Technical Review: Development and Application of Bycatch Mitigation Devices for Marine Mammals in Mid-Water Trawl Gear

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EXECUTIVE SUMMARY

A technical review to evaluate existing work relating to the application, development and trial of marine mammal mitigation devices was undertaken to assess the availability and effectiveness of mitigation measures that could be used in mid-water trawl fisheries for small pelagic species. Where appropriate the review drew on lessons learnt from trawl fisheries, particularly those using mid-water trawl gear, targeting species other than small pelagic fish. The intent of the review was to highlight global examples of interactions between marine mammals and mid-water trawl gear, the mitigation measures developed, and their efficacy.

The review was undertaken by reviewing and compiling relevant information from both worldwide and Australian fisheries. Management and mitigation measures to reduce marine mammal bycatch typically include the introduction of codes of practice (including offal management), the imposition of fisheries-related mortality limits, temporal and spatial closures of the fishery and the deployment of mitigation devices. This review focussed on interactions between marine mammals and large mid-water trawl vessels, and the technical details of mitigation devices employed in each.

Fisheries that operate mid-water trawl vessels were identified and relevant professionals contacted to obtain information. Countries or locations where most work on bycatch mitigation has been undertaken include Australia, New Zealand, Northwest Africa, Antarctica, the United Kingdom and France. Information and data from global fisheries that utilise mid-water trawl gear was compiled into fishery case studies, from which conclusions on mitigation efficacy were drawn.

The review of the available literature on management of marine mammal interactions with pelagic trawl gear shows that only two technical solutions have been developed and tested to reduce bycatch at this stage, with another showing potential. These are:

1. Excluder devices (physical barriers to prevent marine mammals entering and becoming entrapped in the cod-end and directing them out of the net through an escape hatch);

2. Pingers (acoustic deterrent devices that emit acoustic signals to alert or deter marine mammals from the immediate vicinity of fishing gear); and

3. Auto-trawling systems (net-monitoring systems designed to ensure the entrance to the net remains open at all times)

Most work has focussed on excluder devices and pingers. The development of auto-trawling systems has been done primarily to improve fishing efficiency, but may also have benefits for reducing incidental mortality of marine mammals.

Excluder devices

Excluder devices comprises an additional section of netting inserted between the entrance and the codend of the trawl net with an angled grid that directs sea lions and other large animals to an escape hole in the top or bottom of the net and prevents them from entering the trawl codend. Excluders have used both hard and soft grids to exclude marine mammals from the codend of trawls. The escape hole may be covered to reduce the loss of target species, or open. Some exclusion devices are fitted with a ‘hood’ and ‘kite’. These function to both minimise the possible loss of commercial catch and to minimise the possible loss of dead or incapacitated marine mammals so that mortalities or injuries can be detected. Exclusion devices are widely accepted internationally as being effective in mitigating the incidental mortalities of many large non-target species in many fishing operations.

Development of an excluder device for a fishery requires careful design to ensure problems of fish-loss via the escape hole and net blockage via the excluder grid are avoided. These devices need to be designed specifically for each fishery, taking into account the particular characteristics of each gear type, fishing operation, the size and operation of gear, towing speed, the hydrodynamics of trawl set up in relation to scaling (trawl size/ grid and escape hole ratios), how trawl nets are stored on the vessel, and the size of target and non-target species. An exclusion device that is effective in reducing mortality of marine mammals in one fishery while maintaining catch per unit effort (CPUE) of target species may not be effective in another fishery that is targeting different fish species and encountering different marine mammal species. Effective design and use of excluders also requires detailed knowledge of the spatial and temporal behaviour of the species of mammal that are to be excluded from fishing gear.

While properly designed excluder devices have been shown to be effective in reducing bycatch of pinnipeds, there are no studies that indicate excluder designs tested to date are fully effective in reducing cetacean mortality in trawls. This is probably because fur seals and sea lions are more manoeuvrable within the confines of a trawl net than are dolphins. Use of underwater cameras monitoring effectiveness of excluder devices typically show pinnipeds entering and leaving a trawl through excluder escape holes, whereas dolphins appear distressed when near excluder grids and reluctant or unable to find an escape hole. Fur seals and sea lions will approach an excluder head-on and readily turn around and swim back. In one study dolphins were mostly observed to back down into the net to a position near the grid and later swim upstream out of the net. Very few dolphins were seen swimming head-first towards the grid, and those that did turned around before reaching the grid and swam out the mouth of the net).

Further information is required on the escape behaviour of dolphin species that are known to interact with trawl nets. At present there exists no solution to filter or deter cetaceans from the net opening. Although individual dolphins can potentially escape from a trawl using an escape hole or escape tunnel, cetaceans appear to be less likely to enter a narrow (3–4 m) and confined release route. The most practical way to reduce cetacean bycatch is to have an exit in the net's top panel because dolphins have been observed to seek an exit in the upper part of the trawl. However some studies report that bottlenose dolphins (Tursiops spp.) prefer to exit at the bottom of the net.

For one fishery concern has been raised about the efficacy of excluder devices and post-escape survival of pinnipeds. It has been proposed the observed mortalities could be underestimated due to "cryptic" mortality, because some animals may suffer head trauma from impacting the excluder's hard grid that may compromise their post-escape survival, or may drown outside the net after escaping through the SLED, because they run out of breath before they reach the surface. These assertions have been extensively investigated and are not supported by scientific evidence.

