.). Th ratio between drop and depth determines the slackness of the net panel as Slackness (S)= d/D.

The entanglement can be facilitated by the amount of slackness between the headrope and footrope. This slackness can be created in various ways:

- by reducing the vertical tension on the net panel with less or without floats on the headline
- By reducing the horizontal tension on the net panel with low ratio of the float line length to the stretched net sheet (Hanging ratio) but with also long staple twine. Increasing the

hanging ratio alone is not sufficient to reduce entanglement and the risk of catching protected species as shown by the comparison of monofilament gillnets with hanging ratios of 0.33 and 0.5 used in anglerfish and ray fisheries in the Gulf of Maine (USA) (Schnaittacher, 2010).

- by increasing mesh flexibility (nature of the thread, smaller diameter, use of multifilament, etc.)
- by increasing the mesh size: the turbot fisheries or the monkfish fisheries using generally very large meshes are among the fisheries in the world with the highest bycatch rate as it has been demonstrated for the Danish fisheries (Vinther M., 1999) and for the Black Sea gillnet fisheries (Bilgin e tal., 2018; Birkun et al., 2014) or point out for US east coast monkfish set net fisheries (Wiedenfeld et al., 2015).
- by bridling the net panel through the addition of one or two shorter panels (trammels) or simply vertical ropes -tie-down gillnets (fig. 4b & c) Some bottom nets, such as in the Mediterranean coastal fisheries, have a longer line of foot than the waterline, giving more looseness in the lower part and increasing entanglement (fig.4d).

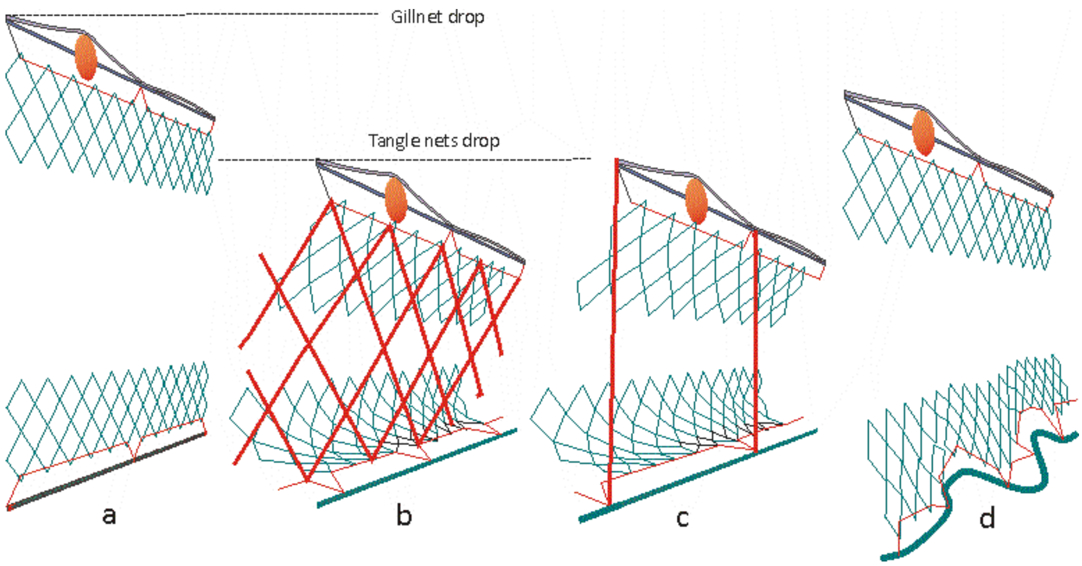

Figure 4 slackness a) gillnet ; b) trammel net ; c) tie-down gillnet ; draped bottom gillnet

Nets with high slackness facilitate the entanglement of large or non-fusiform specimens and consequently the retention of small cetaceans as well as turtles and sharks.

2.1. CETACEANS

Reliable bycatch estimates have largely been hindered by the lack of fisheries effort data, especially for gillnets. From the extrapolation of bycatch data in US fisheries (1994 -2006) and using available metrics of fishing effort from FAO, Read e*t al.,* (2006) estimate gillnet fisheries would responsible of 84% of cetacean bycatch worldwide.

Although FAO data cannot account for the total fishing effort of small fisheries, main users of set net fishing techniques, several studies, especially in the Mediterranean and in the Black Sea (Bearzi, 2002; Birkun et al., 2015) confirms the importance of gillnetting in cetaceans bycatch; numbers of individuals killed in gillnets being to be greatest for species mainly distributed in coastal and shelf waters (Reeves et al.,2013).In addition to the problem of incidental catches of cetaceans, there is the depredation of gillnet fisheries, which provides them with a more accessible food supply. Reported in most coastal areas, particularly in the Mediterranean (Díaz López, 2006), several authors (Lauriano et al., 2009, Brotonnes et al., 2008) note that the depredation of gillnets by cetaceans almost always concerns the bottlenose dolphin. (Tursiops truncatus).

2.1.1. Fishing gear improvements

➢ ***Gillnet drop (height)***

Because gillnets targeting cod catch more harbour porpoises than trammel nets for sole, the Ministry of Agriculture, the Environment and Rural Areas of the Federal State of Schleswig Holstein (MLUR) has limited the height (drop) of bottom set gillnets used in the *German Wadden Sea National Park* to 1.3 m. Nevertheless, further observations showed that this measure was also insufficient to avoid incidental catches of harbour porpoises (Pfander e*t al.,* 2012).In fact, this measure does not appear to take into account other technical aspects of net design (such as the net slackness mentioned above) or even soak time, which is considered the primary predictor of gillnet bycatch (ICES SGBYC, 2009).

2.1.2. Acoustic mitigations

Developed primarily to deter mammals from approaching and interacting with fishing gear or cages, AMD generally fall into two categories: Acoustic Harassment Device (AHD), which were initially developed to reduce depredation by pinnipeds, and Acoustic Deterrent Device (ADD), which were designed to mitigate cetacean bycatch (NRS, 2003; Northridge et al., 2004; Reeves et al., 1996).

➢ ***AHD***

The AHD are designed to produce intense sounds (above 185 dB re 1 µPa 1 meter) sufficiently painful and disturbing to keep animals away from an area to protect as a fin fish cage. AHDs operate mainly in the 5-30 kHz frequency band. The emitted stimuli give rise to an immediate response of the animal and induce hazard perception learning over a period of time. Nevertheless, the high-pressure levels pose a risk of permanent damage to cetacean hearing (Gordon and Northridge, 2002) and these devices may exclude some animals from important habitat (Olesiuk et al., 2002)

➢ ***ADD***

ADD called also “pingers” are acoustic devices emitting middle to high frequency stimuli (10-100 kHz) at low intensity generally below 150 dB re 1 µPa at 1 m with higher harmonic frequencies (up to 160 – 180 kHz). These harmonic frequencies are deterrent for the dolphins (Northridge et al., 2004; Reeves et al., 1996); they are therefore unlikely to cause discomfort and their aim is to alert marine mammals to the presence of nets.

ADDs have been shown to be used for reducing dolphin by-catch in a wide variety of fisheries (Reeves et al., 1996; Franse, 2005; Dawson, et al., 2013 ; Mackay & Knuckey, 2013; Gönener & Özsandıkçı , 2017), but their success depend on the species, the technical characteristics of pingers and the terms of use. Several of these studies show that pingers significantly reduce catches of porpoises (*Phocoena phoconea*) and Cuvier's and Hubbs' beaked whales *(Ziphius cavirostris, Mesoplodon carlhubbsi*).

On the other hand, they have more variable effects on *Tursiops truncatus* (Barlow and Cameron, 2003; Zahri *et al.,* 2004; Carretta *et al*, 2008, Carretta and Barlow, 2011), *Delphinus delphis, Stenella coeruleoalba* and *Pontoporia blainvillei* (Dawson *et al*., 2013; Balle *et al.*, 2010; Rossi and Rossi, 2004).

Often the lack of success is due to the misuse of these devices: the attempts to reduce *Stenella coeruleoalba* bycatch in the bluefin tuna driftnet fishery in Provence (Imbert *et al.,* 2007) using AquaMark pingers were inconclusive due to the parsimonious use of the devices by fishers, the insufficient spacing of the devices, and no systematic replacement of used batteries.

Habituation to repulsive sounds is often mentioned in the literature (Cox et al., 2001, 2003 Dawson et al. 1998; Gordon and Northridge, 2002; Reeves et al., 2001; Trippel et al., 1999) as a leading cause of failure in the use of acoustic repellents.

However, long-term deployment of acoustic alarms in several commercial fisheries has not resulted in an increase in cetacean bycatch rates in properly equipped nets with functioning pingers (Palka et al. 2008, Carretta & Barlow 2011; Dawson et al., 2013). It is not always observed and seems to depend on the species. Cox et al. (2001) found that non-captive harbour porpoises appear to habituate to Dukane Netmark1000 pingers relatively rapidly after a few days with a diminution of the initial avoidance distance by 50 %. the same experiment conducted later with the same pingers on groups of bootlenose dolphin did not bring any decisive results (Cox et al., 2004).

The question of habituation rises also with the issue of depredation (or prey removal. Depredation of gillnets by cetaceans almost always involves bottlenose dolphins

Observations of the behaviour of bottlenose dolphins around nets equipped with pingers suggest that if the pingers do not completely eliminate the interaction, they can help to reduce the effects: Northridge et al., (2003) recorded significantly fewer holes (69%) attributed to being caused by dolphin depredation in trammel nets in Greece equipped with Saver pingers; identical results were obtained in the Balearic Islands by. Gazo et al. (2008) and by Brotons et al., (2008) and by Buscaino et al. (2009) in Sicily on interactions between bottlenose dolphins and nets with, however, differences in interaction rates depending on the devices used.

According to Dawson et al. (2013) bottlenose dolphins involved in depredation could easily use pingers to enhance their ability to find nets and presence of prey caught in nets thanks to their cognitive ability to adapt their behavior for foraging and likely to tolerate higher acoustic pressures than other dolphins. Gazo et al., (2008) suppose that the risk of habituation may and rapidly if the acoustic disturbance is moderate and particularly for bottlenose dolphin which is "a species thought to be more adaptable to human impact than many other cetaceans" (Whitehead et al., 2000).

Therefore to reduce the risk of habituation, pingers must emit randomly with pulses selected over a broad frequency spectrum (from 30 to 150 kHz) and with variable 3 to 10 second intervals between signals (Le Gall, 2004). This line of research requires further development and at-sea testing. Restricting pinger use to certain periods of time may be a relevant alternative as Amano *et al., (*2017) suggested for reducing by-catch of *Neophocaena asiaeorientalis* in Omura Bay set net fisheries (Japan).

Other avenues have been explored such as using percussion tubes (e.g. Zahri *et al.,* 2004) and mimicking killer whale calls (ICES, 2010).

Table 1 – Studies on the deterrent performance of some pingers on *Tursiops* (from Dawson, 2013)

PINGER	FREQUENCY (kHz)	SOURCE LEVEL (dB)	RESPONSE	LOCATION	AUTHOR
SaveWave Dophin saver	30-160	155	Significant reduction in depredation and number of holes in the nets 1 dolphin caught	Aegean sea (Greece)	Northridge *et al.,* 2000
Aquamark 210 **Dukane Netmark 1000** **SaveWave Dolphin saver**	5-160	130-155	49% reduction in interactions No impact	Balearic islands	Brotons *et al.,* 2008
Aquamark 100	20-160	145	87% fewer holes Depredation rate reduced by about 50%	Balearic islands	Gazo *et al.,* 2008
DDD 0.2	0.1-200	160	31% fewer holes and 28% more fish	Favignana island (Italy)	Buscaino *et al.,* 2009
Fumunda	10	132	Risk of interactions decreases from 81 to 50%	Hatteras, North Carolina	Read & Wapples, 2010
Fumunda	70	145	No difference with control nets	Hatteras, North Carolina	Read & Wapples, 2010
SaveWave Dolphin saver		155	Significantly fewer interactions	Hatteras, North Carolina	Wapples, 2013

➢ ***Net acoustic reflectivity***

Increasing net reflectivity to echolocation is a passive way to reduce the incidental catch of delphinids and alternative technical measure to acoustic alarms.

Using thicker thread and adding metallic-based coating (barium sulphate, iron oxide) increases acoustic reflectivity and in this way may reduce incidental catch of species utilizing echolocation (Larsen et al., 2002; Trippel, 2003; Cox and Read, 2004) with more or less difference in catches of commercial fish species between control and reflective nets. However Larsen et al., (2002) indicate that there were no significant differences in the acoustic target strength of modified and control nets, suggesting that the reduction in by-catch was not caused by an increase in acoustic reflectivity but by probably by the mechanical properties of the thread (e.g. stiffness) as it is also done for the target species. However, while these modifications have been shown to be effective in Hawaiian waters on *Tursiops truncatus* and *Phoconea phoconea* (Mooney *et al., 2007).* Experimental trial undertaken in on gillnet artisanal fishey in Argentina did not show a reduction of by-catch of *Pontoporia blainvillei* (Bordino et al., 2013). Trippel (2003) think that coating as thicker twine increases the net stiffness. reducing its entanglement properties. undoubtedly, increasing the rigidity of the net may help reduce bycatch in some cases, but with the risk of reducing catches of target species and should therefore be associated with other changes in the net.

- ***Passive acoustic devices***

Several studies (Koschiski and Culik, 1997Goodson 1997; Goodson, 1997; Goodson, 2001; Gordon and Northridge. 2002; McPherson, & Nishida, 2010; Mc Pherson, 2011) are dealing with the use of reflectors as passive acoustic devices able to make gillnets more acoustically visible to echolocating cetaceans. have been tested in several studies with mixed results. These r**eflector devices**, (metallic heads, barriers gillnets, floatlines, etc.) could induce avoidance behavior for some species maintaining dolphins at short distance from the net but their effects are not consistence for all groups.

2.1.3. Chemosensory mitigation

Cetaceans (Odontoceti) do not have olfactory bulbs or nerves and they are poorly developed in Mysticeti (Kishida et al., 2015a,b). However, cetaceans have taste buds in the root region of their tongue and research on deterrent solutions using chemoreception in cetaceans appears to be more promising (Friedl *et al.,* 1990). According to studies undertaken on captive animals (*Delphinus delphis, Tursiops truncatus, Phocoena phocoena*), this quasi-olfaction (Kuznetzov, 1990) that helps detect pheromones, different chemical cues produced by animals, (Nachtigall, 1986; Kishida *et al.,* 2015), might play a role in reproduction in particular.

2.1.4. Visual mitigation

Few significant studies have been undertaken on the use of the cetacean visual ability as a deterrent in the case of conflict between cetaceans and fishing.

2.2. BIRDS

In general, knowledge of seabird bycatch in gillnet fisheries is highly fragmented. Even from regions where numerous reports are available, e.g. the Baltic Sea, information often originates from short-term studies and opportunistic observations. However, several regions can be identified as being especially information deficient and where presence of both susceptible species and gillnet fisheries implies potential existence of high seabird bycatch. (Zydelis *et al.,* 2013). It is mainly in shallow waters and coastal areas that gillnets present a risk for diving seabirds who can get entangled and drown.

A number of factors could be determining such as bird abundance and species composition, overlap between bird foraging areas and fishing grounds, fishing gear characteristics, water clarity and also meteorological conditions. Some mitigation measures have been suggested in Europe and abroad, few of which have been applied (Bull, 2007).

Moreover, Under the aegis of BirdLife International, a workshop was organized in 2015 to examine the mitigation methods best adapted to different protected species caught in gillnets (Wiedenfeld e*t al.,* 2015).

2.2.2. Acoustic mitigation

Sound plays an important role in bird behaviour. However, there are very few studies of seabird hearing. Pingers with frequencies adapted to birds' audiograms were tested on murres with a 50% reduction in incidental catch but had no effect on puffins (Melvin *et al.,* 1999). The difficulty of using sound as a signal for the presence of the net is to determine how accurately such signals are received by the birds (Martin and Crawford, 2015).

2.2.3. Visual mitigation

➢ ***Warning Net panel***

The introduction of monofilament nets has increased seabird bycatch because of their quasi-transparency. Monofilament nylon gillnets result in a greater bycatch than the traditionally used twined nets (Zydelis et al., 2009). Given their reduced frontal vision as sensitivity has been traded off against visual resolution, diving seabirds are unable to see, especially in poor light, the obstacle posed by set gillnets, particularly those in monofilament nylon.

Replacing the monofilament panels over 10 to 25% of the upper part of the nets with a section of more visible white braided nylon wire is a sufficiently dissuasive obstacle to prevent birds from getting entangled in the nets as they dive (Fig. 4). A significant reduction in seabird bycatch in the coastal gillnet fishery targeting salmon in Puget Sound Washington USA was achieved by combining two technical solutions: visual alerts (panels of visible mesh in the top part of the net) and acoustic alerts (pingers).

Catches of common murre (*Uria algae)* were reduced respectively by 40 and 45% in 50 mesh- and 20 mesh- visual alert nets whilst the rhinoceros auklet (*Cerorhinca monocerata)* bycatch was reduced by 42% solely in larger 50-mesh nets (Melvin *et al.,* 1999).

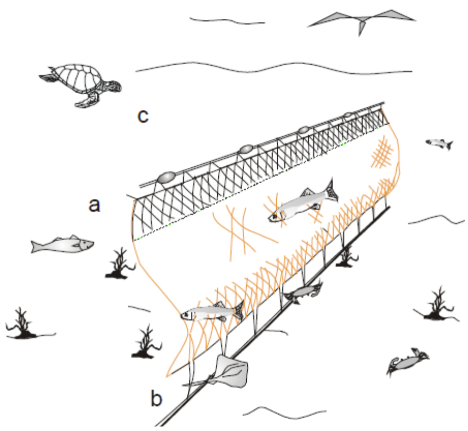

Figure 4 – Mitigation devices for birds, turtles and demersal sharks (Sacchi, 2008): a) strip of net to ward off birds; b) more elaborate installations to enable small demersal sharks to escape; c) the net height must not occupy the whole water column to allow pelagic species to pass.

In a similar vein, Martin and Crawford (2015) proposed attaching "warning panels" on nets at regular intervals. They consist of alternating black and white grating or a checkerboard pattern to achieve maximum contrast.

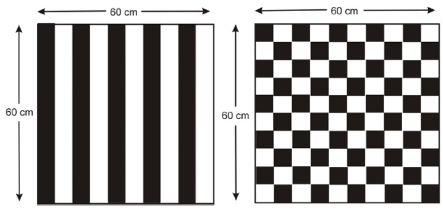

Figure 5 – Examples of patterns recommended for warning panels. The stripes are 6cm wide (Martin and Crawford, 2015).

Figure 6 – Net equipped with warning panels in Lithuania © Julius Morkunas (Seabird Lithuania)

When the weather becomes colder, Lithuanian gillnetters in the Baltic Sea (Klaipeda harbour) target cod closer to the coast and this is the time when birds are most at risk of being caught. A Lithuanian team therefore undertook trials on the effectiveness of black and white panels comparing them with standard fishing nets during the 2015/2016 fishing season. The team obtained encouraging results over some twenty sets with a one-third reduction in bird bycatch and no impact on the commercial catch.

With funding from the European Commission, SPEA (Birdlife in Portugal) conducted trials near the Berlengas islands and the Wild Bird Society of Japan (Birdlife in Japan), thanks to support from the Kingfisher Foundation and the Keidanren Nature Conservation Fund, undertook similar work off Teuri Island.

➢ ***Net lighting***

Originally developed for sea turtles (Wang *et al.,* 2013), experiments undertaken on set nets in Peru suggest that making them more visible using LEDs reduce significantly bird bycatch with 85.1% decline in the cormorant catch rate (Mangel *et al.,* 2014). However, Martin and Crawford (2015) noted that diving birds may find it harder to detect parts of a net that are not immediately illuminated as acuity (resolution) decreases with light level.

2.3. SHARKS

Despite a 1992 United Nations ban drift gillnets can still be used in some national waters, as in Mediterranean Sea, catching mainly large pelagic sharks (e.g. *Prionace glauca, Isurus* *oxyrinchus and Alopias vulpinus*) or pelagic rays (*Pteroplatytrygon violacea and Mobula mobular*) that come into contact with them or for depredation (Tudela et al. 2005).

If some bottom or mid-water gillnet fisheries target commercial species of sharks, (e.g. Mustelidae, Squalidae, Scyliorhinidae) as in the northern Adriatic or in the Gulf of Gabes (Bradai et al., 2006), most of gillnets and trammel nets fisheries are responsible of important by-catch of vulnerable species (*Myliobatis aquila, Pteromylaeus bovinus Galeus melastomus, Centrophorus granulosus, Carcharhinidae*) as in the south Brazilian gillnet monkfish fishery (Perez and Wahrlich, 2005). In the Black Sea, the turbot gillnet fishery is associated with high rates of incidental catches of demersal sharks (e.g. piked dogfish) and dolphins. Turbot (*Scophthalmus maeoticus*) is the target species captured by tangle nets in Turkey (Kara, 2012), which can also catch discard and by catch of unwanted species as and endangered selacians species. . Studies on gillnets report high mortality rates of sharks which, excepted nurse sharks, breath only by swimming, and consequently entanglement in gillnets inhibits this mechanism (Thorpe and Frierson 2009; Cosandey- Godin and Morgan. 2011).

2.3.1. Fishing gear improvements

➢ ***Enmeshment***

Gillnets mesh size have a major effect with hanging ratio, twine material, twine thickness and visibility, a major effect on fish catchability and catch composition in size (Hamley 1975). Accordingly, Gillnets are highly selective for small sizes classes and certain shark species (Walker, 1998, Carlson and Cortes 2003. Thorpe & Fierson, 2009). The capture of small or juvenile sharks in gill nets is highly dependent on mesh size as it was demonstrated on blacknose sharks (*Carcharhinus acronotus*) (Carlson and Cortés, 2003), and Juvenile blacktip sharks (*Carcharhinus limbatus*) are caught as bycatch in commercial gillnet fisheries in the U.S. Atlantic Ocean, (Baremore et al.:2011). Likewise Ceyhan et al., (2010) show the selectivity of trammel nets inner mesh size on Smooth-hound shark; (*Mustelus mustelus*) in small-scale coastal fisheries, using trammel nets and longline in the Izmir Bay, Aegean Sea.

Therefore, with mesh size regulations can be an effective tool for managing unintentional catches of threatened sharks or enhancing juvenile and adult survival by limiting the size composition of catches. For instance, for recovery declining stock of juveniles sandbar (*Carcharhinus plumbeus*) sharks which are the primary catch component of a West Australian multispecies demersal gillnet fishery and also for a more sustainable fishery management McAuley et al. (2007) suggest to restrict both the fishery’s minimum mesh size and the maximum to reduce catches of target large classes and smaller sharks.

Nevertheless, in such case of multispecies fishery mesh size modification must take into account effects on commercial species yields and possible consequences for other protected species before to be implemented.

➢ ***Entanglement***

Small sharks, such as dogfish, are usually enmeshed in the lower part of the nets whilst large sharks are often entangled in the middle part. In order to avoid bycatch, it is important to reduce the entanglement rate notably in the lower part of the net. To the same end, it is recommended to increase the tension in the net panel by increasing float buoyancy and lead-rope weight to fix the gillnet more securely on the bottom making it less flexible. In a such a way that sharks will probably bounce off the webbing instead of being entangled; this type of modification with stiffer materials has significantly reduced the number of Atlantic sharpnose sharks (*Rhizoprionodon terraenovae*) caught by gillnetters in the Spanish mackerel (*Scomberomorus maculatus)* fishery in North Carolina without significant reduction of commercial catch (Thorpe and Frierson 2009). Loose nets more easily entangle large-bodied species such batoid-like sharks as Rhynchobatus spp. (White et al., 2013). He, (2006) shows that while the reduction in stowage lengths to reduce the gill net drop used for cod (*Gadus morhua*) reduces the capture of *Squalus acanthias*, it increases the catch of skates by four time.

2.2.1. Setting improvements

➢ ***Spatio-temporal closures***

Numerous authors consider that the spatio-temporal management of fishing effort is one of the most reliable solutions to mitigate the incidental catch of seabirds in gillnet fisheries. Seabird abundance, and consequently the risk of entanglement, varies by season and over the day as well as by species: for example, the probability of puffin entanglement is highest at dawn whereas murre entanglement is high both at dawn and dusk (Melvin *et al.,* 1999).

Temporary fishing closures in important seabird feeding zones (for example, areas adjacent to significant breeding colonies) will reduce accidental bird mortality in those zones.

Although difficult to establish and to enforce, the use of spatial and temporal fishery closures is unavoidable in the management of gillnet impacts (Regular *et al.,* 2013).

➢ ***Restrictions on the minimum net-setting depth***

The majority of diving birds prefer shallow waters and the most significant incidental catches occur at depths of less than 20m (Stempniewicz, 1994). Bellebaum *et al.* (2013) noted that the probability of incidental catches decreased with increasing depth. In California, the ban on gillnet fishing at depths less than 60 fathoms has almost completely eliminated murre bycatch (Carretta and Chivers, 2004).

2.3.2. Magnetic mitigation

Sharks can sense at short ranges weak electrical fields as small as 5 nV/m thanks to sensing organs located on the snout and called “ampullae of Lorenzini”. These organs are sensitive to frequencies from 1 to 8 Hz (Haine et al., 2001). Sharks are consequently capable of detecting weak electric fields generated by neuromuscular activity of prey in seawater. Laboratory experiments based on this capacity showed the repellent effect on sharks and suggested the utility of tests to limit by-catch (Brill et al., 2009). With this in mind, Jordan (2012) suggest the use of electrical barriers affixed to the net, either powered or magnetic, which could repel elasmobranchs, preventing entanglement.

3.4. SEA TURTLES

2.4.1. Fish gear improvements

➢ ***Net panel heigth***

Several species of sea turtle, including the loggerhead sea turtle (*Caretta caretta*), which is an endangered species protected by the federal Endangered Species Act (ESA), are found in North Carolina waters. The deep waters of Pamlico Sound are an important site for the large-mesh gillnet fishery targeting southern flounder (*Paralichthys lethostigma)* from September onwards, which is when sea turtles start moving away from the bay as the water temperature begins to fall. The combination of this autumn migration and the fishing season explains the significant bycatch.

In order to reduce the impact of this commercial fishery on sea turtles, a study evaluated the effect of net panel height. These nets comprise a 12 ft (3.6m) panel which is reduced to a fishing height of 4ft (1.2m) by tie downs (wires stretched vertically between the floatline and the leadline) (fig. 10). This system creates a kind of bag that increases dab entanglement. The study showed that halving panel height (6ft instead of 12 i.e. 1.8m) significantly reduced the net slackness and therefore sea turtle bycatch without affecting the catch rate of target species (Price and van Salisbury, 2007).

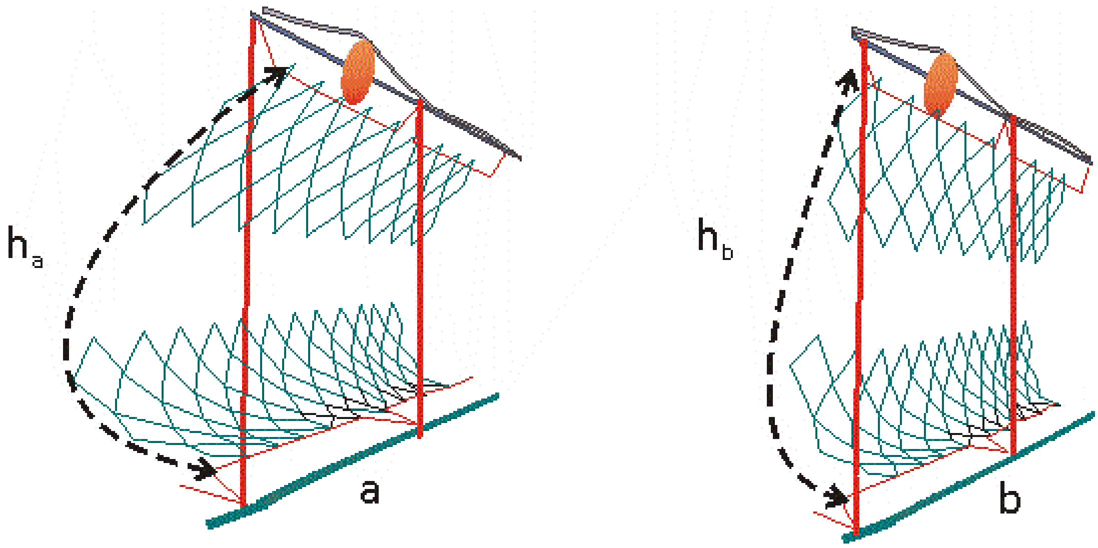

Figure 10 – Reduction of net slackness by diminution of the net height (hb< ha) keeping the same tie-down length.

➢ ***Buoyancy***

One way to limit the fishing height of a set net without reducing its entanglement capacity for catching large fish is to reduce its floatability. An experiment undertaken with fishers from Puerto Lopez Mateos in Mexico showed, based on 136 observations, that nets without floats reduced turtle catch rate (mainly *Caretta caretta*) by 68% without affecting the commercial catch of California halibut (*Paralichthys californicus)* and grouper (*Mycteroperca sp.*) (Hoyt Peckam *et al.,* 2015).

➢ ***Other net modifications***

One of the major concerns with gillnet fishing is the low survival potential of the animals caught given their long immersion time. Various strategies have been suggested in the literature to increase the survival rate of turtles caught in the nets and facilitate their release, for example set the net in shallow waters or adjust the ballast so that the individuals caught may reach the surface to breathe during net immersion (Gilman, 2009b, Gilman *et al.,* 2010).

Gill and trammel nets are the principal fishing techniques used by small-scale Mediterranean vessels. Mainly used in the coastal zone, they are a potential hazard for all endangered megafauna species. To catch anglerfish and flatfish, Mediterranean fishers mainly use large-mesh trammel nets. The use of these nets results in sea turtle and delphinid bycatch particularly in the Black Sea. Improving the technical characteristics, such as the overall reduction of the entanglement risk, is a simple solution that can be implemented in sensitive areas.

2.4.2. Acoustic mitigations

Sea turtles and fish have similar hearing characteristics and are low frequency specialists (Brill et al., 2004; Swimmer and Brill, 2006) so much so that any sound produced to stop turtle interaction with fishing gear will also be detected by fish and might frighten target species (Southwood et al., 2008). Nevertheless recent works carried out on bottom gillnets spring/summer halibut (*Paralichthys californicus*) in Baja (Mexico) demonstrated that low-frequency acoustic deterrent devices (ADDs) reduced catch o green by 60% with no change in commercial catch rates (Piniak et al;, 2018).

2.4.3. Visual mitigation

- ***Scarecrow***

Following experiments undertaken on set nets along the Mexican coast of the California peninsula, Wang *et al.* (2010) noted that shark-shaped silhouettes trigger an innate flight reaction from sea turtles bred in captivity and which therefore have never been exposed to sharks or other predators. In more recent sea trials, shark shapes helped to reduce the number of turtles caught in nets. However, as these visual deterrents have an impact on target species, the authors suggest that differences in the visual aptitude of turtles and fish should be exploited, especially in the ultraviolet (UV) light spectrum, for example by constructing shark shapes that absorb UV and become visible to turtles only.

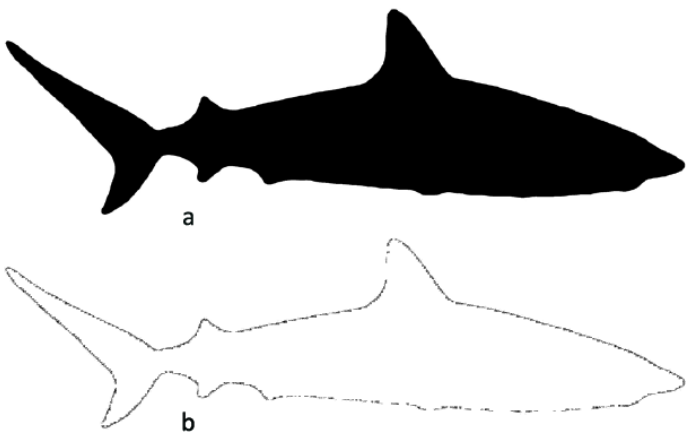

Figure 7 – Shark silhouette made of plastic that absorbs UV visible to turtles (a) and invisible to fish (b) (following Wang et al. 2010).

➢ *Light deterrents*

Light-sticks are known to attract some species; experiments in test tanks seem to demonstrate that they can also have an attractive effect on some age-groups of sea turtles (Wang *et al.,* 2007). On the other hand, placing these luminous lures on gillnets reduces the catch rate of green turtles (*Chelonia mydas*). Two experiments were undertaken on the impact of LED lights or light-sticks on set gillnets targeting flatfish along the coast of the California peninsula (Mexico). Light-sticks were fixed 5m apart on the branch line of the floats of an experimental net whilst LEDs were placed on another experimental net at 10m intervals. Each experimental net was coupled with an identical control net equipped with the same but inert light devices. The results show that the catch rate of green turtles (*Chelonia mydas*) fell by 40% in LED-illuminated nets and by 60% in those equipped with light-sticks.

These results suggest that by affecting turtle behaviour, net lighting provides the visual guides necessary to avoid entanglement. The intervals between light sources and their radiometric differences may be important factors in reducing catch rates. The better results obtained by light-sticks may be explained by the fact that the light they emit has a wider spectrum with less irradiance; however, the drawback is that they deteriorate faster over time (Wang *et al.,* 2010).

Research undertaken with the artisanal gillnetter fleet targeting flounders (*Paralichtys spp*.) and several ray species in Sechura Bay (Northern Peru) showed that adding electroluminescent diodes (LEDs) to equipped nets could be an effective way to reduce green turtle (*Chelonia mydas*) bycatch; whilst 125 green turtles were caught in the control nets, 62 were caught in illuminated nets with no significant reduction in commercial catch. A typical boat in this fishery utilises 2 200m of net and would require at least 221 LEDs (Ortiz et al., 2016).

L 

Figure 8 – Green LEDs (Centro Power Light Model CM-1, Centro) are placed every 10m on the float line in the tested nets; the control nets are placed 200m away to avoid the influence of the light. (Ortiz *et al.,* 2016).

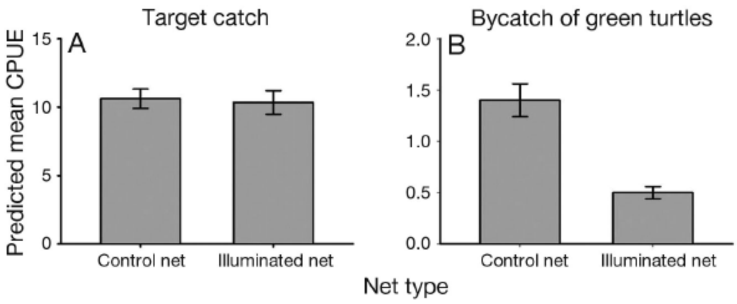

Figure 9 – The average CPUE of target species in control nets (without LEDs) compared with illuminated nets (with LEDs) shows no significant different (A) whilst the comparison of green turtle catch rate between the two types of nets shows a significant reduction of 63.9% with the use of LEDs (B) (Ortiz *et al.,* 2016).

III. LONGLINES AND LINES

Various configurations of longlining are existing regarding target species as we generally consider two main categories: bottom longlining targeting bottom fishes and pelagic longlining focused on the capture of pelagic and midwater fishes. The key components to longline gear include a main line, branch lines, hooks and bait (fig.). Type, material and dimensions of these three last ones are the main factors determining the fishing efficiency of these gear. Branch lines are made of nylon, polypropylene, polyester or of steel; hooks are either made of forged metal (steel or alloy) or from a metallic wire; they are typically "J"-shaped or "G"-shaped (circle hook) and the bend can be offset (offset hook) or in line with the axis of the shank of the hook (non-offset) (fig. 2). Interactions between protected species and longlines concern mainly depredation of capture or of bait and entanglement into the gear.

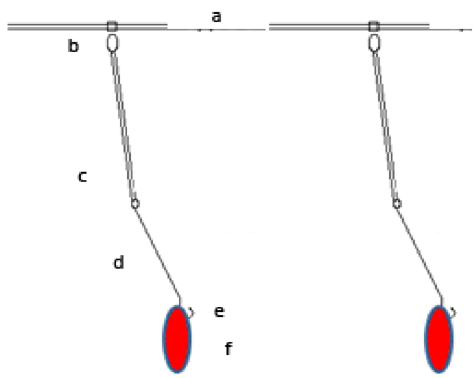

Figure 5 : main components of a longline: a) mainline; b) connexion device (e.g. swivels, agrafhe; c) branchline ; d) steel leader; e) hook; f) bait.

Figure 11 – (a) "J"-shaped hook; (b)"G"-shaped hook called "circle hook"; (c) off set hook

3.1. CETACEANS

Although dolphins may occasionally become entangled in branch lines, incidental catch of cetaceans by longlines is often due to their being hooked whilst foraging. This problem mainly concerns *Pseudorca crassidens*, *Orcinus orca*, *Globicephala spp*., *Tursiops truncatus, Lagenorhynchus obscurus, Delphinus delphis, Stenella coerualba* (Clarke *et al.,* 2014).

Bluefin tuna (*Thunnus thynnus*), a prey of the killer whale (*Orcinus orca*) in the Strait of Gibraltar, is fished in the summer by small-scale fishing boats using vertical handlines, along the steep continental slope of Morocco and Spain at depths of 200 and 250m (Pérez Gimeno *et al.,* 2001). Killer whales swimming among the fishing vessels snatch a part or all of the caught tuna before it can be hauled onboard. The only method used by fishers to avoid this foraging is to leave the tuna on the seabed attached to a buoy until the killer whales leave the fishing zone (de Stephanis *et al.,* 2006).

In the literature, a number of papers discuss studies and systems that seek to keep cetaceans away from fishing operations (e.g. Anon, 2007; Mooney *et al*., 2009; Rabearisoa *et al*., 2010; Hamer and Childerhouse, 2012; Werner, 2015). Three strategies emerge from this literature: 1) develop alternative techniques or modify the design of fishing gear, 2) reduce the acoustic attractiveness of fishing operations (change engine speed, change fishing vessel), 3) regularly change the time and duration of fishing in areas shared with killer whales.

3.1.1. fishing gear improvement

➢ ***Hook type***

The use of circle hooks has been shown to be effective in reducing sea turtle bycatch but less so for sea mammals. For these species, other approaches have to be identified, such as "weak hooks" which straighten more easily (Bigelow *et al.,* 2012).

➢ ***Weak or breakable hook***

The use of hooks with low mechanical resistance, in particular standard hooks (non-forged), was tested in several pelagic longline fisheries in order to reduce bycatch without significantly affecting target species' catch rate. In the Gulf of Mexico, these hooks have been used as a selective device to reduce bluefin tuna catches in the albacore fishery (Foster & Bergmann, 2012). They are made of flexible metal and can be straightened easily when they are bent. This feature helps large animals to escape more easily.

The use of such hooks, that are deformable but strong enough to retain target species, may help to reduce the bycatch of cetaceans foraging on bait and catches (Clarke *et al.,* 2014; Bayse & Kerstetter, 2010).

This type of hook has been shown in the laboratory by McLellan *et al.,* 2014 to have another advantage, which is that they cause little trauma to odontocetes mouths (*Globicephala macrorhynchus, Grampus griseus, Pseudorca crassidens*) compared with the injuries caused by forged hooks. The barb of deformable hooks neatly cuts the lip tissue freeing the hook. Forged hooks on the other hand are more rigid and do not open completely tearing the flesh irregularly and sometimes leaving the broken barb in the wound.

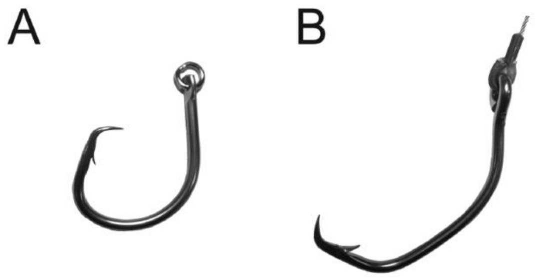

Figure 12 – (A) standard circle hook, (B) the same hook bent by a false killer whale (*Pseudorca crassidens*) from Bigelow *et al.,* 2012.

3.1.2. Setting improvement

Two factors can significantly reduce the level of depredation: setting **shorter longlines** (less than 5 000m) and hauling lines as quickly as possible (50 hooks per minute according to Tixier, 2012) when in the presence of killer whales (Guinet *et al.,* 2007, 2015; Tixier *et al.,* 2010, 2014). **Hauling speed** can be increased significantly by using powerful automatic line-haulers (e.g. AZTI "automatic tuna fishing pole"[2] or automated winding ("tuna tug troll line"). However, this equipment requires vessels over 12m long with an appropriate source of energy.

Figure 13 – Automatic live bait rod (AZTI)

3.1.3. Visual mitigation

Given that odontocetes mainly use their vision to forage on the fish, these devices create a kind of screen which prevents the predator from seeing the catch. These systems can be applied to any type of longline or handline.