Pingers

Pingers were originally developed to warn dolphins about the presence of gillnets used in fishing operations, and the technology has now been extended to pelagic trawl gear. Pingers are commercially available and are marketed under various trade names. These differ in the level of sound emitted, the direction of the pulse emitted and the pulse duration of the sound emitted. The trade name Dolphin Dissuasive Devices or DDD is also used in a generic sense to refer to loud pingers.

The effectiveness of commercially available and protype pinger devices has been trialled in the UK bass pair trawl fishery and the adjacent European fishery. Tests have evaluated parameters such as sound source level, pulse durations, immersion depths, and distance from dolphin groups whilst assessing the behavioural response of animals. The placement of pingers within trawl gear has also been evaluated and is considered a critical factor in their effectiveness in deterring small cetaceans from interacting with fishing gear. Experimental work has produced mixed results, with significant reductions in bycatch rates being observed when pingers have been used, but the absence of a sufficient number of control tows prevents confidence in the results.

The results of monitoring pinger deployment over three years showed three potential problems with implementing these devices as a mitigation measure. Devices may not always be properly charged or working when deployed; they may be placed too close to the surface; and, they may degrade after three years and are unable to hold adequate charge

As a result, the effectiveness of pingers in reducing bycatch of dolphins in pelagic trawls is unclear. A decline in observed bycatch in UK pair-trawl fisheries was reported following the introduction of pingers, and trials with pingers in French trawlers indicated a 70% reduction in common dolphin bycatch. However, at-sea trials off Ireland indicated that pingers may not provide a consistently effective deterrent signal for common dolphins.

Of the commercial gillnet pingers, only the DDD has shown some effect in pelagic fisheries. Pingers (DDDs) should be fully charged and deployed on the lower wing ends or bridles of the trawl to ensure they continue to function correctly. Although DDDs appear to be effective in reducing dolphin bycatch, there are still challenges to address including determining the most effective configuration for mid-water trawls.

Deployment of pingers may interfere with normal fishing operations, and French fishermen prefer to use a softer pinger set on the rear part of the trawl rather than use a DDD set on the wings of the trawls because there is less interference with the netsonder. Concerns also exist that cetaceans will become habituated to pinger use over time, and their effectiveness will, therefore, decline. Currently, habituation is not thought to pose a problem, although it may be hard to test for this and to link any changes in pinger effectiveness to habituation. Concerns have also been expressed that the wide use of pingers in certain fisheries may result in the exclusion of cetaceans from habitat that may be significant to their survival. There is currently no evidence that this occurs where pingers have been used.

Auto-trawl systems.

Some trawlers employ auto-trawl systems that are designed to maintain the shape of the trawl gear when turning, thus ensuring the entrance to the net remains open at all times. Auto-trawl systems are able to do this by monitoring and controlling the trawl doors via telemetry and sensors. It has been proposed that the use of auto-trawling systems has a potential mitigation effect for pinnipeds and cetaceans

Auto-trawl systems have never been evaluated as a marine mammal bycatch mitigation approach. It is intuitive that ensuring the net entrance does not collapse during trawling operations will be effective in reducing marine mammal entrapment in trawl nets and maintaining the effective operation of excluder devices. However, while this may reduce the likelihood of marine mammal entrapment and ensuing mortality, there is currently no evidence that the use of auto-trawl equipment will be effective in minimising the capture of marine mammals. Use of auto-trawl systems as a marine mammal mitigation device should therefore be treated with caution until the efficacy of these systems has been demonstrated.

INTRODUCTION

This technical review evaluates existing work relating to the application, development and trial of marine mammal mitigation devices around mid-water trawl gear. The review focuses on the gear type, rather than on vessel size. Where appropriate the review draws on lessons learnt from trawl fisheries, particularly those using mid-water trawl gear, targeting species other than small pelagic fish. The review highlights global examples of interactions between marine mammals and mid-water trawl gear, the mitigation measures developed, and their efficacy.

Brief description

The need for this work arose from a decision by the Minister for Sustainability, Environment, Water, Population and Communities (now the Minister for the Environment, to prevent a certain type of fishing activity – a decision known as the Final (Small Pelagic Fishery) Declaration 2012 – which came into force on 20 November 2012.

The Final Declaration provides that a commercial fishing activity that:

a. is in the area of the Small Pelagic Fishery (SPF);
b. uses the mid-water trawl method;
c. uses a vessel which is greater than 130 metres in length, has an on-board fish processing facility and has storage capacity for fish or fish products in excess of 2000 tonnes; and
d. is a Declared Commercial Fishing Activity for the purposes of Part 15B of the EPBC Act.

The Declared Commercial Fishing Activity (DCFA) has been prohibited for up to two years while the Expert Panel conducts an assessment and reports to the Minister on the activity. The Expert Panel commenced its assessment in February 2013 and the technical review described here will inform the Panel's report, which is due in October 2014.

Scope

The aim of this report is to assess the availability and effectiveness of mitigation measures for marine mammal bycatch in mid-water trawl fisheries for small pelagic species. The following scope was used to achieve these aims:

- Use case studies of the development and application of marine mammal mitigation devices that:

    i. describe the fishery (species targeted, nature of vessels and gear used);
    ii. outline the nature and extent of the problem with marine mammal interactions (species involved and level of interactions);
    iii. describe the technical details of the mitigation devices adopted to address the problem;
    iv. provide the results of trials of the devices;
    v. provide, where possible, data that demonstrate the effectiveness of the devices; and
    vi. detail any specific vessel operating or structural characteristics that impact on the effectiveness of the devices.