➢ ***Umbrella or "Cachalotera"***

This technique, used originally by the Chilean small-scale fleet to reduce odontocetes' depredation, was adopted by the pelagic longline commercial fleet targeting the Patagonian toothfish (*Dissostichus eleginoides*) with some modifications (Moreno *et al.,* 2008; Goetz *et*

[2]https://www.youtube.com/watch?v=x3cBIo1sVhU

al,. 2011; Hamer *et al.,* 2012). The longline comprises a main line in polypropylene supporting several 8mm polypropylene branch lines each with 6 hooks. Each branch line has an 8kg weight and is equipped with an "umbrella" which is composed of an upper and a lower ring (of 10cm and 80cm diameter respectively) supporting a cone-shaped net sleeve of 1.5 to 2m. The positive buoyancy of the rings and the net allow the umbrella to float over the baited hook while the gear is soaking. When the longline is hauled in, the umbrella slides down and covers the baited hook. As depredation takes place primarily during gear retrieval, this mechanism protects caught fish from cetacean foraging.

The system was tested over 297 sets. Although it effectively reduced depredation, it also significantly reduced the catch rate (Goetz *et al.,* 2011).

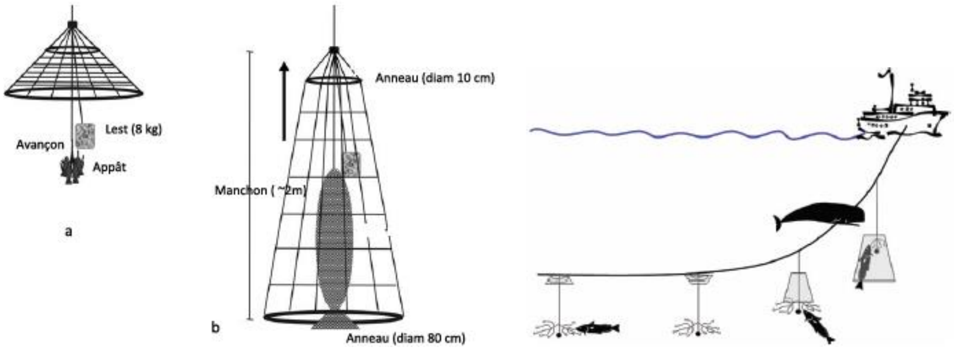

Figure 14 – Cachalotera a) the umbrella floats over the baited hook during the set; b) the umbrella slides down to cover the fish when the line is hauled in (from Goetz *et al.,* 2011; Hamer *et al.,* 2010).

➢ *The "Friendly octopus"*

This system was used with some success in the Falklands and tested in the Ross Sea. This method uses a main line with branch lines, like a traditional longline, but each branch has two additional lines.

The intersection line that is attached to the main line has dangling ropes attached to it so that when the line is being hauled the rope shields the baited hooks. Cetaceans do not like the hanging ropes which consequently keeps them away from the caught fish (Pethybridge et al., 2006).

➢ *The "sock"*

The "sock" is designed to completely cover the fish. It comprises a conical nylon or polypropylene net, the base of which is kept open by a metallic hoop. Weights can be added to the hoop to increase the device's sink rate. The same triggering system is used as for the spider consisting of a beta pin and an elastic ring. The "sock" is placed above the hook and folded up by pulling on the branch line and inserting the beta pin. When a fish takes the bait, the "sock" slides down and covers it, hiding it from predators (Rabearisoa *et al.,* 2012).

The effectiveness of "spiders" was tested in November 2007 during 26 longline operations on the north of the Mahé plateau (Indian Ocean). The effectiveness of "socks" was evaluated in October 2008 during 32 longline fishing trips in the same area. Although the results were not particularly conclusive, the authors remain convinced that this type of technology may help to reduce cetacean depredation (Rabearisoa *et al.,* 2012).

Figure 16 – The "sock" (Rabearisoa *et al.,* 2012).

3.1.4. Acoustic mitigations

➢ ***Passive acoustic deterrents***

An alternative to the emission of warning acoustic (pingers) or painful (AHD) signals is to disrupt the cetacean's use of echolocation to detect potential prey.

- **Beaded gears**

In order to reduce the depredation of sperm whales (Physeter microcephalus) on sablefish longline, O'Connell et al. (2015) attached 25mm pearls near hooks, with a target strength similar to that of a 71 cm average sablefish; speculating that whales would be disturbed in their echolocation ability to isolate a single sablefish. Although sablefish catches increased and depredations decreased, the authors found that this experiment was not statistically significant due primarily to the field study design.

- **Reflector streamer**

McPherson et al. (2008) described a streamer-based system tested in the Coral Sea for approximately 50 fishing sets. This device can be deployed from a polycarbonate tube holding wire-embedded electric fence tape with steel wire to maintain target strength. When a fish strikes, the streamer is extracted from the tube and tangled around the tuna. At the end of the experiment, it was obvious that the depredation seemed to be reduced. Nevertheless according several further experimentations (Nishida and McPherson. 2010), the authors conclude that the logistics for deployment are not suited to high seas and large-scale longline activity but could useful to limited scales of longlining and trolling where depredation occurs (Mc Pherson, 2010).

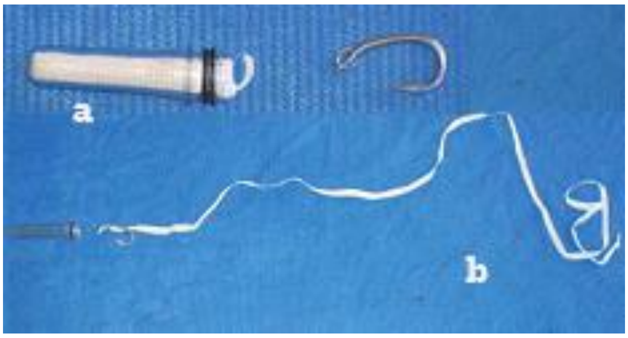

Figure 6 streamers of electric fence a) tube with hook fixed at 50 cm distance b). streamer after deployment from the tube (from Mc Pherson, 2010)

- **The "spider" system**

Combining visual and acoustic mitigation, this device comprises a 100 mm plastic disk with 16 holes in its outer range and a 37 mm central hole through which passes the branch line or the lower part of the line. Four polyester strands are inserted in those outer holes forming eight 1.2m hanging legs. The triggering system comprises a beta pin and an elastic ring. The branch line is inserted in the pin and the latter is tightened by the ring. The device is designed such that the biting fish triggers the system and is then covered by the eight hanging legs with the disk in its mouth (Rabearisoa et al., 2012).

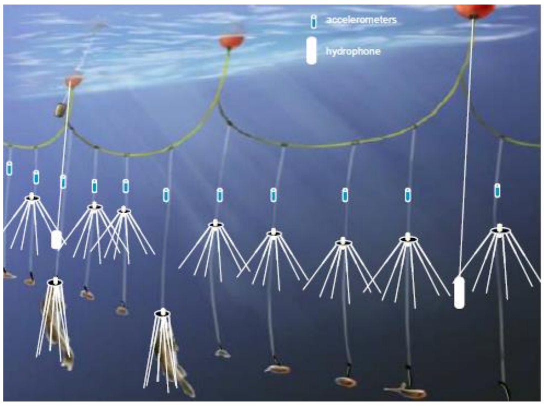

Figure 15 – The spider system (IOTC Workshop 2007)

➢ ***Active acoustic deterrents :***

- **« Pingers »**

To reduce depredations, various solutions are proposed by manufacturers as to use more louders than standard by-catch pingers, randomization (e.g. Fishtek, Future Oceans, etc.), including sound constant frequency, amplitude modulated, frequency modulated and impulsive signals, etc.

In response to frequent depredation by cetaceans a test was conducted in 2005 on the fishing vessels of the South Pacific and Indian Oceans where 10 kHz fixed-frequency acoustic pingers or 5–160 kHz random frequency small pingers were affixed to longlines. The results indicated that the 10 kHz pinger had the deterrent effect, which could reduce the amount of line snapping caused by cetaceans (Chen 2005 in Huang, 2011).

On the other hand, Nishida & Mc Pherson., (2011) tested the effectiveness of the newly developed dolphin deterrent device (DDD) pinger model in the high depredation area off south of Hawaii. According the authors, preliminary assessment results suggested that depredation rates by toothed whales (mainly killer and false killer whale) were probably reduced with DDD pingers and also with the interactive DiD pingers.

- **"Longline saver"**

To this effect, a device (Longline Saver) was developed in 2008 by the Dutch company *Savewave* (http://savewave.eu/) to dissuade false killer whales (*Pseudorca crassidens*) from coming near pelagic longlines in the North Pacific. This acoustic deterrent can produce a series of complex broadband signals (1-250 kHz) at high intensity levels (up to 195 dB). In its 2013 version (Orcasaver) the device comprises 40 transducers with 3 different signal types emitting at 6.5 kHz, the frequency considered to be the most effective with a sound pressure of 196 ±2dB re1. Given its weight and cost, the device can only be used on large longliners in industrial fisheries.

Tested by the Institute of Marine Biology (HIMB) on a captive animal, the experiment showed that the *Longline Saver* reduced by 54% the echolocation performance of the animal at high emission levels and that the animal recovered up to 85% of its detection capacity at the end of the experiment (Mooney *et al.,* 2009).

In addition to its short effective duration, the system cannot cover a longline several kilometres long when operated from the vessel. Whilst this configuration might be suitable for vertical longline fisheries, it is too cumbersome and costly to be used in small-scale vessels, such as those targeting bluefin tuna in the Strait of Gibraltar and faced with killer whale foraging (*Orcinus orca*).

Nevertheless, this solution is promising and consequently systems based on this echolocation-masking principle that are less cumbersome and more powerful would be worth testing if the aim is to reduce interactions between cetaceans and pelagic longline fisheries.

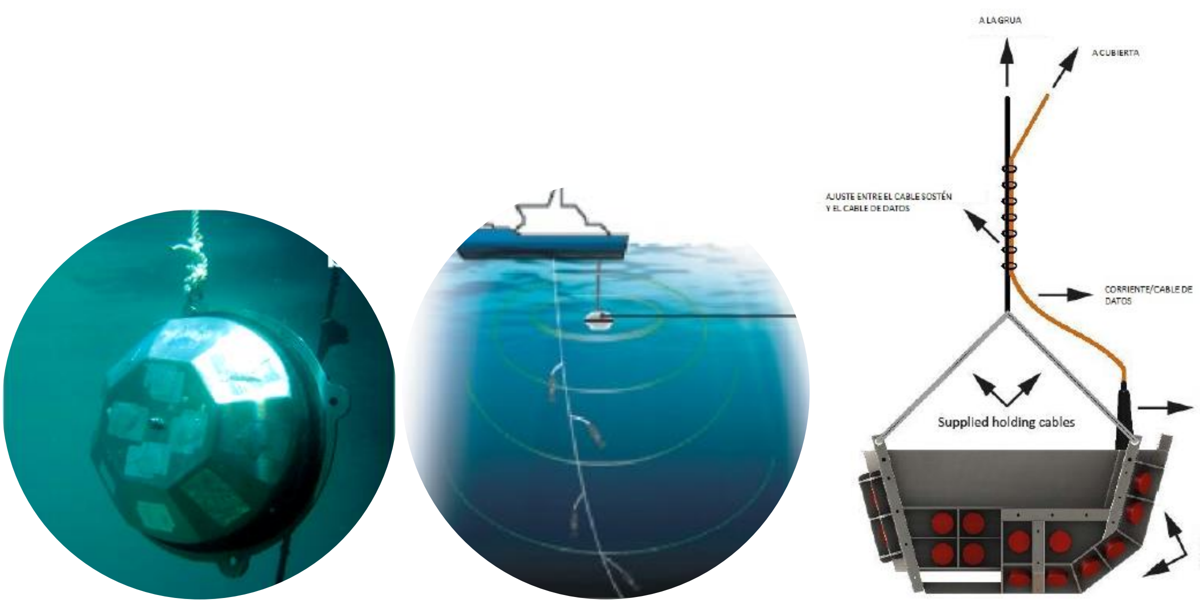

Figure 18 –The Longline Saver is hemispherical with a 38.1 cm diameter and weighs 24 kg; it is lowered to 10 meters under water and is designed to be activated during hauling of the longline (from Savewave and Mooney *et al.,* 2009); on the right, the larger size (90 X 45 X 35cm) and weight (150 kg) of the Orca in Saver necessitates a crane for its deployment.

3.2. BIRDS

Birds can peck the bait fixed on longline hooks and can be dragged under water and drown during hauling. In the Mediterranean, the most critical area is located in the Balearics where three puffin species (*Calonectris diomedea*, *Puffinus mauretanicus, Puffinus gravis*) have been classified as "critically endangered" by the IUCN (BirdLife International briefing, September 2009). Furthermore, bird interaction with longlines represents an economic loss given the amount of bait consumed and the number of hooks immersed without bait. It is important to avoid conditions where fishers perceive birds as genuine competitors.

3.2.1. Fishing gear modifications

➢ ***Hooks***

Little research has been undertaken on the impact of the type and dimension of hooks. It appears that the combination of these two characteristics has an effect on bird bycatch which is however difficult to dissociate from the impact of the bait, the species, the set conditions and the longline design (Li *et al.,* 2012). Nevertheless, a case can be made for the use of circle hooks in that their wide bend makes their ingestion more difficult, the fact that their barb is turned towards the inside reduces the risk of their hooking the body or the wings and finally birds that are hooked during line-hauling are more easily freed and more likely to survive (BirdLife International, 2013).

➢ ***Bait***

- **Condition of the bait**

In fisheries where no weights are added to the branch lines, the use of thawed bait reduces the sink rate. For the same reason, live bait is not recommended as it sinks more slowly than dead bait.

- **Size and species**

Small fish species (sardines and various mackerel species) should be preferred to squid which sinks more slowly. There is only a small difference in immersion rate between large and small bait of the same fish species.

- **Position of the bait on the hook**

For faster immersion, bait must be fixed preferably head-first (fish) or tail-first (fish and squid) but not by the dorsal part or the top of the mantle (squid).

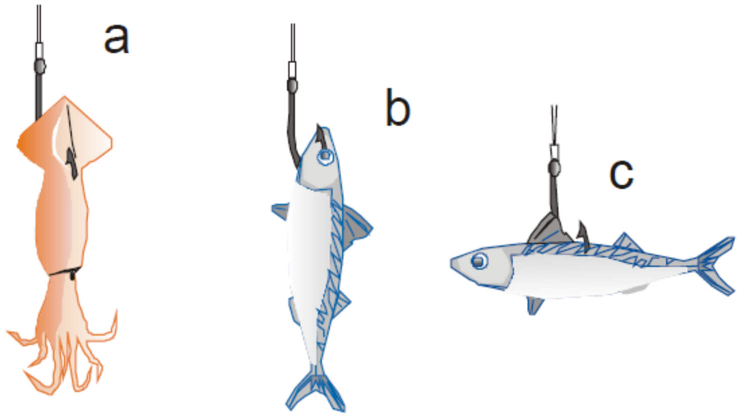

Figure 19 – Different ways of fixing the bait: (a) and (b) help the immersion of the baited hook; (c) helps reduce turtle bycatch.

- **Dyed bait**

In the 1970s, fishers tested dyed bait to improve their catch. More recently, experiments have been undertaken on the use of blue-dyed bait to reduce seabird bycatch in pelagic longline fisheries. In theory, the blue dye should reduce the contrast between the surrounding sea water and the bait making it more difficult to detect. Other theories suggest that seabirds are simply less interested in the blue-dyed bait than in undyed bait: Cocking *et al.,* (2008) showed that during 26 longline sets the use of blue-dyed squid reduced by 68% puffin (*Puffinus pacificus*) foraging during hauling. Several other factors may influence the effectiveness of blue-dyed bait such as light, water colour, food competition and habituation.

The dyeing process requires that the bait be entirely thawed to absorb enough colorant. The bait is often refrozen after dyeing and used in a semi-frozen state to improve its hold on the hook. It is worth mentioning that brilliant blue FCF is the 30etween30r30ze colour specified by the Indian Ocean Tuna Commission (IOTC) for use in squid bait dye (Birdlife International, 2013).

➢ ***The "hookpod"***

This product results from collaboration between BirdLife International and Fishtek Ltd and remains at an experimental stage. The "hookpod" is designed to reduce seabird bycatch by protecting the barb of the hook when the line is hauled. Once the branch lines have reached a pre-determined depth, the pod opens freeing the hook (fig.20). The pod is later recovered during hauling and stored until the next deployment. Different types of bait (large and small fish, live bait and squid) and various positions on the hook have been tested with success. More recently, an LED was integrated into the chamber of the device to replace the chemical lightsticks. The next development stage is to adjust the release mechanism for selected depths, in particular beyond the 40 meters frequently reached by sea turtles (Sullivan, 2010).

Figure 20 – The "hookpod" – Hookpod Ltd 2014 http://www.hookpod.com

- ***Weighting longlines***

Petrels and puffins are known to dive deep for food; puffins for example can dive to 65m. In order to minimize bycatch during hauling, baited hooks must reach as quickly as possible the first ten meters below the water surface (Friesen *et al.,* 2017).

In the case of demersal longlines, foraging is rare because the branch lines are short (< 0.6m) and the main line is often weighted; by contrast, branch lines of pelagic longlines are much longer (15-40m) and the main line is light. Weighting the longline is necessary to reduce the incidental-catch risk because seabirds are particularly vulnerable during the short period when the baited hooks remain on the surface during setting. In many pelagic longline fisheries, weights are added to branch lines in order to reach the target species depth as fast as possible. During setting, the added weight pulls the lower line and the baited branch line very rapidly towards the sea bed.

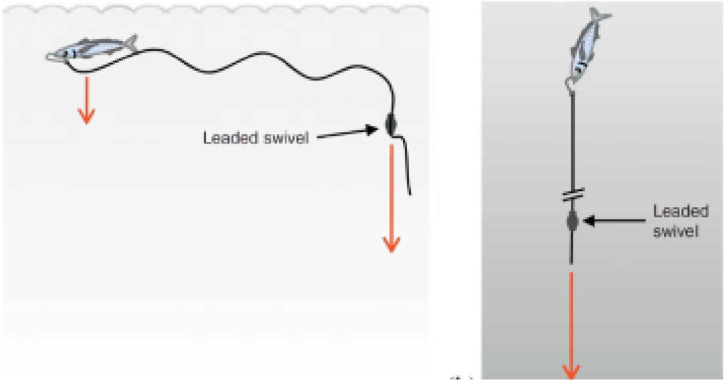

Figure 21 – Working principle of a weighted branch line during setting (Clarke, 2014)

The closer the weight is to the hook, the more rapidly it sinks, thereby reducing seabird bait-foraging and mortality without affecting the catch of target species (Gianuca et al., 2013; Jimenez et al., 2013). An experiment undertaken in Australia on longlines targeting yellowfin tuna (*Thunnus albacares*) showed that placing 40g weights about 50cm from the hook reduced sinking time by 25 to 33% whilst facilitating longline setting without risk of line entanglement or crew injuries (Roberton et al., 2013).

- **Double or triple weights**

The Yamazaki system (fig. 13) used by some Japanese vessels consists of placing 2 weights at each end of a stainless-steel wire 1 to 1.5m long added to a monofilament branch line 2 meters above the hook. The weight closest to the hook can slide freely along the branch line whilst the second one remains fixed. This double-weight system reduces the risk of crew injury from "fly-backs" of lead weights, also dampened by the stainless-steel wire; it also means that the heaviest weight is within reach of the crew member responsible for deploying the branch line. In 2010, more than 95 000 branch lines equipped with this system were hauled without incident, reducing incidental bird catch by 89% without affecting the catch rate of target species (Clarke, 2014). Combined with dual streamer lines, this system reduced bycatch by 86% compared to non-weighted lines, with the same target species' catch rate (Melvin *et al.,* 2011).

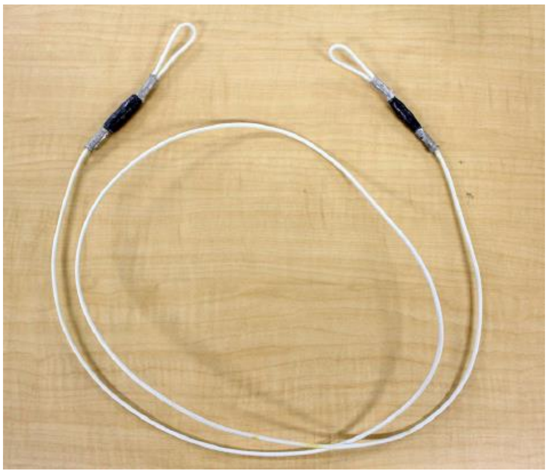

Figure 22 – Branch line with double weight: 15 and 26g weights are placed at each end of a sleeved monofilament line 1.5 m long. This element is inserted between the hook and the main line 2m from the hook; the lighter weight being located near the hook (Sato *et al.,* 2014).