- Assess the current status of mitigation measures for marine mammal bycatch in mid-water trawl in small-pelagic fisheries and make recommendations on the most effective devices for use, trial or further development in the SPF.
- Identify further research that may be required in order to develop or prove the effectiveness of marine mammal mitigation devices for use in mid-water trawl gear.

Preparation of the technical review

Relevant information from both worldwide and Australian fisheries was reviewed and compiled. Management and mitigation measures to reduce marine mammal bycatch typically include the introduction of codes of practice (including offal management), the imposition of fisheries-related mortality limits, temporal and spatial closures of the fishery and the deployment of mitigation devices. This review focussed on interactions between marine mammals and large mid-water trawl vessels, and the technical details of mitigation devices employed in each (if any). Such devices include:

- Pinniped and dolphin exclusion devices;
- Acoustic deterrent devices (‘pingers’); and,
- Auto-trawl systems.

Fisheries that operate mid-water trawl vessels were identified and relevant professionals contacted to obtain information. Countries or locations known to be of particular interest included New Zealand, the north and south Pacific, South Africa, Namibia, Senegal and West Africa, and Europe and the north Atlantic. Information and data from global fisheries that utilise mid-water trawl gear was compiled into a fishery description with the following structure:

- Description of fishery,
- Nature and extent of the marine mammal interaction and bycatch problem,
- Technical details of mitigation devices,
- Trials of the device,
- Efficacy of the device, and
- Specific vessel operating or structural characteristics.

Further research was identified that may be required to develop or improve the effectiveness of marine mammal mitigation devices for use in mid-water trawl gear. Based on the available information, an assessment was conducted of the current status of mitigation measures for marine mammal bycatch in mid-water trawl in small-pelagic fisheries and, where possible, recommendations were made on the most effective devices for use, trial or further development in the SPF.

BACKGROUND

How are marine mammals captured in trawl nets

Direct interactions between fishing gear and marine mammals (cetaceans, i.e. whales, dolphins and porpoises; and pinnipeds, i.e. seals and sea lions) occur in many fisheries worldwide and may result in incidental capture and mortality of some individuals (Read *et al.* 2006; Reeves *et al.* 2013).

Fishing-related mortality is considered the most severe and immediate threat to populations of small cetaceans worldwide (Jaiteh *et al.* 2012; Read *et al.* 2006; Reeves *et al.* 2013) with gillnet bycatch (Reeves *et al.* 2013), longline fisheries bycatch (Hamer *et al.* 2012) and purse seine fishing bycatch (Hamer *et al.* 2008) identified as the major threats to many non-target species. Incidental takes of cetaceans and pinnipeds exist in most areas where trawling occurs (Fertl and Leatherwood, 1997; Hamer and Goldsworthy 2006; Tilzey *et al*. 2006). Marine mammals and commercial fisheries often target the same food resource leading to 'operational interactions' between animals and fisheries when they come into direct contact with fishing gear.

In a study of Australian fur seals that identified the environmental and operational aspects of the winter blue grenadier trawl fishery that were associated with increased observations of seals, an increase in seal numbers observed at the surface was assumed to be proportional to the increased risk of bycatch and mortality incidences with trawlers (Hamer and Goldsworthy 2006).

Several factors appear to influence incidental catches of pinnipeds, including behavioural traits of individual species, age of individuals, fishing gear type and the temporal and spatial overlap of a species' range with fishing activities. Incidental catches appear to occur at least occasionally wherever seal distribution and fishing effort overlap, but are most prevalent where a species' range coincides temporally and spatially with intense fisheries activities (Woodley and Lavigne 1991).

Similarly, differences in susceptibility of certain cetacean species to interactions with fishing activities have been attributed to differences in behaviour, such as migratory pathways intersecting fishing zones and/or the use of common feeding grounds for prey that are also targeted by fisheries (Couperus, 1997).

Marine mammals may not be feeding on the same target species of the fishery but an associated non-target species, or may be attracted to discards made available by fishing activity (Fertl and Leatherwood, 1997; Morizur *et al*. 1999). There are four feeding patterns typically used around fishing vessels: (1) foraging behind working boats; (2) entering working trawl nets to feed; (3) feeding on discards or fish fallen from the net; and (4) feeding on prey attracted to vessels (Fernández-Contreras *et al*. 2010; Fertl and Leatherwood, 1997; Morizur *et al*. 1999; Northridge *et al*. 2005).

Marine mammals are more often caught in mid-water trawls than in bottom trawls (Crespo *et al.* 1997; Fertl & Leatherwood, 1997; Hall *et al.* 2000; Ross and Isaac, 2004). The following reasons have been suggested for this:

1. Mid-water nets generally target small pelagic fish species, which are often the same species preyed upon by marine mammals.
2. Mid-water gear is generally towed at relatively high speeds.
3. Mid-water trawl nets are generally much larger than most demersal trawl nets.

4. Mid-water trawls often operate for extended periods within the normal diving depth and duration of marine mammals. Consequently, for individuals caught in the net, trawl time exceeds their breath-holding capacity, hence they drown.

The expansion of trawl fisheries may have contributed to an increase in the rate of marine mammal bycatch. For example, improvements in fishing technology, such as the introduction of large freezer and factory vessels, have enabled vessels to fish with larger gear, for longer and farther from shore, thus increasing the likelihood of interactions with cetaceans (Crespo *et al.* 1997; Zollett and Rosenberg, 2005). (Note, however, that in some cases large freezer and factory vessels do not use larger nets). Trawls with a larger circumference have a larger net opening and the greater extension of their rigging parts (bridles and doors) likely provides a significant herding effect for large marine predators such as cetaceans (Zeeberg *et al.* 2006).