An optimal weighted-branch line design consists of a 45g weight about a meter from the hook, a 60g weight about 3.5m from the hook and another 98g weight about 4 meters from the hook (fig. 23).

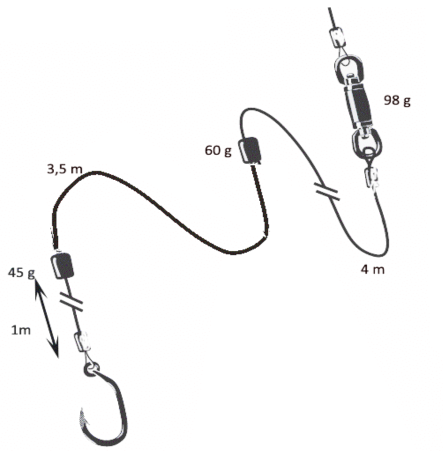

Figure 23 – Branch line with triple weight

- **Sliding weights**

Tested in Australia and in South Africa, sliding weights are an alternative to weighted swivels. They are designed to increase the sink rate of the branch line and protect the crew from the risk of injury if the line breaks under stress and from hazardous fly-backs of the branch line when the fish is unhooked (Sullivan *et al.,* 2012).

Figure 24 – Sliding weight (Sullivan *et al.,* 2012).

The “Lumo lead” is a variant of sliding weight, designed by the Fishtek Marine company working closely with fishers and the Australian Fisheries Management Authority to reduce the incidental catch of albatross. These weights are encased in a luminescent nylon sheath that glows for more than 6 hours attracting fish, and protecting the crew during fishing operations and gear rigging (Gianuca *et al.* 2013*,* Jimenez *et al.,* 2013; Melvin *et al.,* 2011; Robertson *et al.,* 2013).

Lumo Lead type sliding weights were tested in 2015 in the Brazilian pelagic fishery during fishing trips in the Southwest Atlantic. The longlines are traditionally set at night with branch lines that are weighted with swivels placed 3.5m from the hook. Compared to this technique, Lumo Leads placed 1m from the hook sink more quickly with no difference in the target species' catch rate. However, bird mortality rates remain high which shows that the combination of night setting and branch line weighting is insufficient. The use of an added deterrent, of the streamer line type, might reduce the incidental catch of seabirds to acceptable levels in this fishery (dos Santos, 2016).

Figure 25 – Lumo Leads (info@fishtekmarine.com)

3.2.2. Setting improvements

Different setting techniques may contribute in various ways to reducing the incidental catch of birds. Tests have been undertaken mostly in waters visited by large seabird colonies such as the Antarctic or the North Sea (IOTC-2011).

- ***Day or night setting***

In the Mediterranean, the most effective way to reduce the incidental catch of birds is to avoid setting longlines at sunrise or sunset, times when the birds usually feed (Belda and Sanchez, 2001). Night setting requires no gear modification and simply needs to be undertaken during hours of darkness. The effectiveness of this tactic is obviously considerably reduced during moonlit periods with some species such as the Cory's shearwater and the Audouin's gull also feeding at night, especially when the moon is full (Cortés & Gonzalez-Solis, 2015).

It is therefore recommended to start setting the longlines at least 1 hour after dusk and to finish at least 1 hour before dawn. The deck must be sufficiently lit to ensure safe handling but must not illuminate the line which is being deployed. These recommendations may however be restrictive especially because they reduce the duration of a set (BirdLife International, 2013).

➢ *Side setting*

Traditionally, longlines are deployed from the stern. When deployed from the side, birds are less willing to approach the vessel to forage for bait. Moreover, side-setting avoids setting baited hooks in the propeller wash which slows their sink rate as is the case with stern-setting. The lines are deployed just as rapidly as when stern-set. This method was tested on small vessels in the North Pacific and proved to be more effective than other measures such as blue-dyed bait, etc (Gilman *et al.,* 2003).

For better results, this technique can be combined with branch line weighting. A horizontal pole with vertical streamers may deter birds from grabbing the bait (BirdLife International, 2013).

Figure 26 – Side-setting protected by a bird curtain (BirdLife fact sheet n°9).

➢ *Underwater setting*

This system enables deployment of longlines under water and therefore out of the sight of seabirds. It is traditionally done using a chute which is fixed at the stern of the vessel with 1 to 2 metres of its length under water. As with many mitigation measures, environmental and operational factors affect the chute's effectiveness. In heavy seas, the pitching of the vessel may raise the end of the chute clear of the water surface making it less effective (Williams *et al.,* 2017).

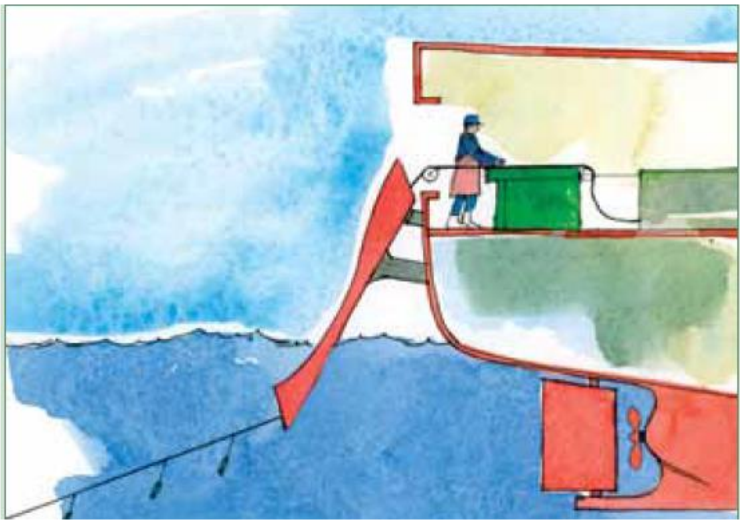

Figure 27 –The underwater setting system (BirdLife Fact Sheet n°6)

- ***Branch line hauler***

In longline fisheries, branch lines can reach 40m in length. During hauling, birds may forage on baited hooks as they come to the surface; using a line hauler speeds up the branch line hauling process.

- ***Line shooter***

By decreasing the tension in the longline, this hydraulically-operated mechanism is designed to deploy the main line forward at a greater speed than the moving vessel so that the main line enters the water faster and the baited hooks sink faster and deeper (Robertson *et al.,* 2010). However, the WCPFC stipulates that "line shooters" cannot be considered a sufficient mitigation measure and must be used in conjunction with at least one other such measure (WCPFC CMM-2012). This system, tested in demersal longline fisheries in Norway, has proved to be less effective than underwater- or side-setting (Lokkeborg, 2003).

3.2.3. Visual mitigations

- ***Streamer line***

"Streamer lines" (SL), also called "tori line" and "scaring line", appear to be one of the most effective systems to keep birds away from baited hooks during longline setting. They consist of 1 or 2 lines with brightly-coloured streamers attached at regular intervals, mounted on a high vantage point at the stern and towed behind the vessel when the longline is deployed. An object attached at the end of the line ensures sufficient tension in the system. The aim is to keep the SL above the sinking area of the bait so that birds hindered by this kind of scarecrow cannot forage on baited hooks and get caught.

The diving capacity of birds, such as the puffin that can dive to depths of more than 10 meters, enables them to reach bait even if it is already under water, which, when they form a group, can lead to massive catches from a single longline set.

It has been shown that the use of SL alone can reduce bird mortality by more than 70% (Boggs 2001; Gianuca *et al.,* 2011; Domingo *et al.,* 2011). However, it is strongly recommended to combine their use with other systems such as night setting and weighted branch lines.

Several documents provide detailed recommendations for their design (Bull *et al.,* 2007; Melvin *et al.,* 2007; Melvin *et al.,* 2010, Stephenson, 2014). We will only present here the specifications given in the good practice guide prepared for the Balearic longliners (Cortes and Gonzales-Solis, 2015).

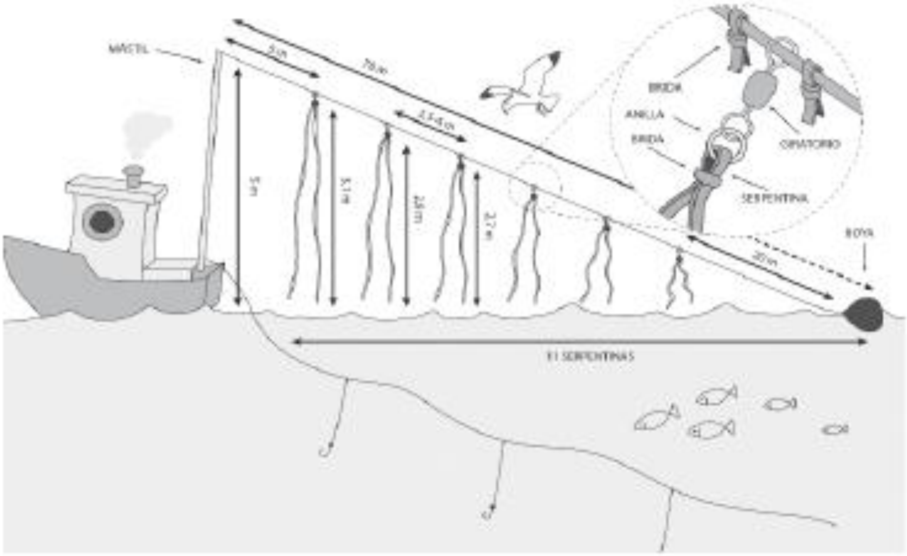

Figure 28 – Streamer line

The Streamer Line comprises a 70m wire of 6mm diameter on which every 3 to 4m brightly-coloured PVC light streamers of decreasing lengths are attached using swivels; a buoy used as a weight is fixed at the end of the wire, about 20m away from the last light streamer. The other end of the wire is fixed to a pole with a snap hook so that it remains more than 5 meters above sea level.

Increasing the size of the SL aerial structure reduces the risk of entanglement with the longline (Melvin *et al.,* 2010). The light streamers must protect the baited hooks until they sink deep enough to be out of bird reach (around 10m). Weighting the branch lines makes it possible to reach this kind of depth within reasonable distances.

The fixation point must be strong and adjustable as it must withstand the drag of a 70-meter long aerial section. It must also be able to withstand sudden tension if a float or some debris becomes entangled in the streamline.

The setting operation starts with the launch of the buoy whilst the boat is moving and the SL is then shot from its storage box. The SL must be entirely deployed with the maximum number of streamers. It must be long enough so that the number of streamers can be reduced or increased. Once the SL is in place, the longline can be set and at the end of the set it is hauled before the SL (Cortés, Gonzales-Solis, 2015).

Generally, pelagic longlines are set faster than the vessel speed and the hooks sink more slowly than in the case of demersal longlines. This increases the distance to be protected behind the vessel.

Streamer lines must be deployed along the outer edge or outside of the vessel wake and the hooks deployed under its protection in the wake area or outside of it.

In calm wind situations, this deterrent system can sometimes become ineffective as the streamer lines do not move and frighten the birds.

In crosswind conditions, the streamer lines must be adjusted downwind so that the birds looking for food, which usually fly close to the wind, are deterred from foraging on baited hooks (Domingo *et al.,* 2011; Gianuca *et al.,* 2011).

In order to reduce the presence of birds, fish should not be thrown into the sea before the set or on exiting the harbour. It is also preferable to cover the fish caught and the bait storage containers.

Finally, even if incidental bird catch can be partly avoided during setting, this remains a risk during the hauling of the longline. Thus the Commission for the Conservation of Antarctic Marine Living Resources (CCAMLR) has developed a device to ward off the birds from the haul area (BED, Bird Excluder Device) which, in its more sophisticated version, comprises streamers suspended from a rope strung between two booms, suspended over the longline hauling area (Reid *et al.,* 2010).

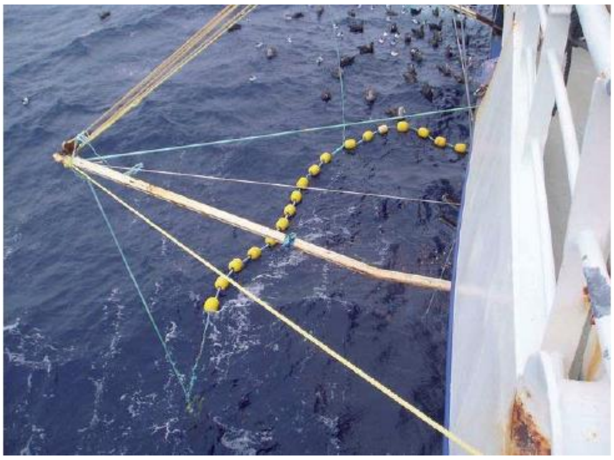

Figure 29 – BED comprising two booms supporting a purse seine float line (Reid *et al.,* 2010)

- ***Laser beam***

Figure 30 – Seabird Saver visual deterrents from the Dutch company Save Waver. Marketed by Mustad, it produces a broad laser beam especially effective in darkness; it can be operated as a static or sweeping laser beam and can be combined with an optional sound system (*www.seabirdsaver.com/wp.../RSBS-Information-Pack20151.pdf).*

The use of a laser beam to keep seabirds away during longline setting was first tested in 2014 onboard an Icelandic vessel fishing for cod with a bottom longline. The trial lasted 5 fishing days and 5 sets of a 2 500-hook longline. The system was designed by the Mustad and Savewave companies as a broad light beam to reduce risk of eye damage in seabirds. During the trials, the SeaBird Saver effectively warded off Northern Fulmars (*Fulmarus glacialis*), present some distance from the vessel stern in the critical area where baited hooks are immersed. In the future, it should be complemented with a sound component mimicking a mixture of predator and distress calls.[3]

3.1.1. Acoustic mitigations

Acoustic deterrents currently used range from firing shotguns, cannons and hitting the steel hull to commercial devices that emit loud, high-frequency noises or distress signals (Bull, 2006). However, these devices may also be ineffective and should be used sparingly to avoid any habituation (Brothers et al., 1999).

3.3. SHARKS

In a recent study on reducing the risk of shark bycatch and mortality in the New Zealand longline fisheries (Howard, 2015), 20 methods were identified and ranked according to how quickly they could be applied to the commercial fishery. The highest-ranked methods were large hooks, nylon leaders, squid bait, and non-forged hooks (weak hooks). Other parameters, such as the depth and timing of sets, depend on the species and on environmental conditions in the fishery or may be controversial such as the use of circular hooks.

3.3.1. Fishing gear improvements

- ***Hook type***

Given their better hooking capacity, circle hooks are often associated with an increase in shark bycatch. However, they complement the use of nylon leaders as they reduce the risk of lodging

[3] http://www.doc.govt.nz/Documents/conservation/marine-and-coastal/marine-conservation-services/bycatch-bylines/bycatch-bylines-june-2014.pdf

in the oesophagus, improving the survival rate of these animals. In most longline fisheries, 17/0 and 18/0 circle hooks are the most commonly used and moving to larger sizes might further reduce the bycatch of sharks, especially of smaller ones.

Gilman *et al.* (2007) reviewed studies of shark catchability as a function of hook and bait types. They refer to a study carried out in the Azores where it was found that fishing with a circle hook resulted in a higher blue shark (*Prionace glauca*) catch rate compared with fishing with a J-hook (regardless of bait type). However, this difference was thought to result from the unrecorded de--hooking of blue sharks from monofilament branch lines or much deeper hooking on J-type hooks. Apart from this study, there appears to be no significant difference between hook types in the case of blue sharks, although hooking has been found to be deeper (e.g. oesophageal or stomach) with J-type than with circle hooks. Mouth hooking is less traumatic for the shark as the branch line can be cut free and the hook will eventually corrode and fall off (Patterson and Tudjman, 2009). On the other hand, an internal injury from the ingested hook is likely to reduce survival rate (Gilman *et al.,* 2007).

In the Mediterranean, the pelagic stingray (*Pteroplatrygon violacea*) is the main bycatch of swordfish longline fisheries. A study undertaken in the Strait of Sicily showed that the larger the J-hook, the smaller the pelagic stingray bycatch. However, circle hooks are still far more effective than J-hooks with an 80% reduction in ray bycatch, arguing for the adoption of this type of hook to reduce the environmental impact of fishing (Piovano *et al.,* 2010).

- **Weak or breakable hook**

The use of weak hooks (cf.3.1.1) to reduce the catch of large specimens is a simple measure to implement but it has not yet been shown to be effective in reducing shark bycatch.

- **Corrodible hooks**

These hooks are made of metal, other than stainless steel, such as different alloy compositions with various coatings that affect their durability. They decay more or less rapidly following their ingestion according to their diameter and composition (from a couple of days to a few months). Their use is of interest because it reduces the mortality rate of an animal freed with a hook still in place. The need to replace the hook more frequently can be a drawback but making this hook is technically simple and therefore less costly (Patterson & Tudman, 2009; Mc Grath *et al.,* 2011), justifying a preliminary economic evaluation before applying this type of hook to a fishery.

➢ ***Bait***

- **Bait type**

Changing the type of bait may have a larger impact on reducing shark bycatch than the type of hook (Gilman *et al.,* 2007). Most studies show that using fish such as mackerel or mullet as bait rather than squid reduces pelagic shark bycatch, including blue shark (*Prionace glauca*) (Godin *et al.,* 2012; Galeana-Villasenor *et al.,* 2009; Gilman *et al.,* 2008, Gilman *et al.,* 2007; Watson *et al.,* 2005).

However, a study undertaken with the Portuguese longline fleet operating in the equatorial Atlantic ocean revealed higher catch rates with mackerel bait for a number of pelagic sharks such as the blue shark (*Prionace glauca*) and the big eye thresher shark (*Alopia superciliosus*) (Coelho *et al.,* 2012).

A study undertaken on the Grand Banks of the North Atlantic Ocean from 2002 to 2003 showed that mackerel bait increased the odds of gut hooking for *Prionace glauca* and *Lamna nasus* (Epperly *et al.,* 2012).

- **Artificial bait**

The challenge is to design bait which will only attract target species. Recent trials with pelagic longlines and artificial bait showed that it is possible to reduce pelagic ray bycatch with such bait.

Erickson & Berkeley (2008) used artificial bait made from products derived from fish waste incorporated into a gum-based matrix. When tested on bottom longline gear targeting the Pacific halibut (*Hippoglossus stenolepis*) in Alaska, this bait significantly reduced bycatch of spiny dogfish (*Squalus acanthias)* and longnose skate (*Raja rhina*). Halibut catch was unaffected but cod catch fell substantially. A variant of the artificial bait reduced spiny dogfish catches by 99%. However, a study of the impact of artificial bait in large pelagic longline fisheries (tuna and swordfish) showed no reduction in bycatch of blue shark (*Prionace glauca*) (Bach *et al.,* 2012).

The objective of research undertaken on this topic in the 1980s and 1990s was both to free longline fishers from natural bait supply constraints and to reduce waste from the processing industry. Designs must meet 3 requirements: a synthetic attractant, preferably as effective as the natural bait that is commonly used; a support that is sufficiently strong to stay on the hook but capable of diffusing the attractant throughout the set; and a product that is easily stored without being significantly more expensive than natural bait. Despite some limited success in a few industrial demersal fisheries, no further research has been undertaken in this area which however has the potential to reduce fishing effort on the species currently used as bait.

- **Luminous lures**

The suppression of lightsticks is a simple measure but it is unlikely to produce significant results despite the positive correlation reported in the literature between their use and shark bycatch.

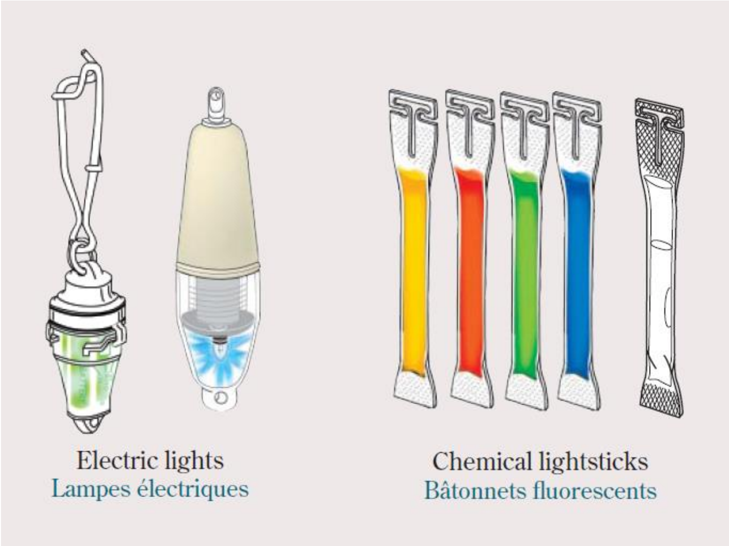

Figure 31 – LEDs and lightsticks (Beverly & Park, 2009)

Many fishers believe that the use of lightsticks increases shark bycatch but do not agree on the colors that are most attractive for sharks. In fact, little is known about the responses of sharks and rays to the light lures used by longliners. According to a study undertaken on the swordfish longline fishery in the Strait of Sicily, light lures appear to have little impact on the catch rate of pelagic stingray (*Pteroplatytrygon violacea*) (Piovano *et al.,* 2010).