Marine mammal mortality occurs when individuals enter the net and become trapped, typically when the boat stops 'hauling' and the trawl entrance collapses, or when the net is being shot away and the net is relatively shapeless and slow-moving at this time. Long haul times increase the risk of drowning (Du Fresne *et al.* 2007). Dolphins may also have their rostrums caught in the net while pulling out fish, they sometimes drown when they are caught around the tail stock and have also been caught in turtle and marine mammal exclusion devices (Fertl and Leatherwood, 1997; Wakefield *et al.* 2014).

TECHNICAL SOLUTIONS TO MITIGATE THE BYCATCH OF MARINE MAMMALS

Our review of the available literature on management of marine mammal interactions with pelagic trawl gear shows that only two technical solutions have been developed and tested to reduce bycatch at this stage, with another showing potential. These are:

4. Excluder devices (physical barriers to prevent marine mammals entering and becoming entrapped in the cod-end and directing them out of the net through an escape hatch);
5. Pingers (acoustic deterrent devices that emit acoustic signals to alert or deter marine mammals from the immediate vicinity of fishing gear); and
6. Auto-trawling systems (net-monitoring systems designed to ensure the entrance to the net remains open at all times).

Most work has focussed on excluder devices and pingers. The development of auto-trawling systems has been done primarily to improve fishing efficiency, but may also have benefits for reducing incidental mortality of marine mammals. More detail on the technical aspects of the mitigation devices and systems has been provided in Part B – Case Studies.

Excluder devices

An excluder device comprises an additional section of netting inserted between the entrance and the codend of the trawl net with an angled grid that directs sea lions and other large animals to an escape hole in the top or bottom of the net and prevents them from entering the trawl codend. Excluder devices are variously known as Seal Excluder Devices (SEDs), Sea Lion Excluder Devices (SLEDs), Cetacean Excluder Devices and Marine Mammal Excluder Devices, depending on the type of animal that they have been designed to avoid catching in fishing gear. Diagrams depicting excluder devices can be found in Part B, figures 1, 4, 6-12, and 14-17.

The grid used to exclude the marine mammal is usually constructed of stainless steel (known as a hard grid) but can be made from softer material such as fishing mesh or rope, or braided stainless wire and pipe (known as a soft grid or semi-flexible grid). Grids may be constructed as a single piece, or as a two or three piece unit. The spacing between the bars that form a grid, and the size, shape and location (top or bottom) of the escape hole, are dependent on the behaviour and size of the species that are to be excluded from trawl gear.

The escape hole may be covered to reduce the loss of target species, or open. Some exclusion devices are fitted with a ‘hood’ and ‘kite’. A netting hood with a forward-facing opening held open by floats and a panel (or ‘kite’) fitted to a top-opening escape hole directs water flow into the net and across the grid. These function to both minimise the possible loss of commercial catch and to minimise the possible loss of dead or incapacitated marine mammals so that mortalities or injuries can be detected.

Exclusion devices have been used successfully in a number of trawl fisheries to separate a range of animals, such as turtles, dolphins, seals and sharks from commercial catch and to prevent these larger animals from being killed. Exclusion devices are widely accepted internationally as being effective in mitigating the incidental mortalities of large non-target species in many fishing operations.

Development of an excluder device for a fishery requires careful design to ensure problems of fish-loss via the escape hole and net blockage via the excluder grid are avoided. It may be beneficial to test excluder device designs in a flume tank to ensure hydrodynamic efficiency under operational conditions. These devices need to be designed specifically for each fishery, taking into account the particular characteristics of each gear type, fishing operation, the size and operation of gear, towing speed, the hydrodynamics of trawl set up in relation to scaling (trawl size/ grid and escape hole ratios), how trawl nets are stored on the vessel, and the size of target and non-target species. An exclusion device that is effective in reducing mortality of marine mammals in one fishery while maintaining catch per unit effort (CPUE) of target species may not be effective in another fishery that is targeting different fish species and encountering different marine mammal species. Effective design and use of excluders also requires detailed knowledge of the spatial and temporal behaviour of the marine mammals that are to be excluded from fishing gear. For example, many dolphins and seals forage principally in the upper 100 m of the water column. With such species, effective operation of an excluder may only be necessary during the shooting and haul of the gear e.g. Australia’s Winter Blue Grenadier Fishery Case Study 1.

Key points that can be drawn from the Case Studies where excluder devices have been thoroughly designed and trialled are:

- Properly designed excluder devices have been shown to be effective in reducing bycatch of some pinnipeds e.g. Case Studies B5.1 and B5.5, but there are no studies that indicate excluder designs tested to date are fully effective in reducing cetacean mortality in trawls e.g. Case Studies B5.2 and B5.6.

- **Excluder devices appear to be more effective for pinnipeds than they are for small cetaceans.** This is probably because fur seals and sea lions are more manoeuvrable within the confines of a trawl net than are dolphins. Use of underwater cameras monitoring effectiveness of excluder devices typically show pinnipeds entering and leaving a trawl through excluder escape holes (e.g. in the Australian Winter Grenadier and Auckland Island Squid Trawl Fisheries Case Studies B5.1 and B5.5, respectively); whereas dolphins, while adept at foraging adjacent to and in the mouth of trawl nets, appear distressed when near excluder grids (Case Studies B5.2 and B5.6) and reluctant or unable to find an escape hole. Fur seals and sea lions will approach an excluder head-on and readily turn around and swim back (Case Studies B5.1

and B5.5). In one study dolphins were mostly observed to back down into the net to a position near the grid and later swim upstream out of the net. Very few dolphins were seen swimming head-first towards the grid, and those that did turned around before reaching the grid and swam out the mouth of the net (Case Study 6).