- ***Branch lines***

Nylon or stainless-steel-wire branch lines are used indifferently in various longline metiers (Beverly and Park, 2009). Stone and Dixon (2001) showed that the use of monofilament in pelagic swordfish longline fisheries increases the catch of both target and bycatch species, such as sharks, by similar amounts.

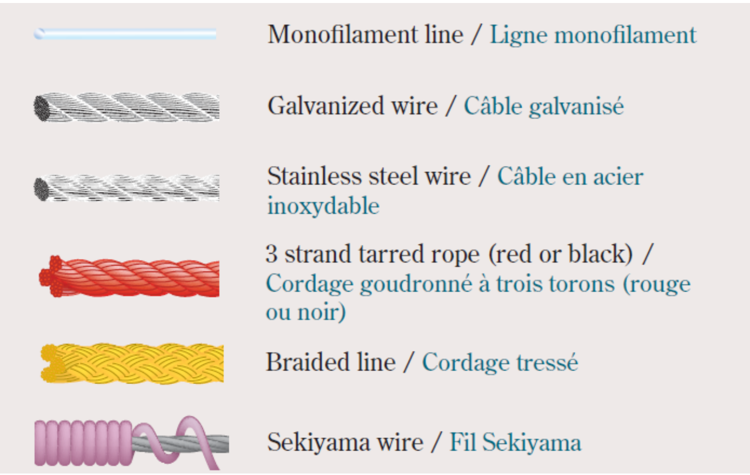

Figure 32 – The different types of material used for longlines (Beverly and Park, 2009)

It is easier for sharks to free themselves from monofilament branch lines, which they can more easily break, than from steel lines (Gilman et al., 2008; Ward et al., 2008). Although this leads to an apparent decrease in shark catches, it does not necessarily mean a reduction in mortality as the freed shark will still have the hook attached to its oesophagus or its jaw. This scenario was observed in the Brazilian longline fishery where 97% of escapees had been caught with nylon branch lines; the difference between nylon and steel branch lines was only significant for those equipped with J-hooks. The use of steel branch lines therefore does not necessarily mean higher shark catch rates (Afonso *et al.,* 2012; Clarke *et al.,* 2014).

The branch line length may affect shark survival rate; if they are too short, they restrict the swimming motion required for ram ventilation and may lead to asphyxia in captured individuals (Gallagher *et al.,* 2014).

Furthermore, in 2013 and 2014, 40g and 60g lumo leads were tested on New Zealand tuna and swordfish longliners. The bycatch of blue shark (Prionace glauca) was significantly lower than with normal longlines, with no impact on the catch of target species (Pierre et al., 2014).

3.3.2. Setting improvements

➢ ***Time and duration of the set***

The duration and the time of setting and hauling affect catch rates presumably because of differences in the environmental conditions that determine elasmobranch behaviour. However, this issue has been the subject of little researches and what there is tends not to differentiate between the impact of the timing and duration of the set.

➢ ***Set depth***

The Bigeye thresher (*Alopias superciliosus*) catch rate in the Marshall Islands' longline fishery is higher during shallow night sets and deeper day sets (Bromhead *et al.,* 2012).

Changing the set depth may thus be an effective way to reduce elasmobranch bycatch in longline fisheries. However, even if the longline is rigged for deep-sea fishing, some parts can remain in the surface water layer for a period of time that depends on the sink speed of the longline. In order to reduce the risk of interactions with surface-swimming pelagic sharks, there are simple ways to increase this speed such as weighting the branch lines and deploying the longline faster than the vessel speed (SPC, 2005).

In the case of longlining for demersal species, the use of longlines where the main line is off the bottom so that baited hooks do not touch the bottom reduces the risk of depredation by demersal sharks (for example, *Scyliorhinus canicula*) or by invertebrate scavengers. The drawback of this longline is that it takes longer to sink during deployment which increases the risk of incidental bird catch. Coelho et al. (2005) show that removing the lower three hooks in the hake bottom longline fishery in the Algarve, reduce the number of caught sharks by 16 to 33 percent, depending on the species. Hoey and Moore (1999) also found that reducing the number of hooks or setting the gear farther from the seafloor achieved a reduction in shark bycatch.

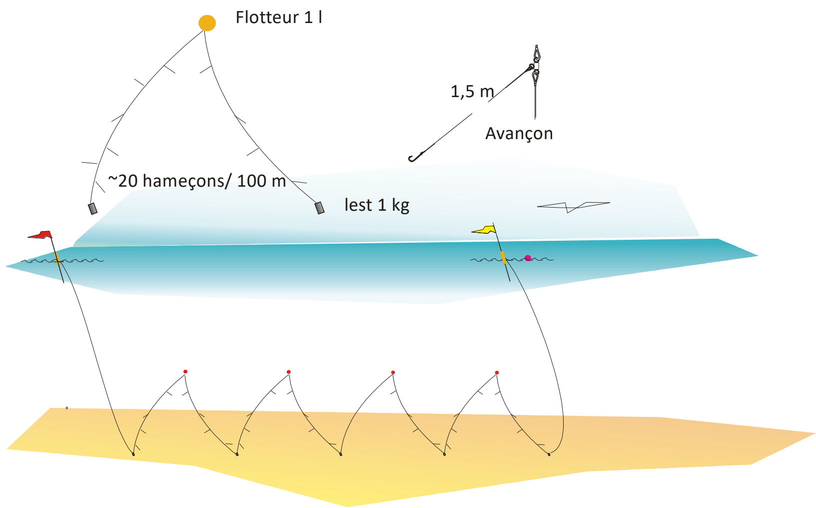

Figure 34 – Semi-pelagic hake longline

3.3.3. Acoustic mitigation

Sharks, like all pelagic teleosts, are known to be sensitive to low frequencies (Southwood *et al.,* 2008). Silky sharks (*Carcharhinus falciformis*) and oceanic whitetip sharks (*Carcharhinus longimanus*) are attracted to low-frequency sounds within the range of 25 to 1 000 Hz with attractiveness increasing as sound frequency decreases. Irregularly-pulsed sounds, similar to those produced by struggling prey, are more attractive than regularly-pulsed sounds. Sudden transmission of high intensity sound at close range prompts an immediate and rapid withdrawal of the sharks, but this effect does not last as they rapidly habituate to such signals.

3.3.4. Chemosensory mitigation

Sharks display attraction to odours derived from fish and invertebrates as potential prey, particularly those from stressed fish; it is one of main reason of by-catch by longline. Red Sea soles (*Pardarchirus spp.*) are known to secrete a surfactant-like substance containing pardaxin, a natural shark repellent (Clark & George 1979). However, its potential use is hindered by its difficult synthesis and its extreme lability. This line of research was pursued further by Stroud et al., (2014), but the dissuasive effect of semio-chemical substances derived from decaying shark tissue is of limited interest to longliners for the time being, given the large quantities and concentrations required for them to be effective throughout a set. However, sea trials using squid treated with a chemosensory substance showed a 37% reduction in shark bycatch in surface longlines (NOAA, 2013).

Concerning predation, chemoreception is most likely the dominant detection system in sharks. Jordan et al., (2012) made a comprehensive review on linking sensory biology of elasmobranchs with bycatch reduction.

Review current knowledge of elasmobranch sensory biology and feeding ecology with respect to fishing gear interactions and include examples of bycatch reduction methods used for elasmobranchs as well as other taxonomic groups

Using aerosol canisters at the surface to deliver a substance produced by putrefied shark tissue induced an immediate flight reaction in the Caribbean reef shark population (*Carcharhinus perezi* and *Carcharhinus acronotus*) at South Bimini. By contrast, no aversion response was detected in the teleosts also present (Stroud *et al.,* 2014).

Shark Defense Technologies (http://www.sharkdefense.com/shark-repellent-technologies/), a company based in New Jersey, has invented a new polymer called *SuperPolyShark* the smell of which deters sharks from approaching baited hooks while still attracting the target species such as swordfish. This polymer inserted into bait is effective for around twelve hours under water. Researchers tested different scenarios using *SuperPolyShark* and overall managed to reduce bycatch by 39% on average.

3.3.5. Magnetic or electropositive mitigations

Permanent magnets have been to have a repellent effect on sharks by creating an abnormally strong electrical stimulus overwhelming the elasmobranch's acute electrosensory system. Using as "rare earth metals" (Electro Positive Rare Earth Metals – EPREM e.g. lanthanides) they were introduced into longlines in 2006 by the winner of the WWF Smart Gear competition, Michael Herrmann, as a means of keeping sharks away from baited hooks. These magnets or "rare earths" are either added to the line in the form of metal disks or directly incorporated into hooks. A New Jersey company (Shark Defense Company) developed a magnetic hook called the SMART Hook coated with special polymer and metal that create a 1.05 V galvanic cell in seawater (fig. 33). According to Stroud (2011) the hook loses its electromagnetic property after 5 days as the metal dissolves rapidly.

Figure 33 – The Shark Defense SMART Hook and its galvanic coating (http://www.sharkdefense.com)

Overy (2014) reviewed the different studies of the impact of permanent magnets and of lanthanides on various shark species and showed in particular that the deterrent effect varied according to the studied species (Table 2). Whilst *Sphyrna lewini* (Hutchinson *et al.,* 2012), *Squalus acanthias* (Stoner and Kaimmer, 2008), *D. Americana* and *G. cirratum* (O'Connell *et al.,* 2010) showed significant sensitivity to lanthanides in the laboratory, the limited number of trials undertaken at sea, mainly on the Scotian shelf (Cosandey-Godin *et al.,* 2013), did not show any reduction in the bycatch of blue shark (*Prionace glauca*) or any other common shark species. Furthermore, all the trials showed that avoidance responses only occurred within approximately 1m of the source of the magnetic field (Overy, 2014). Following dissection, it was also noted that sharks that avoided capture had higher levels of satiation.

Brill et al., (2009) show in the field that electropositive metals (mixtures of lanthanides elements) placed within 10 cm of the bottom longline hooks reduced the catch of sandbar sharks (*Carcharhinus plumbeus*) by around two thirds, compared to the catch on hooks with a placebo.

On the other hand, recent study using neodymium magnets during commercial longline fishing operations show that magnets (model 8850 gauss, and model 4640 Gauss), do not reduce blue shark (*Prionace glaucae*) catch rates and can even have an attractive effect (Porsmorguer et al., 2015). The author corroborates that all the tests with an electromagnetic system obtained highly contrasted results between laboratory and field experiments, between species and according to the electro-magnetic system used.

Table 2: Impacts of magnetic materials on some sharks

AUTHORS	SPECIES	MATERIAL	APPROACH		DETERRENT	
			Control	Magnet	Control	Magnet
O'Connell *et al.,* 2010	Dasyatis americana	Barium ferrite	20	18	5	49
O'Connell *et al.,* 2010	Gingliostoma cirratum	Barium ferrite	6	8	2	20
O'Connell *et al.,* 2011	Carcharhinus limbatus	Barium ferrite	16	2	N/A	N/A
O'Connell *et al.,* 2011	Carcharhinus plumbeus	Barium ferrite	4	7	N/A	N/A
O'Connell *et al.,* 2011	Dasyatis americana	Neodymium-iron-boron	10	5	N/A	N/A
O'Connell *et al.,* 2011	Mustelus canis	Neodymium-iron-boron	10	1	N/A	N/A
O'Connell *et al.,* 2011	Raja eglanteria	Neodymium-iron-boron	4	1	N/A	N/A
O'Connell *et al.,* 2012	Carcharhinus carcharias	Barium ferrite	66	2	6	20
O'Connell *et al.,* 2012	Squalus acanthias	Neodymium-iron-boron	1 296	930	N/A	N/A
O'Connell *et al.,* 2012	Torpedo nobiliana	Neodymium-iron-boron	1	0	N/A	N/A
O'Connell *et al.,* 2012	Lamna nasus	Neodymium-iron-boron	1	0	N/A	N/A
Rigg *et al.*, 2009	Carcharhinus amblyrhyncus	Ferrite	388	302	51	109
Stone & Kaimmer, 2008	Squalus acanthias	Neodymium-iron-boron	79	64	N/A	N/A

3.4. SEA TURTLES

From small craft to large industrial vessels with processing facilities, longline and mainly pelagic longline fisheries are responsible for significant bycatch of sea turtles, juveniles and breeders. Of the seven species of marine turtles in the world, the logger (*Caretta caretta*) and the leatherback (*Dermochelys coriacea*) are the most affected species and are of particular concern because of their vulnerability status. As Gilman & Huang, (2017), the literature gives several study reports and reviews on various mitigation solutions, both on the improvement of fishing gear and on fishing strategies.

3.4.1. Fishing gear improvements

- ***Hooks***

In the hoking process, the most important parameters are the overall hook width which can be correlated with turtle mouth dimension, the distance between the point and the shank which ensures deeper penetration of the point and better holding power of the fish, and its shape which can influence hooking position (Lucchetti and Sala, 2010).

Following Santos et al., 2012, while leatherback sea turtles (*Dermochelys coriacea*) are mostly hooked externally by the flippers, loggerhead turtles (*Caretta caretta*) are mainly hooked by the mouth. . Specifically, they most often swallow J hooks and are hooked internally, which probably is the most lethal form of hooking interaction (Watson et al., 2005).

- **Circle hooks**

An increasing number of studies tend to show that circle hooks are more effective than J-hooks in reducing sea turtle bycatch as their greater width prevents deep hooking and their curved shape reduces external hooking.

Piovano *et al.,* (2009) stress that circle hooks significantly reduce bycatch of juvenile *Caretta caretta* without substantially affecting the target species catch rate in swordfish longline fisheries in the Strait of Sicily.

In the Brazilian longline fishery operating in the Southwest Atlantic Ocean, Sales *et al.,* (2010) showed that the use of circle hooks instead of J-hooks reduced bycatch of loggerhead turtles by 55% and leatherback turtles by 65%. Furthermore, deep hooking was reduced from 25% to 5.8% with circle hooks, thereby increasing survival rate after de-hooking.

As well as reducing bycatch rates and facilitating dehooking, the use of circle hooks decreases light hooking (mouth) and deep hooking (oesophagus) and hence the post release mortality rate. However, circle hooks with significant offset (for example greater than 10°) are likely to behave similarly to J-hooks, increasing the proportion of caught turtles that are deeply (oesophagus) or lightly (mouth) hooked (FAO, 2009).

The working group on reducing sea turtle bycatch in EU longline fisheries (STECF, 2005), drawing on research by Watson (2004) and Gilman *et al.* (2005), noted that different hook shapes did not appear to have the same effects according to the species and that both bait and hook size were probably more important. It concluded that the scientific data were insufficient to introduce circle hooks as an effective mitigation measure.

- **Corrodible hooks**

This type of hook has the same advantages as for sharks (cf. 3.3.1).

- **Smart Tuna Hook**

The Smart Tuna Hook, designed by Hans Jusseit, prevents hooking of seabirds and turtles during line setting by protecting baited hooks with a metal shield, held in place with a biodegradable pin. The shield and the pin are both made of a metal alloy which dissolves, leaving no contaminants in the water. The hook is a modified tuna (or circle) longline hook adapted to the fishery which is attached to branch lines in the same way as standard tuna hooks. The protective shield is fixed manually and does not require any particular skill. Once the hook sinks beneath critical depths (25m for seabirds and 100m for sea turtles), the pin dissolves, the shield falls off and the baited hook is ready to fish.

A recent pilot study, funded by the Australian Fisheries Management Authority, demonstrated the effectiveness of the system using a range of bait (fish and squid) and hook types (Jusseit, 2010) with no effect on setting time. The system was also perceived to facilitate baiting and bait retention down to the required depth, thus increasing the catch of target species.

The use of this kind of system also enables access for fishing vessels to restricted zones and eliminates the need for other mitigation methods such as branch line weighting, Tori lines or night setting; it may also improve fisher safety during setting and hauling manoeuvres.

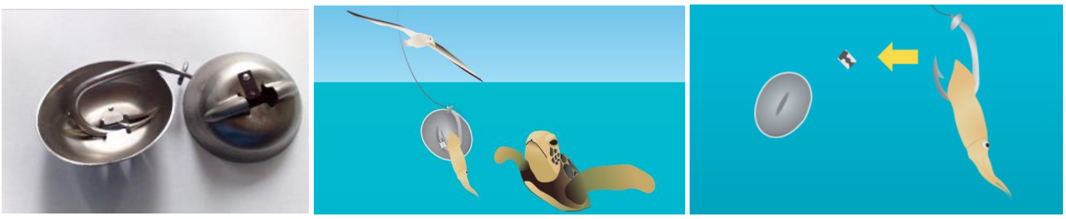

Figure 35 – Smarthook from Jusseit, 2010 http://www.smarthook.net

- ***Bait***

  - **Bait type**

It is difficult to analyse the selective effect of bait as the impact of bait and hook are generally studied together. However, some studies have shown that for certain species, the bait may be more important than the hook, in particular for *Dermochelys coriacea* (Read, 2009).

Various trials (Watson *et al*., 2003, 2005) have shown that bait type is a determining factor in sea turtle bycatch. The texture of squid, considered to be the most effective bait in swordfish fishing, means that it holds more firmly onto the hook and turtles can therefore only swallow it whereas they can easily tear the flesh off mackerel with very little risk of ingesting the hook (fig. 36). The horizontal position of the bait on the hook may have a similar effect without modifying the effectiveness of the longline (Broadhurst *et al.,* 2001). A number of experimental studies confirm that substituting mackerel or other fish for squid reduces the probability of sea turtle bycatch (Yokota *et al.,* 2009; Santos *et al.,* 2012).

Circle hooks and mackerel bait significantly reduced both loggerhead (*Caretta caretta*) and leatherback (*Dermochelys coriacea*) sea turtle bycatch. Replacing J-hooks with circle hooks while substituting mackerel for squid may increase swordfish and bluefin tuna catch and reduce sea turtle and blue shark bycatch (Watson *et al*., 2005)

The impact of changing the bait on other vulnerable species must also be considered (Santos *et al.* 2012). A study of a shallow-water swordfish fishery showed that replacing squid with mackerel decreased the sea turtle bycatch but significantly increased the catch rate of some large pelagic sharks such as *Prionace glauca* and *Alopias 48vulpes* (Coelho, 2012).

- **Dyed bait**

Blue-dyed bait is a way to dissuade birds from taking the bait. However, there is no concrete evidence that this might also reduce interactions between fishing gear and sea turtles. Colour preferences shown in laboratory settings, that is avoidance of blue-dyed bait by loggerhead and Kemp's ridley sea turtles could not be verified in the field (Swimmer *et al.,* 2005). Laboratory trials with loggerhead sea turtles suggest individual colour preferences (Piovano *et al.,* 2012).

- **Location of the bait**

A laboratory study showed that the odds of sea turtles attempting to swallow threaded-baits was 2.5 times greater, probably because they are more difficult to tear off the hook (Stokes *et al.,* 2011).

Figure 36 – a) single bait hooked through the eye (or in the mantel in the case of squid); b) threaded-bait hooked through the eye and body

➢ ***Branch lines***

There is no clear difference in bycatch risk between monofilament and steel branch lines. The monofilament used in surface longline fisheries is less supple than multifilament which has a tendency to loop, significantly increasing the risk of bycatch by entanglement. On the other hand monofilament, being less flexible, disentangles easily when it is no longer under tension (WCPFC, 2014).

In order to avoid tangles, floats were set in pairs separated by 50 metres of blank mainline with no baited branch lines (Beverly, 2004).