- **Further information is required on the escape behaviour of dolphin species that are known to interact with trawl nets**. At present there exists no solution to filter or deter cetaceans from the net opening. Cetacean exclusion devices generally include an escape hatch that is used in conjunction with a large diameter mesh barrier that can be detected by dolphins (Northridge *et al*. 2005). Although individual dolphins can potentially escape from a trawl using an escape hole or escape tunnel, cetaceans appear to be less likely to enter a narrow (3–4 m) and confined release route because of 'claustrophobia' (Zeeberg *et al*. 2006). The most practical way to reduce cetacean bycatch is to have an exit in the net's top panel because dolphins have been observed to seek an exit in the upper part of the trawl (Case Study 2). Note, however, that others state that bottlenose dolphins (*Tursiops* spp.) prefer to exit at the bottom of the net (Zollett & Rosenberg, 2005).

- **The use of hoods and kites is an effective refinement to an excluder device.** The escape of New Zealand sea lions from trawl nets was enhanced when a hood and kite were fitted to the trawl (Case Study 5).

- The majority of cetaceans captured in pelagic trawler fisheries are the smaller dolphins that live and forage nearer the sea surface i.e. common dolphins *Delphinus delphis*, bottlenose dolphins *Tursiops truncatus,* (as opposed to deeper-diving dolphin species) (Zeeberg *et al*. 2006)

- **Post-escape survival.** Despite evidence from observer data that captures of sea lions were reduced to low levels following the full use of an excluder device, a level of scepticism exists about the efficacy of excluder devices in Case Study 5 and other fisheries where excluder devices are used. It has been proposed the observed mortalities of sea lions could be underestimated due to "cryptic" mortality, because some sea lions (1) may suffer head trauma from impacting the excluder's hard grid that may compromise their post-escape survival; (2) may die in the trawl net and fall out of the escape hole; or (3) may drown outside the net after escaping through the SLED, because they run out of breath before they reach the surface. These assertions have been extensively investigated and are not supported by scientific evidence. It is likely that some uncertainty will always exist on post-escape survival unless significant efforts are directed to resolving this question. To do so would require extensive resources. Bradshaw *et al*. (2013) suggested one method would be to tag acoustically large numbers (hundreds) of NZSL each year and place acoustic receivers on a high proportion of SLED-equipped nets. A mark-recapture history of these individuals could be used to estimate the probability that exposure to SLEDs affects survival rates.

- **Excluder devices need to be tailored to suit individual fisheries** – one size does not fit all. It is not possible to make any general recommendations as excluder devices/measures need to be designed on a fishery by fishery basis taking into account vessel and gear characteristics, and target and non-target species and issues.

Pingers

A pinger is a small self-contained battery operated device that emits regular or randomised acoustic signals at a range of frequencies that are loud enough to alert or deter animals from the immediate vicinity of fishing gear. Originally developed to warn dolphins about the presence of gillnets used in fishing operations, the technology has been extended to pelagic trawl gear with extensive testing of a range of pingers carried out in the UK Bass Pair Trawl Fishery and the adjacent, overlapping European fishery (Case Study 7).

Pingers are commercially available from a number of suppliers and are marketed under various trade names such as Dolphin Dissuasive Devices, Cetasaver, Aquamark 100, Aquamark 200, FMDP 2000, and High Impact Black Saver and Pinger. These differ in the level of sound emitted ('soft' and 'loud' pingers), the direction of the pulse emitted (directional or omnidirectional) and the pulse duration of the sound emitted. The trade name Dolphin Dissuasive Devices or DDD is also used in a generic sense to refer to loud pingers.

The effectiveness of commercially available and protype pinger devices has been trialled. Tests have evaluated parameters such as sound source level, pulse durations, immersion depths, and distance from dolphin groups whilst assessing the behavioural response of animals. The placement of pingers within trawl gear has also been evaluated and is considered a critical factor in their effectiveness in deterring small cetaceans from interacting with fishing gear. Experimental work has produced mixed results, with significant reductions in bycatch rates being observed when pingers have been used, but the absence of a sufficient number of control tows prevents confidence in the results (Case Study 7).

Further experimental work, while appearing encouraging, has shown that pingers may not always be effective, although on some of such occasions pingers may not have been working or had been placed in a suboptimal position on the gear close to the surface. The manufacturer recommends that the devices should always be deployed in at least 10 m of water for the acoustic signal to propagate properly (Northridge *et al.* 2011).