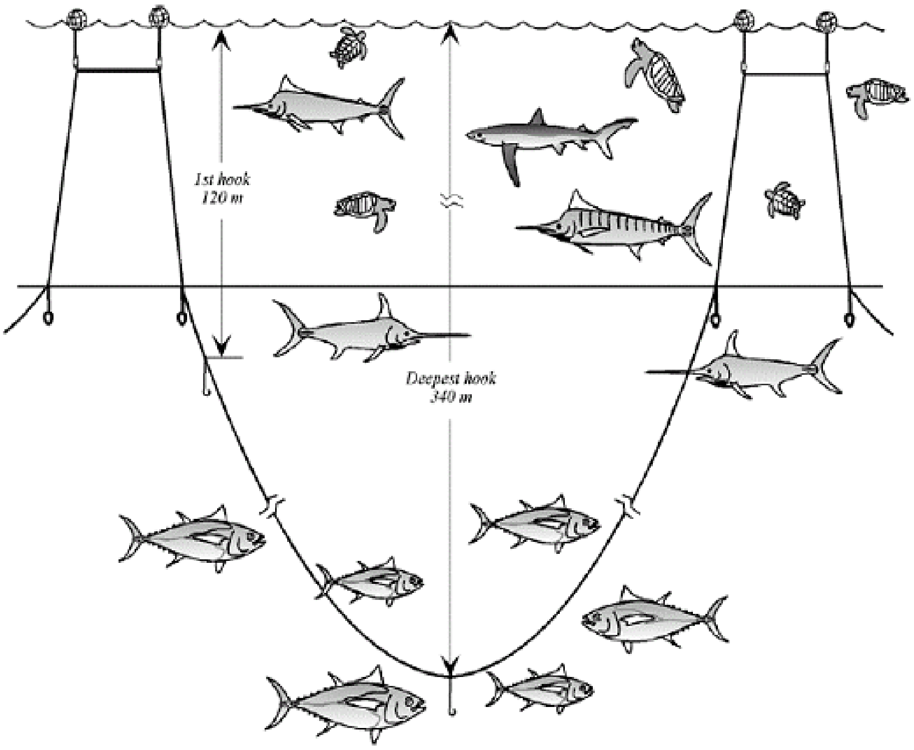

Figure 37 – Illustration of the Smart Gear longline 2005 (Beverly, 2004).

3.1.1. Setting improvements

➢ ***hook setting depth***

Tuna or billfish pelagic longline hooks can be set at variable depths depending on the strategy adopted to catch target species, running the risk of significant bycatch. Even with deep-setting, a good portion of the baited hooks are left in shallow water within reach of sea turtles and non-targeted species.

Caretta caretta are known to spend 90% of their time less than 40 m from the surface (Polovina *et al.,* 2004) and *Dermochelys coriacea* less than 100 m (Hays *et al.,* 2004); in areas where these species are highly abundant, pelagic longlines must be rigged so that hooks are out of reach in order to avoid the risk of bycatch.

Steve Beverly, one of the winners of the international Smart Gear competition (www.smartgear.org), suggested modifying longlines targeting bigeye tuna (*Thunnus obesus*) so that the baited hooks remain below the first critical 100 meters. In order to deep-set the longline, the part of the main line comprising the hooks is attached to long sections of the main line, loaded with 3kg weights at each end and suspended by ordinary floats.

➢ ***Setting time***

Gillman (2011) suggested that the timing of gear setting, soak and hauling may contribute to interactions between sea turtles and longlines. However, this has not been clearly demonstrated as the effects of these parameters cannot be differentiated from those related to depth (Clarke *et al.,* 2014).

In the Mediterranean, line and longline encompass the seasonal activity of small fishing vessels targeting in particular demersal species in the coastal zones and the more specialized activity of some 1 500 vessels over 12m long targeting large pelagic fishes. The soak duration and depth of demersal longlines result in much higher mortality rates than with pelagic longlines targeting bluefin tuna or swordfish. Efforts must therefore first between on avoidance techniques (zone closures, side-setting, deterrent devices, set depth, choice of bait). These measures are equally applicable to demersal and pelagic longlines.

1.1.1 Visual mitigations

- **Luminous lures**

Laboratory experiments on juvenile loggerhead turtles (*Caretta caretta*) showed that sea turtles are attracted by the luminous lures used in longline fishing. They appear to be more attracted by bright green, blue and yellow chemical lightsticks or by orange LEDs (“Electrolume”). However, further research, particularly at sea, is required to confirm these observations and evaluate various strategies that could make lightsticks less attractive or less visible to sea turtles (Wang e*t al.,* 2007). Discussing the effects of light on sea turtles, Wang *et al* (2006) hypothesize that lightsticks generating specific wavelengths might repel them (cf. 2.4.3).

3.1.2. Acoustic mitigations

As mentioned previously, any sound emitted to keep sea turtles away would have the same effect on longline target species (Southwood *et al.,* 2008). There is no real evidence for a possible habituation of sea turtles to acoustic deterrents. It has been noted that loggerhead sea turtles (*Caretta caretta*) submitted to repeated sounds during short periods initially avoided the noise source but fairly quickly grew accustomed to it (Moein *et al.,* 1994). On the other hand, sea turtles may be attracted to the sound produced by longline floats. In order to reduce this interaction, Barton and Ketten (in Brill *et al.,* 2004) proposed studies to determine the sound spectrum and sound pressure levels produced by both hard and soft floats used in longline fishing.

IV. TRAWLS

4.1. CETACEANS

Several studies, mainly in the United States and in Europe, have attempted to resolve the issue of cetacean mortality in pelagic trawl fisheries. They have focused essentially on delphinid (*Phocoena phocoena, Delphinus delphis* and *Tursiops truncatus*) bycatch. Some of the different solutions examined seek to avoid bycatch through dissuasion, using either a system of branch lines placed at the trawl mouth (de Haan *et al.,* 1998) or acoustic deterrents. Other techniques aim to reduce the risk of drowning and use exclusion devices that enable large specimens to escape (de Haan *et al.,* 1998).

4.1.1. Acoustic deterrents

The emission of acoustic signals between 99 and 117 dB at frequencies ranging from 7.5 to 140 kHz is sufficient to keep the harbour porpoise (*Phocoena phocoena*) away from the trawls (de Haan *et al.,* 1998; Kastelein *et al.,* 2007). However, acoustic deterrents are of limited use given the habituation capacity of cetaceans (Zollet and Rosenberg, 2005). Over a variable period, the mammals come to recognize the emitted sound as a signal for available food (the "dinner-bell" effect). Using increasingly more powerful emissions, such as those used in devices to prevent seals from approaching fish farms (the Acoustic Harassment Device that emits sounds at more than 190 dB), has the drawback of probably causing serious auditory damage in cetaceans (Olesiuk *et al.,* 2002).

4.1.2. Exclusion “barriers”

Whilst the results of trials using vertical ropes before the trawl extension (de Haan, 1998) have not been convincing so far, the use of square-mesh barriers placed further forward (the NECESSITY project[4]) at the level of the junction with the large mesh may provide better results. Currently, however, this solution does not prevent enmeshment of dolphins in the barrier or their entanglement in the large meshes of the front part of the trawl (the trawl body).

This problem is difficult to comprehend insofar as trawls are more easily detected than gillnets by cetaceans, which nonetheless appear to find it difficult to escape from the meshes despite their large size (800mm).

4.1.3. Escape devices

Escape devices (BRD or Bycatch Reduction Device), although very effective in reducing bycatch of other megafauna species, have not so far produced satisfactory results for cetaceans.

In an attempt to reduce the significant bycatch of protected species by pelagic trawlers fishing sardinella (*Sardinella aurita*) in the Mauritanian EEZ, a megafauna excluder device (LARD = Large Animal Reduction Device) was positioned before the codend. It comprises a filter grid that forces large non-target specimens downward to an escape tunnel. Whilst rays, sharks and sea turtles nearly all escaped through this BRD, none of the 8 dolphins (*Delphinus delphis*)

[4] http://www.ices.dk/explore-us/projects/EU-RFP/Pages/FP6-NECESSITY.aspx

caught managed to pass through the tunnel excluder (Zeeberg *et al* , 2006 ; De Haan, D., Zeeberg, J.J., 2005).

Wakefield *et al.,* (2017), whilst attempting to improve the escape of chondrichtians, reptiles and cetaceans in an Australian demersal trawl fishery, made subsurface observations which showed that dolphins (*Tursiops truncatus*) enter the trawl deliberately but do not cope well with the high trawling speeds. Despite the presence of an exclusion grid to help them escape, stressed dolphins may try to exit through the mouth of the net and become trapped. This behaviour is a cause of mortality, in particular during trawl-hauling. According to the authors, since 2009 dolphin mortality has fallen between 20 and 59% in this fishery on the Northwest Australian coast through the use of electronic sensors and the avoidance of too rapid hauling of the trawl.

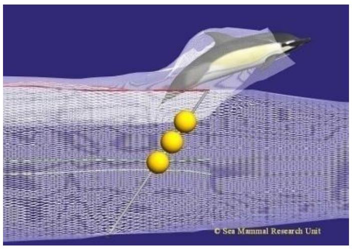

Figure 38 – Escape tunnel for small cetaceans

However, to our knowledge, none of these systems is used in Atlantic or Mediterranean trawl fisheries, mainly due (GFCM, 2012; Sacchi, 2008) to the difficulties experienced in developing and marketing these devices and the low dolphin bycatch rate in pelagic trawls (Fortuna *et al*., 2010).

1.1.2 Alternative methods

Cetacean-fisheries interactions can be minimized by gear modification, time or area closures or fishing practices. Fernández-Contreras et al. (2010) found that if pelagic trawlers only operated in water deeper than 250 m, bycatch of common dolphins could be significantly reduced, and almost entirely avoided if fishing was restricted to waters over 300m. Several studies have found that most bycatches in trawls occur during nocturnal trawling (e.g., Morizur et al, 1999; López et al., 2003; Fernández-Contreras et al., 2010), limiting trawling to only during daylight hours, hauling the gear more slowly during the night, or not setting gear when cetaceans are present would also reduce cetacean bycatch (Read, 2016). (Read & Dollman, 2017).

4.2. BIRDS

In trawl fisheries, birds can be caught and sometimes strangled in the cables pulling the trawl and the netzonde monitor cable (Bartle, 1991; Weimerskirch *et al*., 2000). Large-winged birds are the most vulnerable (CCAMLR, 2006). Bird scarers of the "streamline" type can reduce this risk significantly as long as entanglement in the trawl warps is prevented (Melvin *et al*., 2011).

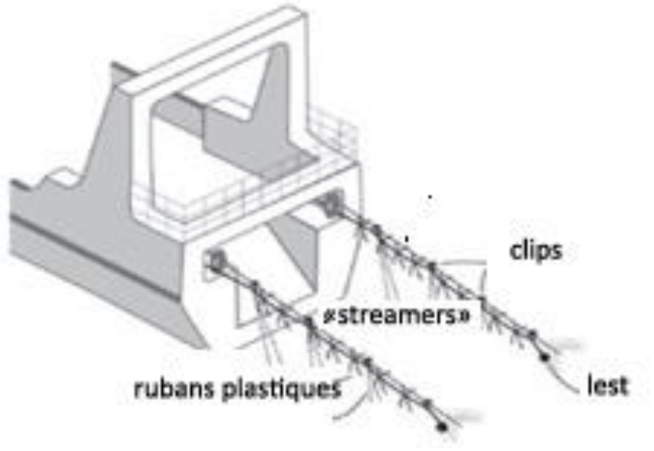

Figure 39 – Bird scarer devices for trawls: streamers are clipped on each of the two warps. They are weighted and comprise a series of plastic ribbons (Bull, 2009).

4.3. SHARKS

Towed by one or two boats, pulled on the bottom or in mid waters, trawls are responsible of important by-catch and mortality of various species of elasmobranchs. Trawlers targeting small pelagics with their very large vertical opening trawl can occasionally catch one or two pelagic sharks n (*Prionace glauca, Alopia vulpes, Isurus oxyrinchus*). On the other hand Although never targeted, selachians can be a significant part of the bottom trawling; with large discards quantities of small species (*Scyliorhinus canicula, Mustelus spp., Galeus melastomus, Etmopterus spinax,* etc.) and juveniles, particularly for deep shrimp and Norway lobster fisheries

1.1.3 Fishing gear improvements

➢ ***Tickler chains***

In the mixed-species bottom-trawl fisheries of the North Atlantic, catches can be increased by fitting a length of chain known as a “tickler” in front of the groundgear of the trawl; Kinoch et al., (2015) demonstrated that the catch rate of skates and sharks can be significantly lowered by removing the tickler

➢ ***BRD***

Adapting the bycatch reduction devices (BRDs) used for sea turtles would be an effective means of reducing shark mortality rates by allowing them to escape during trawling. Successfully tested in Australian fisheries, these escape systems placed before the codend, comprise a rigid filter grid that forces sharks and rays downward to an escape tunnel. Some of these systems, such as the Nafted or the Super shooter, work as well for sharks and rays as for sea turtles. Brewer et al. (2006) evaluated the effect on different combinations of turtle exclusion devices (TED) with by-catch reducing device (BRD) in shrimp trawling operations in northern Australia and showed that trawls equipped with this technology captured far fewer large species. sharks (86 to 94%) (more than one meter long).

Brčić *et al.* (2015) showed that, with appropriate adaptations, these BRDs may represent a reasonable compromise between the escape of sharks (*Galeus melastomus*) and the economic loss due to reduced catch of the target species (*Nephrops norvegicus* and *Phycis blennoides*).

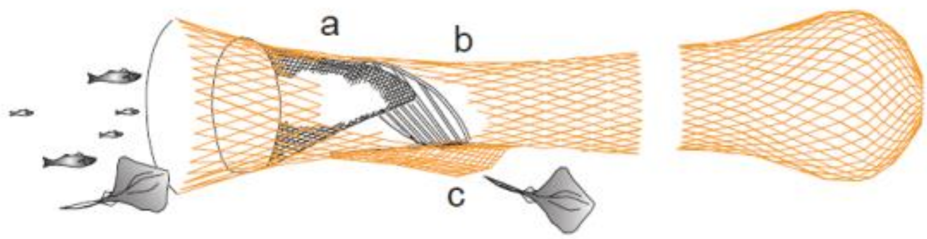

Figure 40 – Selective device enabling benthic species (rays, sharks) to escape through an outlet placed on the lower part of the net extension before the codend ©.

Tested in the trawl fishery targeting Atlantic seabob (*Xiphopenaeus kroyeri*) off Surinam, the combination of a square-mesh panel and a turtle exclusion device (TED) of the super-shooter type may increase considerably the escape of large rays such as *Dasyatis geijskesi* (77%) whilst the reduction in catch of smaller species, such as *Urotrygon microphthalmum*, is less significant as their morphology enables them to pass through the grid towards the codend. The escapement rate of medium-sized species, which are the most abundant such as *Dasyatis guttata* and *Gymnura micrura*, depends mainly on their size (Willems *et al.,* 2016)

In the study cited above (Wakefield *et al.,* 2017) that compared the escapement behaviour of different megafauna species, 1 320 hours of observation showed that most of the specimens that had escaped were demersal sharks (80%), rays (66.3%) and hammer sharks (57.1%). Whilst all types of BRD suit most demersal chondrichthyan, BRDs placed on the upper part of the trawl are 20 to 30% more effective for benthopelagic species.

1.1.4 Setting improvements

Except for restrictions on access to spawning and nursery areas, there are no preventive measures that would enable shark capture by trawls to be avoided.

4.4. SEA TURTLES

All trawling fisheries can have sea turtles by-catch but the most impacting trawling fisheries are those that target shrimps on tropical continental shelves. Mortality caused by trawlers depends mainly on hauling time and depths.

Apart from a few vessels targetting small pelagics in the Adriatic, the Gulf of Lions and the Black Sea, most Mediterranean trawling targets demersal species on the continental shelves. According to the literature, pelagic techniques appear to be little affected by the issue of protected species' bycatch, but demersal trawling in the coastal zone is responsible for sometimes substantial catches of sea turtles in the wintering and breeding grounds.

4.4.1. Fishing gear improvements

➢ ***Turtle Excluder Devices (TEDs)***

TEDs have proven their efficacy in most shrimp fisheries and have been adopted by several countries and enforced in their fisheries. Their choice depends on local fishing conditions and the dimensions of the trawler (clutter on the fishing deck). They may be either a soft turtle excluder device (of the Morrison type) or a hard device (of the Super Shooter type) used preferably when there is an important risk of bycatch and debris clogging. These devices are fixed in front of the codend on the upper or lower part of the trawl body, depending on the species. Made compulsory in Australia in March 2006, the use of BRDs (grids and escape outlets) in trawls has led to a significant reduction in sea turtle and dolphin mortality (Stephenson *et al.,* 2008; Mckay, 2011).

BRDs can be used if they are not too cumbersome and too difficult to handle on small-sized vessels such as those of Mediterranean fleets especially if they do not cause a significant reduction in the commercial catch. Boopendranath et al., (2010) propose for artisanal trawlers a range of soft BRDs made with the minimum use of rigid parts. The development of flexible or pliable high-density polymer is also promising in terms of reducing sea turtle bycatch in areas of high concentration or large debris such as the shallow coastal waters (<100m) of the Northern Adriatic (Luchetti et al., 20016).

Recent studies have shown that TEDs may be an effective way of reducing accidental catch when the trawling impact on protected species is significant (Atabey & Taskavak, 2001; Lucchetti et al., 2008; Biton et al., 2010; Fortuna et al., 2010; Sala et al., 2011). These devices may also enable small specimens to escape without significantly affecting the catch of the target species whilst eliminating large objects such as pieces of wood and concrete blocks (Lucchetti et al., 2008; Lucchetti and Sala, 2010; Bitón et al., 2011).

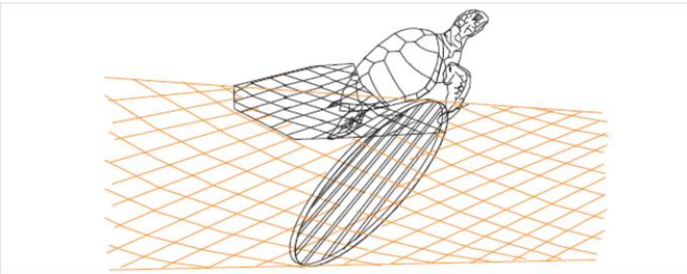

Figure 43 – Escapement outlet placed on the upper face of the trawl body for sea turtles to escape (Sacchi, 2008)

4.4.2. Setting improvement

➢ ***Tow duration and depth***

When caught by a trawl, sea turtles can, if the tow duration is too long, drown by forced apnea or become comatose and die later (Casale, 2008). Tow duration is therefore one of the main causes of mortality (Henwood and Stuntz, 1987) and decompression sickness may occur if the trawl is hauled too rapidly (García-Párraga *et al*., 2014).

➢ ***Season***

Mortality has been found to be higher in the winter than in the summer (Sasso and Epperly 2006) probably depending on the seasonal biological cycle.

- ***Depth of the set***

Atabey and Taskavak (2001) found that most of the catch occurred at depths between 11 and 30m, in particular when the trawling activity took place in coastal areas inhabited by sea turtles (during the dormant phase or in search of food in the demersal phase).

V. PURSE SEINES

Purse seines are mobile gear designed to catch schools of pelagic or mid-water fishes by surrounding them. Purse seines usually consist of a long wall of netting framed between a lead line and a float line, that a purse line can close the bottom. Various configurations are existing depending on the target species and the country. Vessel targeting small pelagic fishes use generally lights to concentrate fish schools before encircling them. Tuna purse seiners fish either by spotting free-swimming schools of tuna or by utilizing floating objects to attract fish, called fish aggregating devices (FADs). When fishing on free-swimming schools, purse seine fishing has an average bycatch rate of less than 1 percent. When utilizing FADs, bycatch rates vary from around 1.75 percent in the western and central Pacific to nearly 8.9 percent, depending on the ocean region (ISSF)[5].

5.1. CETACEANS

Interactions between dolphins and purse-seine fisheries have been abundantly reported in the available literature; either for tuna purse seine fisheries (Hall and Roman, 2013); Hamer, 2012; Donahue and Edwards, 1996) or for small pelagic fisheries (

The development of purse seining in the 50's in East Pacific Ocean on tunas associated to dolphins herds had the unwanted consequence to incidentally kill many dolphins; The mortality was as not sustainable, as most dolphin populations declined until the late 1970s. Faced with the importance of this problem, US purse seining industry was requested to find mitigating solutions or to give up this fishing technique for other alternatives (Hall, 1998).

In the Atlantic and Indian oceans, tuna purse seiners can set around tuna schools associated with whale sharks and baleen whales, although less frequently than around free-swimming tuna schools or around fish aggregating devices, this technique may lead to incidental during at least during the difficult maneuvers to release these great individuals from the encircling gear. Nevertheless, Escalle et al. (2015) show that whales escape unharmed in the majority of the sets according to the observer reports and observed by electronic tagging few mortalities as consequences of these interactions (Escalle et, al, 2019).

About FAD purse seining, the rough-toothed dolphin (Steno bredanensis) which may be associated with floating object is occasionally captured in some FAD sets (Hall and Roman, 2013).