The results of monitoring pinger deployment over three years showed three potential problems with implementing these devices as a mitigation measure (Northridge *et al.* 2011).:

1) Devices may not always be properly charged or working when deployed;
2) Devices may be placed too close to the surface; and,
3) Devices may degrade after three years and are unable to hold adequate charge

Key points that can be drawn from the Case Study 7 where pingers have been trialled are:

- **The effectiveness of pingers in reducing bycatch of dolphins in pelagic trawls is unclear**. A decline in observed bycatch in UK pair-trawl fisheries has been reported since 2007, following the introduction of pingers as a mitigation device (Northridge and Kingston, 2009 cited in de Boer *et al*. 2012). Trials with pingers used by French trawlers indicated a 70%reduction in common dolphin bycatch (Morizur *et al*. 2008). However, at-sea trials off Ireland indicated that pingers may not provide a consistently effective deterrent signal for common dolphins (Berrow *et al*. 2009). Low bycatch figures reported since 2007 may also be explained by less fishing-effort from 2007 onwards due to high fuel prices and low sea bass availability (Northridge and Kingston, 2009) cited in de Boer *et al*. 2012.
- Of the commercial gillnet pingers, only the DDD has shown some effect in pelagic fisheries.
- **Pingers (DDDs) should be fully charged and deployed on the lower wing ends or bridles of the trawl** to ensure they continue to function correctly. Although DDDs appear to be effective in reducing dolphin bycatch, there are still challenges to address including determining the most effective configuration for mid-water trawls (Northridge *et al*. 2011).

- **Deployment of pingers may interfere with normal fishing operations.** French fishermen prefer to use a softer pinger set on the rear part of the trawl rather than use a DDD set on the wings of the trawls because there is less interference with the netsonder because of the geometry of the beams (Morizur *et al*. 2007).

- **Concerns exist that cetaceans will become habituated to pinger use over time**, and the effectiveness of pingers will, therefore, decline. Currently, habituation is not thought to pose a problem and it is thought that any decline in the pingers effectiveness would be identified by the use of observer programmes (DEFRA 2003). However, it may be hard to test for this and to link any changes in pinger effectiveness to habituation.

- Concerns have also been expressed that the wide use of pingers in certain fisheries may result in the exclusion of cetaceans from habitat that may be significant to their survival. There is currently no evidence that this occurs where pingers have been used. However, if pingers were to be used intensively in coastal areas there may be problems with cetaceans being unable to access (or leave) bays or inlets (DEFRA 2003). Experiments conducted using DDDs and a quieter device to determine how significant any exclusion might be produced equivocal results, although there was some evidence of decreased cetacean activity when a single DDD was in the water out to at least 1.2 km from the device and possibly as far as 3 km or more. The quieter device appeared to have an effect up to about 400 m, though this particular result is considered to be preliminary (Northridge *et al*. 2011).

Auto-trawling systems and net monitoring systems

Some trawlers employ auto-trawl systems that are designed to maintain the shape of the trawl gear when turning, thus ensuring the entrance to the net remains open at all times. Auto-trawl systems are able to do this by using self-tensioning winch systems (e.g. RAPP Hydema, Hydaulik Brattvaag systems). To a lesser extent, net monitoring systems are also able to do this through monitoring and controlling the trawl doors via telemetry and sensors (e.g. Marport TrueTrawl geometry system, a wireless monitoring system designed to improve trawl geometry through use of a master geometry transponder placed on the headrope with slave geometry sensors placed on each trawl door, the wings or other locations. Each sensor communicates with another using underwater wireless acoustic communications technology).

It has been proposed that the use of auto-trawling systems has a potential mitigation effect for pinnipeds and cetaceans (Wakefield *et al.* 2014; Gerry Geen, Seafish Tasmania, pers. comm). Wakefield *et al*. (2014) reported on discussions with fishers around potential circumstances resulting in the entrapment of dolphins. These involved the collapsing of the mouth of the trawl net from reduced trawl speed or sharp turning of the vessel during hauling, which may have prevented dolphin escapement during the trial of the three exclusion grid configurations in Case Study 6. Two of the three vessels involved in experimental work described in this case study used monitoring sensors (MARPORT Canada Inc.) on their otter boards to provide immediate feedback to the fishers on the board’s orientation (pitch, roll, depth) and performance to prevent net collapse. It was suggested that observed net captures of dolphins occurred in the few instances when net collapse occurred because a relief skipper, unfamiliar with the operation of the auto trawl system, was on board. Preventing net collapse through maintaining a high standard of operational procedures would be beneficial in reducing dolphin interactions. The extensive evidence provided from the high level of subsurface within-net observations at the exclusion grid in Case Study 6 suggested that the initial causes of dolphin distress are occurring toward the mouth of the net. Therefore, it would be beneficial to obtain in situ observations of dolphin behaviour in this forward part of trawl nets to develop and trial further mitigation measures and strategies in this part of the net (Wakefield *et al*. 2014).

Key points that can be drawn from the Case Study 6

- Ensuring the net entrance does not collapse during trawling operations may reduce the likelihood of marine mammal entrapment and ensuing mortality.
- **Auto-trawl systems have never been evaluated as a marine mammal bycatch mitigation approach.** There is no currently no evidence that the use of auto-trawl equipment will be effective in minimising the capture of marine mammals. However, it is intuitive that ensuring the net entrance does not collapse during trawling operations will be effective in reducing marine mammal entrapment in trawl nets and maintaining the effective operation of excluder devices.

RECOMMENDED MANAGEMENT NEEDS AND RESEARCH IDEAS

The following management and research considerations have been identified following our review, relevant to the application of marine mammal bycatch mitigation measures to large freezer-factory trawl vessels operating in the Small Pelagic Fishery.