Unlike the Eastern Pacific tropical tuna fishery, the Mediterranean bluefin tuna fishery does not entail cetacean encirclement and does not result in a significant catch of these mammals. Whilst there are occasional catches of a few *Stenella coerulea, Delphinus delphis* or *Globicephalus maleana,* these very rarely result in death (di Natale, 1991; Silvani *et al*, 1992). As fishing is during the daytime, animals can be released alive with more or less difficulty according to their size.

[5] https://iss-foundation.org/about-tuna/fishing-methods/purse-seine/

At the opposite, interactions between marine mammals and purse seiners targeting small pelagic fishes are more frequent. As dolphins searching for their main food source compete with this activity, they can be caught occasionally but the mortality rate is low.

Depredation of sardine purse seines by some cetaceans is more of an issue. This problem appears to be widespread in the Mediterranean, in Greece, Italy (Lauriano *et al.,* 2009), Morocco (*Abid et al.,* 2002), Tunisia (COPEMED, 2004; Benmessaoud, 2008; Ben Naceur, 1998) and in the Atlantic regions where purse seining is widely used, for instance in Portugal (Marçalo *et al.,* 2011; Wise *et al.,* 2007) and in Galicia (Goetz, 2014). This depredation results in the dispersion of small pelagic shoals during setting of the net and in particular causes significant tears in the purse seines.

Abid *et al.,* (2002) note that the species most involved in depredation in the Moroccan seine sardine fishery in the Mediterranean is the bottlenose dolphin (*Tursiops truncatus*). According to these authors, foraging occurs when the encircled shoal of sardines crowd against the seine. Although most of the tears occur in the lower part of the seine (Zahri, 2004), recent studies undertaken in Morocco and Tunisia show that the whole net can be affected.

➢ *Fishing gear improvement*

• Backdown and “Medina” panel

To reduce dolphin mortality in EPO purse seining fishery, one of mitigating solution was the development by tuna fishers of a maneuver called the “backdown”. As soon as a group of dolphins is encircling, the purse seiners goes into reverse and pulls the net. The purse seine while lengthening causes the corkline to sink so the dolphins can exit the net through the opening. The “Medina panel” consist of small-meshes webbing set in the part of the purse seine with which dolphins most often come in contact, helps to keep them from entanglement and to increase the sinking of the corkline.

• Net strengthening

For over three decades, the Mediterranean sardine fisheries in Tunisia and Morocco have been affected by a growing problem of depredation by *Tursiops truncatus* resulting in a significant loss of income and increase of expenses. Biting small pockets of enmeshed sardines, results in numerous holes in the webbing claiming expensive mending and vessel downtime. In the framework of the “Project on mitigating the interactions between endangered marine species and fishing activities” (funded by MAVA and coordinated by-ACCOBAMS-CGPM) one proposed action is the reinforcement of the threads of the most weakness parts of the purse seine to increase their resistance to the attacks of the Bottlenose Dolphin (Tursiops truncatus). First trials of a modified purse seine have been started in 2018 for the Moroccan fishing fleet with promising results.

➢ *Acoustic or visual mitigation*

Banging the hull, fireworks, laser are usually employed by fishers to deter dolphin during the purse seining operation in sardine fisheries but with unequal success.

For reducing depredation in Moroccan and Tunisian sardine purse seining fisheries, acoustic deterrents have not yet provided sufficiently reliable evidence of their effectiveness, at least for Tursiops truncatus.

In north-east of Tunisia, pingers (Aquamark 210) were used as deterrents of bottlenose dolphins interacting with purse seining for small pelagics. The experiments carried out from June to November 2010 showed limited and irregular reduction of dolphin attacks (given by comparing the number of rips) with the use of pingers (Benmessaoud, 2018; 2008).

In Morocco, 3 types of acoustic devices from the same company (SaveWave) with different configuration were tested in 2005 and 2010 without significant results; at the beginning, the experiment of the deterrent effect was effective but it was gradually attenuated as if dolphins accustomed themselves to the signal. One another device the DDD H3 from STM was tested by Moroccan fishers without getting satisfying results (Najih et al., 2011.

Pinger failure, difference in fishing techniques or bad experimental conditions can be the causes of irregular results but most part of users point out an additional problem of habituation to signals. The use of new products generating random frequencies and pulse times could delay this behavior and reducing depredation but do not avoid it completely.

➢ ***Saft release***

Sardine purse seining for occurs essentially at night so detection of cetaceans near the purse-seiner are very difficult. Dolphin entering in a purse seine can be detected after hauling begins, or eventually during pursing. Such as in Portugal fishery, each encirclement involved generally only one animal and technical processes such the “backdown maneuver” as that cannot be envisaged without costly changes in the seine. The current approach (unfortunately commonly used in other fisheries) to release them, include putting a rope around the animal’s peduncle and lifting it with the crane to release it from the net (potentially causing both stress and injury to the animal), added to the vessels’ high edges that make the operation very difficult.

Marçalo et al., (2015) suggest to give priority to seek ways to mitigate operational interactions with cetaceans to avoid encirclements and to improve release techniques and develop new release techniques (e.g. development of simple tools such as a “dolphin release stretcher” that not only will decrease the physical trauma to the cetacean, but also reduce time that the fishers uses to release the animals).

5.2. BIRDS

A survey of Portuguese fishers showed that purse-seine fishing could incidentally catch seabirds (Dunn and Nemcova, 2010). Most purse-seine fleets targeting small clupeids use light sources to attract the shoals at night before encircling them. During these fishing operations, birds foraging for fish can be attracted and become enmeshed. This problem mainly affects the Balearic shearwater, which is on the brink of extinction, the northern gannet, the Cory’s shearwater and the great cormorant (ICES, 2013). Purse seiners operating on the breeding and feeding grounds of endemic species may cause occasional but significant bird mortality (Arcos et al., 2008; Schlatter et al., 2009). Purse seining for small pelagic fishes has also been accused of causing food dependency, similar to that observed with marine mammals, that may lead, for example, to the expansion of these species at the expense of other bird populations (Sacchi, 2008).

1.1.5 Setting improvements

There is little information on incidental bycatch of birds by purse seine techniques.

Large numbers of flesh-footed shearwaters (*Ardenna carneipes*) have been caught in a Western Australia purse seine fishery targeting pilchards. This bycatch occurs when fishing effort is in close proximity to breeding grounds and when birds are provisioning chicks. Baker and Hamilton (2016) show that fishing at night and spatial closures could eliminate seabird bycatch in the fishery. Additional mitigation measures are being explored as water spraying to sink the float-line and create a buffer between the top of the net and the water surface, improving the net retrieval phase have been successful in greatly reducing seabird interaction levels in the Western Australian fishery.

Modifying purse seine nets in Chile seems to offer a promising new way to reduce by catch of Pink-footed Shearwater (*Puffinus creatopus*); first experiences carried out by the Albatross Task Force (ATF), reduced bycatch of birds diving and entangled in the purse seine by 98 percent (not yet published Birdlife; sept 2018).

5.3. SHARKS

Although little information on shark bycatch in purse seining is available in the Mediterranean, we can assume that some species such as *Prionace glauca, Alopias vulpes* and dasyatidae are occasionally caught during bluefin tuna or small pelagic fishing trips. Their large size and low commercial value mean that the individuals caught are often released before the catch is hauled onboard.

On the other hand, to capture tunas, some purse seine vessels use FADs, floating structures that attract fish (Bromhead et al. 2003) and can result in a large amount of shark bycatch. Tropical tuna purse seine fisheries do catch sharks, mainly silky sharks (*Carcharhinus falciformis*), which are lured by the FADs and die by entanglement. Although little research has been conducted on shark bycatch mitigation in purse seine fisheries, there are a few promising ideas, including ecological FADs, deterrents, restrictions on set times, restrictions on sets on FADs and other floating objects, and avoidance of sharks.

- ***Excluder device***

An experimental release panel was installed in purse seine nets to determine their ability to release both silky sharks (*Carcharhinus falciformis*) and non-target finfish. The release panels (5.5 m wide, were installed in a portion of the net that forms a "pocket" toward the end of net retrieval. Tests were carried out during seven purse seine sets, but only two silky sharks (out of 105) exited through this panel. Despite this initial failure of the release panel, the authors feel refinement of the panel and additional testing is still warranted. (Itano et al., 2012).

- ***Ecological FADs***

to reduce the potential entanglement of sharks, new FADs are designed with a smaller stretch purse seine mesh net hung from them Preliminary tests have resulted in no bycatch of sharks (Schaefer and Fuller 2011).

1.1.6 Setting improvement

Restrictions on set times, on sets on FADs and other floating objects areas are useful management measures when technical solutions are insufficiently efficient to reduce by-catch on vulnerable selachians. Pacific Island nations have recently adopted a management measure that prohibits purse seine fishing around whale sharks (FFA 2011).

➢ ***Acoustic and chemical mitigation***

Various ideas that have been proposed for deterring shark bycatch include bait stations and the use of sounds and chemicals that could lure sharks away from FADs before the set is made, therefore reducing incidental capture of sharks (Dagorn 2010, Kondel and Rusin 2007). Preliminary studies investigating the feasibility of deterrents are currently being conducted in areas such as the eastern Pacific Ocean (Kondel and Rusin 2007).

Safe Handling and Release

Releasing large animal from a purse seine after encirclement is difficult to do during the fishing operations. Poisson et al., (2012, 2013) underline in a leaflet of good practices for fishers detrimental conditions that sharks and rays are exposed during purse seining operation, from the purse seine to the deck before to be released at sea. They consequently recommend to avoid the use of hooks, wires or tightening slings; lifting or dragging by the gill slits or cephalic lobes and propose some simple technical ways to reduce risk of mortality after release. These techniques need some deck management and training for the crew.

Whale shark (*Rhyncodon typus*), is particularly vulnerable species owing to its biological characteristics (slow growth, late maturation, great longevity); it can be occasionally encircled in tropical tuna purse-seine. scientific onboard observer programmes and satellite tags results suggest good chance of survival when they released with one of appropriate methods: cutting the lacing between the corkline and net or the net itself may be the safest way to release a whale but; nevertheless, rolling the shark out of the bunt end of the net is generally a more acceptable and safe for the fishers . (Escalle et al., 2016).

5.4. SEA TURTLES

Incidental catch of sea turtles concerns essentially tuna purse seining. When sea turtles are encircled in a purse seine, they may be released by hand, or they may become entangled in the net meshes, usually by their claws. If they are entangled in the net, it is easy to free them. An additional risk factor for sea turtles is the entanglement in the netting materials suspended under the FADs to attrack fish.

In the Mediterranean, only the dolphinfish (Coryphaena hippurus) fishery uses this under-raft attraction technique (“kannizzati”), mainly in Malta, Tunisia and the Balearic Islands, but no information is available on sea turtle bycatch.

Generally speaking, whether in bluefin tuna or small pelagic fisheries, Mediterranean purse seine metiers are characterized by low bycatch and discard rates with the target species representing over 90% of the catch (Tsagarakis et al., 2012). Incidental catch of sea turtles in seines is therefore negligible and most likely to be reported in high concentration areas such as the Eastern Mediterranean (Levy et al., 2015). Sea turtles may also become entangled in the seine meshes and damage their fins or shell during hauling. However, in most cases, if they are quickly removed from the net, they can be released alive and undamaged

- ***Fishing gear improvements***

In order to reduce the risk of entanglement of sea turtles and sharks, the International Foundation for the Sustainability of Fish and Seafood (ISSF) recommends the use of ecological FADs with hanging panels of nets without large mesh that can entangle entanglements of animals; to reduce entanglement of turtles on the FAD itself, the surface structure should not be covered or only covered with a mesh material where the turtles can be trapped. If the surface structure is covered, log-shaped (cylindrical) or spherical floats naturally deter turtles from mounting on the device and should be used in preference to flat rafts. In addition, FADs should be made as much as possible from biodegradable materials to reduce ghost fishing problems when they are lost or abandoned. (Restrepo et al., 2017).

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VI. TRAPNETS

Trapnets as Turkish Dalyan, Italian tonnara, Japanese kaky-ami, pound nets, fyke-net, stow nets, are fixed fishing gear that usually consist of one or two barriers or fences ("leader", "wings) guiding the fish to a final compartment ("chamber, trap or pound") in which the fish cannot escape. set they usually target migrating schools of mid-waters or pelagic fishes swimming in estuarian or coastal waters. Anchored to the bottom perpendicular to shore the netting usually reaches above the waterline; the final compartment is either covered or open air. Under its different configurations, trapnets are responsible of harmful interactions with protected species such as collision, entanglement in the nets of the" leader" or entrapment in the pound which may be fatal for the animals.

1.2 CETACEANS

In Newfoundland and Labrador, Lien et al., (1992) observed that humpback whales (*Megaptera novaeangliae*) frequently collide with inshore fish trapnet due to an inability to detect the presence of the net. In the Kattegat and Baltic pound nets, harbour porpoises sometimes get trapped or entangled but are often released alive (CEC, 2002b).

1.2.1 Fishing gear improvements

➢ ***Mesh size effect***

Todd (1991) found that traps using smaller mesh size (as capelin trasp) have less collisions than trap with large meshes as cod trapnets.

1.2.2 Acoustic mitigation

Lien et al., (1992) tested on cod trap an acoustic alarm producing a 3 or 6s sound at 4kHz peak frequency with intensity of 135 dB (re 1µ Pa at 1 m with a significant decrease in collision and entrapment rate of whales without any reducing target species (cod) catch during the test period.

If pingers offer possibilities to deter dolphins from trapnets, the reactions of whales to acoustic repellents are of variable effectiveness. in Australia, while southward migrating humpback whales exhibited aversion behaviour to acoustic stimuli (Dunlop et al. 2013), northward migrating whales showed no detectable response to pingers (Harcourt et al. 2014; Pirotta et al. 2016). If there were indications that pingers could potentially deter grey whales (*Eschrichtius robustus*) from high risk coastal areas, although results were inconclusive due to low statistical power (Lagerquist et al. 2012).

1.3 BIRDS

1.3.1 Fishing gear improvement

➢ ***Escape windows***

Bundgarn is a type of pound net used in Danish, German and Swedish Baltic Sea to catch migrating fishes as herring, mackerel, cod, garfish and eel (Gabriel et al.200; Andersen et al.2006). Because these trap nets, are set in shallow waters, cormorants and herons are attracted by concentrations of fish and can drown if the catching chambers are closed on the top or equipped with fyke net aft ends (Erdmann et al., 2005). The use of escape windows is suggested to avoid this type of bycatch (ASCOBANS, 2012).

- ***Visual or mitigation***

Common loons (*Gavia immer*) are caught in commercial trap net fisheries in the Great Lakes (Evers 2004). Trap nets with their strung-out wings of netting have a similar problem to gillnets with entanglement. Loons which are attracted by fishes in the trap net dive on the net where they are entangled and often drown (Evers 2004).

In this such case visual mitigation devices as "warning net panels" used for gillnets can be relevant solutions.

1.4 SHARKS

Literature give little information on the incidental capture of selachians by trap nets except those used for tunas.

The Mediterranean tuna traps (matanza, almadraba) incidentally catches some specimen of large selacians as thresher shark (*Alopias vulpinus*), basking shark (*Cetorhinus maximus*), blue shark (Prionace glauca), sea devil (*Mobula mobular*) and sometimes great white shark (*Carcharodon carcharias*) (Vacchi et al., 2002; Hattour et al., 2005; Sorai et al., 2011; Bradai et al., 2012). The tuna traps bycatch events are but they are insufficiently reported considering the depletion of their population in Mediterranean sea.

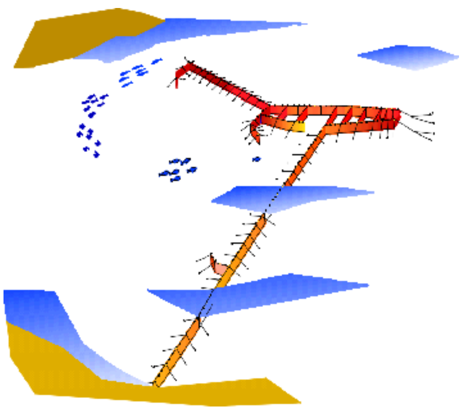

Figure 7 Tuna trapnet

1.5 SEA TURTLES

1.5.1 Fishing gear improvements

A fyke net consists of cylindrical or cone-shaped netting bags mounted on rings or other rigid structures. It has wings or leaders which guide the fish towards the entrance of the bags. This type of fish trap is used in inland waters, in Mediterranean laguna or in estuarians. Sea turtles can be caught inside the fyke net or entangled in one of the wings. Fratto et al., (2008) designed and tested for Wisconsin-type fyke nets, a bycatch reduction device (BRD) which reduce turtle bycatch without affecting fish capture. the BRD was consisted in four lines added in the vertical gap of the net. Similar modifications are tested on fyke net used in inland fishery in Southeastern Ontario using exclusion bars attached on the first hoop of the net (Laroque et al., 2012).

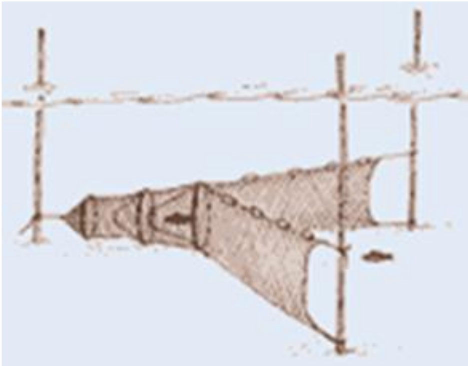

Figure 8 fyke net

- **Trapnet Leader modification**

In Chesapeake Bay, pound nets are responsible for 3 to 33% of stranded turtles in the Bay (6-165 turtles annually), most of which are loggerhead and Kemp's ridley turtles. Most observed turtle captures have been in the upper 3m of large mesh(>30cm) or string leaders in strong currents areas (De Alteris and Silva, 2007).To reduce this risk of mortality De Alteris et al., (2007) tested a modified leader made of vertical ropes and netting based on the assumption that pelagic fishes would be guides by vertical lines toward the bag net whereas turtles would pass through the gaps between the ropes. Comparison with commercial leader indicated a substantial reduction in turtle interaction.

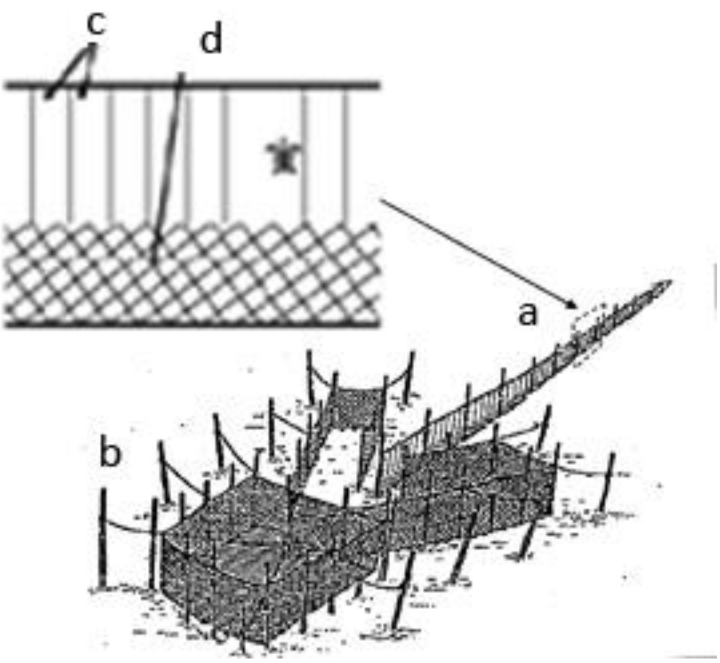

Figure 9 experimental leader modification in a pound-net; a) leader; b)pound; c) vertical ropes; d) mesh panel (froù DeAlteris and Silva, 2007).

- **Excluder device**

In Japanese pound Net Fisheries, small sea turtles (SLC of about 56 cm) have been observed to be captured within pound net capture chambers (pound or trap) and also entangled within the pound net leader.

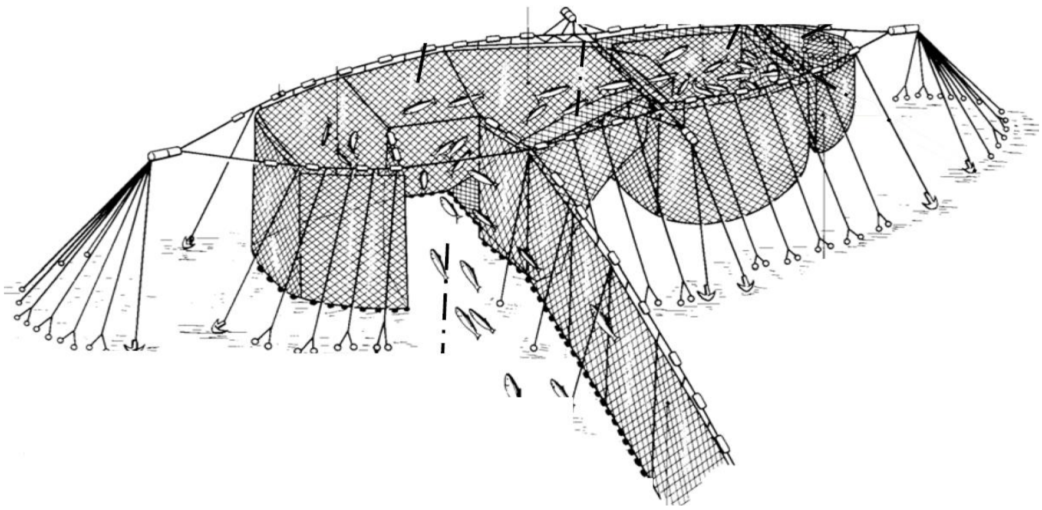

Figure 10 Japanese set-net

Observations reported by Ishihara (2007) support that Japanese pound nets with an open pound will result in substantially lower sea turtle mortality levels than those with a closed pound. Research conducted on Japanese large pound nets, reported by Takahashi et al. (2008) and Abe and Shiode (2009), found that use of a rectangular, pyramid-shaped pound with a top angled at 20 degrees toward the apex may be effective at directing turtles to an excluder device with a small amount of escape of fish. The pound in this fishery is cone shaped, 10 m long, 1.3 m wide. A 40 x 50 cm hole was made in the upper portion of the cone in the pound and a hinged flap was installed over the hole. The excluder device was designed to automatically close after a turtle pushes through the flap by making use of the tension in the net used to maintain the pound's cone shape.

VII. POTS

Pot called also Trap is the simplest and probably one of the most ancient trapping fishing gear that allow fish to enter into them and then make it hard for them to escape [6].

Designed in the form of cages or baskets, they are built generally to catch crustaceans, mollusks but also fish. Their impact on protected species is on due to their catch mode but on their setting mode. Usually set on the bottom, single or in strings connected to a mainline system), they are attached by a rope (mooring line, buoy line, dahnline) to a buoy on the surface of the water. This vertical line is responsible of entanglement of leatherback turtles, or entangle marine mammals. Too long or too slack they can form loops able to entangle marine mammals or leatherback turtle.Improvements here proposed are obviously valuable for any setting gears as gillnets, bottom longlines and anchored FAD.

➢ *Buoy rope modification*

Entanglement in the buoy lines of set nets and of any gear set for several hours (pots, longlines) can be another cause of cetacean bycatch. As shown by Knowlton *et al.* (2015), this can happen in a variety of ways, mostly through entanglement of the fins, the mouth (Mysticeti) or the tail. The main technical reason is excessive rope length resulting in loops in the upper water layer. It is therefore generally recommended to use sinking ropes for the upper 2/3 of the buoy lines and weighted branch lines between the anchor points and the end lines (Johnson *et al.,* 2005).

Generally, buoy line ropes should have a breaking strength sufficient to withstand the hauling of fishing gear in normal fishing conditions whilst allowing a large cetacean to free itself without too much difficulty in case of entanglement. For example, Knowlton *et al.* (2016) showed that the broad adoption of ropes with breaking strengths of 7.56 kN (for example polypropylene with an 8 to 10mm diameter) could reduce by at least 72% the number of life-threatening entanglements for large cetaceans (*Eubalaena glacialis, Megaptera novae angliae*), the large whales in the east coast fisheries of the United States and Canada.

➢ *. Weak links*

The intent is to allow fishers to use them normally for fishing but to allow a large whale to break free if entangled. To this end, various solution are proposed (Werner et al., 2006) as weak links (swivels, check stoppers) connecting the set gear (gillnet, or pots) and the marker buoy line that would break under any pressure maintained longer than the time required for hauling the gear and end lines help free entangled animals (Landry et al., 1955; Knowlton et al., 2016). A range of various solutions is pr Another weak link technique utilizes Rope Of Appropriate Breaking Strength is provided by NOAA Fisheries Greater Atlantic Gear Team.

[6] Fishing Gear types. Pots. Technology Fact Sheets. In: *FAO Fisheries and Aquaculture Department* [online]. Rome. Updated 13 September 2001

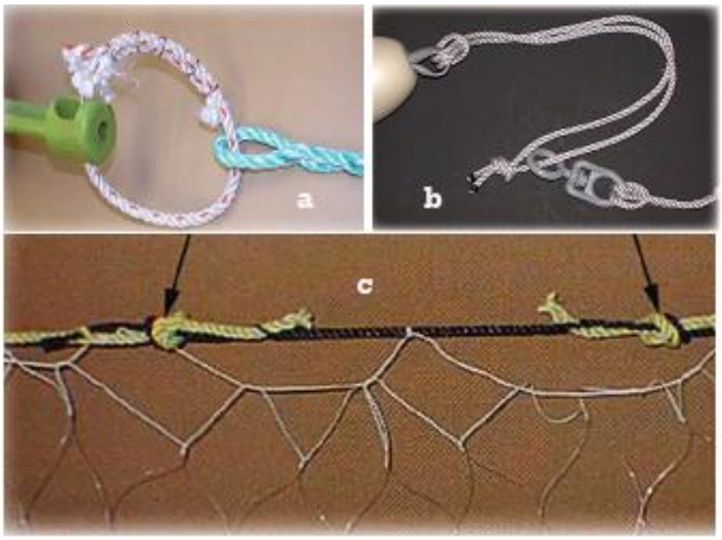

Figure 11 weak links : a); Hog rings can be used to form an eye in the end of a line that will function as a weak link; b):using an "off the-shelf weak" link c): a weak links tied into the float rope with the fi sherman's knots reducing the strength of the rope to about 60% of its original strength (Atlantic Large Whale Take Reduction Plan Weak Links & Anchoring Techniques from NOAA gear teams Contact Us For (www.greateratlantic.fisheries.noaa.gov/whaletrp)

- ***Galvanic Time Release (GTR)***

The more the buoy rope of set fishing gear stays at sea the greater the risk of entanglement of a whale increase. To reduce this risk, the industry proposes various solutions combining coiling line and time release devices. the most sophisticated is proposed by the "Rope-Less Consortium" [7] with the use an acoustic and electronic control system. More simply galvanic swivels can be used to tauten the buoy ropes when they are set [8] (Werner et al., 2006).

First designed to avoid ghost fishing by pots the GTRs consists in anodes joining together two stable metal eyelets which function as cathodes which disintegrate in sea water at a specific time, allowing to release whatever was being held together.

Moreover, these delayed-release devices are an effective way to reduce the risk of incidental catch by nets that have been abandoned or have excessive soak time.

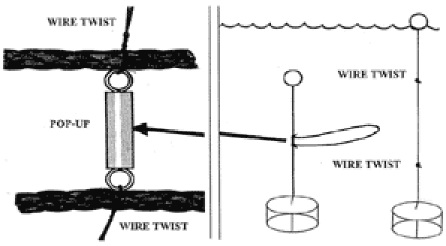

Figure 2: Galvanic time release

[7] https://ropeless.org/background/
[8] http://neptunemarineproducts.com/ghost-fishing/

➢ ***Rope visibility***

The idea of making buoy and branch lines more visible to the megafauna at night or in the darkness of the deep led to the testing of different coloured or luminescent ropes. According to the initial trials undertaken in Cape Cod bay (United States), red, orange or white and green ropes appear to be the most easily detected by cetaceans (Kraus *et al.,* 2016).

Adding a luminescent substance to the composition of the polypropylene in the ropes produces a yellow-green brilliance in the wavelengths detectable by large cetaceans (*Eubalaena glacialis)* at a distance of about twenty metres for around 48 hours; the fabrication process is currently hampered as it is difficult to maintain this luminescence for longer than this and also after the rope has been handled a few times (Werner *et al.,* 2006).

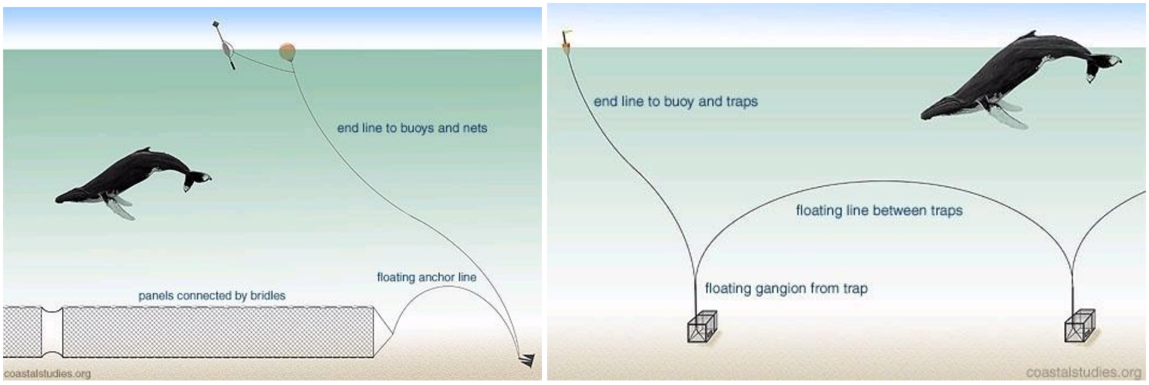

Figure 3 – Main cetacean entanglement risks in the buoy lines of fixed fishing gears.

VIII. Non-technical measures for reducing bycatch

Since fishing effort determines the level of commercial and incidental catches, the use of mitigation techniques must be accompanied by fisheries management measures such as the limitation of the number of fishing units and the number of fishing units. fishing gear, reduction of the duration of operations, seasonality closures of sensitive areas or changes in harvesting techniques and even fishing activities.

For Melvin et al. (1999), the combined use of gear changes, abundance-based fishery openings and hourly restrictions can reduce seabird bycatch by up to 70-75% without reducing commercial catches.

Fishing effort restrictions in an artisanal fishery are constrained by the need to maintain a minimum catch for the fishers concerned, otherwise this effort could switch to other fishing techniques with possibly more serious consequences.

For instance, Monkfish fisheries which have high bycatch ratio of sea turtles and marine mammals (e.g US East coast monkfish set net fishery quoted in Wiedenfeld et al. 2015) need soak time for several days; so in this case changing soak time not a feasible option for the viability or these fisheries.

Changing technique is often seen as a satisfactory mitigation measure in the multi-specific and polyvalent Mediterranean fisheries where it is much easier to implement than in highly-specialized. However, a pre-condition is to prevent the potential consequences of a change in technique in terms of the risk of catching other vulnerable species or of having a negative socio-economic impact if the new mitigation measures prove to be more costly and more restrictive than previous ones.

The substitution techniques selected should be those having available several tried and tested mitigation methods. Gillnetting is the most common fishing technique in small-scale fisheries and unfortunately present few possibilities of technical modification. On the other hand, pots and traps, longlines could be sometimes judicious alternatives to gillnet or trammel if operated in such a way as to maintain their profitability. To a lesser extent, lines and longlines also experience depredation and bycatch problems but they have the advantage of having several tried and tested solutions available.

The temporary closure of protected zones and restrictions on fishing effort are also effective tools to reduce protected species' bycatch, in particular in the areas where, and during the periods when, the bycatch risk is significant (Murray *et al*. 2000 ; Cambiè, 2011 ; Lewison *et al* .,2014 ; Van Beest *et al*., 2017) particularly in set-net fisheries (Childerhouse, 2013). They require a spatial and temporal definition of areas at risk using an overlay map of fishing activities and the sensitive phases of species to be protected. This process, which was undertaken very comprehensively in the Adriatic within the framework of the EU project NETCET (Fortuna *et al.,* 2015), helps define strategies for the reduction of cetacean and sea turtle bycatch. This type of measure must however take into account the potential shift of effort to neighboring zones or other threatened species.

Management Dynamic approach. Environmental variability can render ineffective static spatial management as time closure and may result in heavy economic losses for the fishers.

On the other hand, the Turtle Watch program proposed a dynamic and holistic approach (Howell et al, 2008) to help reduce the interactions between the Hawaiian pelagic longline fishery and Loggerhead Sea Turtles. The study matching logbook fishing data from all fishing years in 1994 through 2006 and satellite data from tagged turtles with sea surface water temperature determined a temperature range of 17.5 to 18.5 ° C which was used as thermal warning band for shallow water fishing.

More recently Hazen et al, (2018) use a data-driven, multispecies predictive habitat modelling framework (EcoCas) able to create predictive surfaces quantifying relative target catch and bycatch probabilities for a specific fishery; applied on the California drift gillnet fishery which also result in bycatch of protected species such as sea turtles, blue shark, small delphinids, etc., this program find that dynamic closures could be 2 to 10 times smaller than existing static closures while still providing adequate protection of endangered species.

These dynamic approaches have the advantage of being the managers of fast and flexible tools facilitating decision making in fisheries management, more economical for fisheries and less impactful for the environment.

Safe handling and release (SHR) refers to using best practice methods for dealing with bycatch species, to maximise their chances of survival after interacting with fishing gear. It may include as well good practices on board as vessel manoeuvring to avoid taking bycatch species. To this end, several programs have developed guide lines for professionals suggesting the best ways to free the animals from the nets, without risk of injury and in complete safety for the crew.

IX. DISCUSSION & CONCLUSION

Analysis of the literature shows that mitigation measures may have objectives of two kinds: 1) to avoid bycatch or 2) to reduce post-catch mortality rate. They are of either a technical or a management nature. Therefore, given these principles, for any fishing technique faced with the problem of protected species' bycatch, the solutions can be:

- to reduce the attractiveness of the fishing gear using all necessary means including alarm or scaring systems,
- to modify the gear in order to reduce the risk of bycatch or facilitate the release of caught animals,
- to reduce or avoid fishing effort in sensitive areas or at sensitive times, where and when there is a higher concentration of endangered species (CGPM 2012).

The different systems used to reduce bycatch in each group ers include gear modifications, setting strategies, acoustic, visual, magnetic and chemosensory deterrents and management measures. Most of the mitigation techniques presented here are still being developed and very few are found in the legislation. Table 3 below summarises the state of advancement of the different solutions without prejudging their effectiveness. This is because many have inconsistent results depending on the species concerned, the fishery and the trial conditions.

Thus, better understanding of the nature and the circumstances of interactions is required, involving new means to observe the behaviour of endangered species.

Most authors agree however that no measure is sufficient by itself and that it is strongly recommended to combine measures for greater effectiveness.

Strategies to manage interactions must take into account that some of the measures discussed have opposing effects depending on the species being protected. It would be useful therefore to apply a multi-taxon approach to any strategy aimed at improving fisheries’ selectivity.

Depredation is an issue discussed by a number of authors; it affects all fishing techniques and concerns all species. It is probably the main cause of protected species’ bycatch, regardless of the fishing technique. Examples drawn from the literature show that all deterrents lead to habituation in the animals that it is intended to keep away. Therefore, it would appear that depredation is a consequence of habituation to a particular fishing activity, for a number of reasons (such as the availability of a more easily-accessible resource) affecting all groups of endangered species. Moe "coercive" strategies are currently being considered, based on the hypothesis that whilst fear induces a flight reaction, anxiety generates wariness and therefore avoidance (Dawson *et al.,* 2014). This idea has prompted the development of systems (in particular acoustic) creating anxiety (producing a startled reaction) which may help depredators to learn the clues or contexts preceding dangerous (painful?) stimuli and would elicit avoidance of the anxiogenic situation (Schakner & Blumstein, 2013).

Along the same lines, some conservation measures may also have conflicting effects, for example the Community discard ban (Reg. CE 1380/2013) or the ban on Sunday trawling and purse seining which has tended to shift seabirds towards longliners and increase the bycatch rate (García-Barcelona *et al.* 2010b; Bàez *et al.,* 2014 ; Soriano-Redondo *et al.,* 2016).

In fact, most of the measures described here are simply non-restrictive recommendations from RFMOs. The only regulatory measures are the EU ban on drift-netting and the compulsory use of TEDs to reduce sea turtle bycatch in Australia, the United States, French Guyana and Europe.

In the Mediterranean, no mitigation measure is currently implemented to reduce seabird, turtle or shark bycatch.

In practice, these mitigation measures can therefore only be implemented within a global management framework for fishing activities and at a regional level. In this context, the action plans relating to the protection of four species groups in the Mediterranean propose a strategy listing the priorities and the measures to be implemented gradually (UNEP MAP RAC/SPA, 2003, 2006, 2007a, 2007b).

The “Sea turtle” action plan illustrates this strategy. It defines the fishing conditions (season, depth) best suited to high concentration areas, and suggests how to modify fishing methods and gears and train fishers in the release of animals.

The European Community Plan of Action for reducing the incidental catch of seabirds adopted by the EU Council in 2013 highlight "the need to evaluate the impact of these measures and the scientific data on the extent of the problem.

Some RFMOs such as the ICCAT (ICCAT, 2011) and the GFCM (GFCM/35/2011/3, GFCM/35/2011/4, GFCM/35/2011/5, GFCM/36/2012/2) have adopted various restrictive recommendations establishing measures to reduce the incidental catch of seabirds, sea turtles, monk seals and cetaceans during fishing activities.

Most of these measures have been integrated into European legislation and aim to ban the use of non-regulatory fishing gear such as the use of drift netfor large pelagic species to reduce the bycatch of cetaceans (GFCM/36/2012/2) and activity in protected areas, such as the ban on trawling within 3 nautical miles off the coast to protect coastal sharks (GFCM/36/2012/3).

In the same sessions, the Scientific Committee of the GFCM recommended that, before any restrictive recommendation be implemented, the application of some of the mitigation techniques described here should be investigated: the use of acoustic devices and nets with acoustic reflectivity to deal with cetacean bycatch in the fishing gear, the banning of stainless steel hooks and metallic branch lines in bottom and demersal longline fisheries, and the reduction of the size of bottom nets or in their soak time.

Finally, no mitigation measure can be effective if it is not fully accepted by the commercial fishers and the fishing industry which means taking into account all fisheries socio-economic constraints, technical fishing conditions and incitation and awareness-raising measures.

Table 3 – Summary of the different techniques and methods used and applicable (in blue), being developed (in green) or being researched (in yellow).

GILLNETS & TRAMMEL NETS					
Method		**CETACEANS**	**BIRDS**	**SHARKS**	**SEA TURTLES**
Gear modification		Slackness reduction		Slackness reduction	Slackness reduction
Set and tactic				Minimum set depth	Minimum set depth
Deterrents	Acoustic	Acoustic deterrents	Acoustic alarm		Acoustic deterrents
	Chemosensory	Chemosensory deterrents		Chemical repellents	
	Visual	Visual deterrents; detectability	Net panel visibility		Luminous or visual deterrents
	Magnetic				
Effort & Strategy		Licence, set duration and length, spatio-temporal closures	Licence, set duration and length, spatio-temporal closures	Licence, set duration and length, spatio-temporal closures	Licence, set duration and length, spatio-temporal closures
LINES & LONGLINES					
Gear modification		Type of hook	Hook, bait, hooking position, weighting, branch lines	Hook, bait, branch lines	Hook, bait, hooking position
Set and tactic		Hauling speed	Setting position, line shooter and hauler	Set time, depth and duration	Set time, depth and duration
Deterrents	Acoustic	Acoustic deterrents	Acoustic deterrents	Acoustic deterrents	Acoustic deterrents
	Chemosensoral			Chemo-sensoral repellents	
	Visual	Masking devices	Hookpod, scarers	Luminous lures	Deterrents and luminous lures
	Magnetic			Repellents or magnetic or electropositive hooks	
Effort & Strategy		Licence, set duration and length, number of hooks, spatio-temporal closures	Licence, set duration and length, number of hooks, spatio-temporal closures	Licence, set duration and length, number of hooks, spatio-temporal closures	Licence, set duration and length, number of hooks, spatio-temporal closures
TRAWLING NETS					
Gear modification		Escape devices		Escape devices	Turtle Exclusion Devices TEDs
Set and tactic					Tow duration, season and depth
Deterrents	Acoustic	Acoustic deterrents	Acoustic deterrents		
	Chemosensoral				
	Visual		Scarers		
	Magnetic				
Effort & strategy		Licence, horsepower, set duration, number of tows, spatio-temporal closures	Licence, horsepower, set duration, number of tows, spatio-temporal closures	Licence, horsepower, set duration, number of tows, spatio-temporal closures	Licence, horsepower, set duration, number of tows, spatio-temporal closures
PURSE SEINES					
Gear modification		Seine strengthening			
Set and tactic					Ecological FADs
Deterrents	Acoustic	Acoustic deterrents	Acoustic deterrents		
	Chemosensoral				
	Visual		Scarers		

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