7. **Experimental testing of mitigation measures** - Developing robust conclusions about the efficacy of mitigation measures requires experimental testing and the use of quantitative methods. Ideally, data would be sourced from designed experiments conducted at sea, where the mitigation measures in question would be deployed head-to-head against a control of no deterrent. In the Case Studies reviewed for this report, there were few examples of mitigation experiments conducted in this way, which made it difficult to draw firm conclusions on the effectiveness of mitigation measures. Future efforts to develop and implement mitigation measures in the Small Pelagic Fishery should seek to embody these experimental principles.
8. **Soft grid SEDs** –The large freezer-factory vessel that proposed to fish in the SPF was to trial a SED with a soft-mesh grid and top-opening escape hatch. The soft-grid was designed so that the trawl net could be hauled onto a net drum. Previous experience in the SPF with soft mesh SEDs showed that they were not effective in guiding seals out of trawl nets. These SEDs were not sufficiently rigid and under the weight of a seal, deformed considerably, sometimes leading to partial entanglements, and providing no passive assistance in directing the seals out through the escape opening. As a consequence they were replaced with a steel or hard grid, which have been shown in a range of fisheries to be more effective in retaining their shape and directing pinnipeds out of trawl nets. Based on the evidence available use soft SEDs in the SPF is not recommended, and any proposals to use this style of SED should require closely-monitored testing before full acceptance.
9. **Excluder post-escape survival** – Despite evidence that hard-grid seal or sea lion excluder devices are effective in minimising the capture of pinnipeds in trawl nets, the issue of post-escape survival of animals remains controversial in one fishery. It is likely that some uncertainty will always exist on post-escape survival unless significant efforts are directed to resolving this question, and the possibility exists that such concerns would be raised with the introduction of a large freezer-factory vessel into the Small Pelagic Fishery. Future research options to address any remaining uncertainty regarding post-escape survival of pinnipeds are described above in Section 3.1, and will require extensive resources to implement. If such research is considered necessary, it may be more feasible and cost effective to undertake these studies in New Zealand (Auckland Island Squid Fishery) where

existing monitoring programmes, including mark-recapture studies, for the New Zealand sea lion are well established.

10. **Behaviour of dolphins around trawls** – Because excluder devices are not fully effective in mitigating bycatch of cetaceans in trawl fisheries, further information is required on the escape behaviour of dolphin species that are known to interact with trawl nets. The extensive evidence provided from the high level of subsurface within-net observations at the exclusion grid in the Pilbara Fish Trawl Fishery, suggested that the initial causes of dolphin distress are occurring toward the mouth of the net. Further development and refinement of technical mitigation measures for cetaceans would benefit from greater understanding of behaviour around fishing gear. In particular, in situ observations of dolphin behaviour in the forward part of the trawl nets to determine the potential circumstances that lead to distress, and to develop and trial further mitigation measures and strategies in this part of the net, are recommended. This work would be best carried out in working fisheries through the use of video-monitoring equipment, focussing on behaviour and search patterns within the net when animals are seeking to escape.

- **Efficacy of auto-trawl gear** - Auto-trawl systems need to be evaluated as a marine mammal bycatch mitigation approach if they are to be deployed specifically for this purpose. Given that these systems are routinely used by some trawlers for reasons of fishing efficiency, evaluation of the mitigation potential of auto-trawl gear in an experimental framework will be difficult to achieve.

11. Hydrostatic net binding release (only relevant if trawl being pulled in and out of water)

SOURCES OF INFORMATION ACCESSED DURING REVIEW

In addition to the comprehensive review of published literature, a number of global experts were contacted to identify unpublished studies of mid-water trawl fisheries where problems with marine mammal interactions have been identified and have been or are being addressed through the development and application of marine mammal mitigation devices (Table 1). A number of fisheries were considered in this review and were either identified to include or reject as a ‘case study’ (Table 1).

Table 1: The fisheries considered in this review and either identified to include or reject as a ‘case study’ along with the key information sources including the global bycatch mitigation experts that were contacted to source published or unpublished literature on bycatch mitigation devices for marine mammals in mid-water trawl gear.

Fishery	Was this included as a case study?	Trawler bycatch and mitigation device details	Key information sources
Winter blue grenadier fishery - part of Commonwealth Trawl Sector (CTS), Southern and Eastern Scalefish and Shark Fishery (SESSF)	Case Study 1	A Seal Exclusion Device (SED) was developed for mid-water factory trawlers in this fishery. Recent work on some new and important innovations in SED design which include: • a hydrostatic net release so that the net only opens at fishing depth (below the diving range of seals) • an acoustic transponder release grid gate. The SED grid includes a hinged gate which is open during fishing and closed before haul is commenced. Any seals in the net are guided by the grid towards an escape hole at the top of the net, and • installation of smaller sized mesh on the hood which reduces fish ‘stickers’ being caught in the mesh.	Hamer and Goldsworthy (2006) Tilzey *et al*. (2006) Mike Gerner (Australian Fisheries Management Authority, AFMA), personal communication
European (Dutch and Irish) pelagic fleet fishing off Mauritania, Northwest Africa	Case Study 2	Large pelagic freezer-factory trawlers targeting small pelagic fish. A Large Animal Reduction Device, or LARD, designed under this program guides pelagic megafauna deflected by a filter to an escape route along the bottom of the trawl. NB: the LARD was not specifically designed to mitigate dolphin bycatch but was for all megafauna bycatch - sharks, manta rays, sea turtles and dolphins. The LARD also includes a cetacean exit in the net’s top panel. Vertical ropes at the trawl net entrance and acoustic deterrents were also being looked into to mitigate dolphin bycatch although no information was found regarding their efficacy in reducing dolphin bycatch in this fishery	Zeeberg *et al*. (2006) Heessen *et al*. (2007) Dr JaapJan Zeeberg, personal communication.
Antarctica krill fishery	Case Study 3	Trawl fishing for krill in Antarctic waters is managed through the Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR). A range of SEDs have been developed and implemented to reduce fur seal bycatch. Each device is tailored according to the characteristics of the fishery and vessels in that fishery. One of the Japanese mitigation techniques involved a 240 mm nylon mesh barrier positioned immediately anterior to the net which prevents seals from entering the net.	Hooper *et al*. (2005) Reid and Grilly (2014) Dr Keith Reid (Science Manager, CCAMLR), personal communication.

Fishery	Was this included as a case study?	Trawler bycatch and mitigation device details	Key information sources
Small Pelagic Fishery, Australia	Case Study 4	Fur seals and dolphins have been caught on mid-water trawlers in this fishery. Three SED designs were trialled by Lyle and Willcox (2008) - (i) bottom opening, small escape hole, (ii) bottom opening, large escape hole, and (iii) top opening. All the SEDs had a hard, steel grid to prevent large bycatch animals from entering the codend of the net. For the top-opening SED, a cover flap of trawl netting was attached to the leading edge of the escape opening. A reduction in seal bycatch was achieved with the larger bottom-opening escape hole. The large freezer-factory trawl vessel that proposed to fish in the SPF was to trial a SED with a soft-mesh grid and top-opening escape hatch. The soft-grid was designed so that the trawl net could be hauled onto a net drum.	Lyle and Willcox (2008) Gerry Geen (Seafish Tasmania), personal communication
Auckland Islands squid trawl fishery	Case Study 5	This fishery which utilises bottom and mid-water trawls across the Shelf at bottom depths of about 150 – 250 m, has reported high levels of New Zealand sea lion bycatch in the past. A Sea Lion Excluder Device (SLED) was developed which includes a hard, steel grid; a top-mounted escape opening; and a hood with a 'kite' and floats to ensure the escape hole remains open. There have been various research projects which have aimed to test the efficacy of SLEDs in reducing New Zealand sea lion bycatch.	Various unpublished reports (cited in Case Study 5). Hamilton and Baker (2014) Richard Wells (Deepwater Group Ltd, New Zealand), personal communication
Western Australian Pilbara fish trawl fishery	Case Study 6	This otter trawl fishery targets demersal scalefish with most fishing occurring in depths of between 50-100 metres. Bycatch species include dolphins, turtles, sea snakes, sawfish, rays and sharks. A number of different excluder devices have been trialled in the fishery which have included both top and bottom opening net configurations. Three different exclusion gear configurations in trawl nets have been evaluated in trials conducted on all three vessels fishing in this fishery. One of these devices included a downward facing escape hole but, additionally, a longitudinal escape slit (~3 m long) was cut into the top of the square mesh net within one metre of and forward to the exclusion grid which aimed to facilitate the subsurface escapement of predominantly airbreathing animals.	Stephenson *et al*. (2008) Wakefield *et al*. (2014) Allen *et al*. (2014).

Fishery	Was this included as a case study?	Trawler bycatch and mitigation device details	Key information sources
UK bass pair trawl fishery and adjacent, overlapping European fishery	Case Study 7	The UK bass pair trawl fishery employs trawl nets towed near the surface by a pair of relatively small trawlers. There has been a range of research projects on dolphin excluder devices and deployment of 'pingers' e.g. Dolphin Dissuasive Devices (DDDs). There are reportedly up to 50 pairs of French boats operating the same gear, but mostly working in the Bay of Biscay area. The European 'Procet' project and 'Necessity' project has included some work on dolphin excluder devices. The main focus in recent years has been on deploying and testing 'pingers' to deter dolphins from trawl nets. There has been at-sea testing of the commercially developed pinger called the Cetasaver which emits a conical direction beam.	Morizur *et al*. (1999) Northridge *et al*. (2011) Various unpublished reports (cited in Case Study 7). Mark Tasker (Joint Nature Conservation Committee, JNCC), personal communication Simon Northridge (Sea Mammal Research Unit, St Andrews University, Scotland), personal communication. Yvon Morizur (IFREMER - French Institute for Exploitation of the Sea), personal communication
New Zealand jack mackerel fishery	This fishery was not included as a Case Study.	Mid-water and bottom trawlers and dolphin bycatch. Exclusion devices have not been utilised in this fishery. Pingers have been deployed but it is unknown whether they have made a significant impact on reducing the mortality of dolphins in this fishery (Richard Wells, pers. comm.). There is currently a review of the use of pingers in this fishery (undertaken by Nathan Walker). There appears to have been a reduction in bycatch but no experimental work - mainly use of pingers. The use of Dolphin Dissuasive Devices (DDD) is part of recent Operation Plan guidelines (Cleale 2013). There is no further literature (grey or published) on the use of pingers in this fishery or on any testing of the efficacy of pingers to reduce dolphin bycatch (Richard Wells, pers. comm.).	Richard Wells (Deepwater Group Ltd, New Zealand), personal communication Cleale 2013

Fishery	Was this included as a case study?	Trawler bycatch and mitigation device details	Key information sources
Wet boats in the CTS, SESSF	This fishery and its mitigation device work was not included as a Case Study due to the demersal trawl fishing method and the lack of data on the efficacy of SEDs in reducing seal bycatch in this fishery.	'Wet boats' are fishing vessels that use demersal trawl methods (18–23 m) and store fresh fish on ice or brine. A trial of three different SED designs on wet-boats was conducted. Of the 3 SED designs, the 'Bennett' SED (with a flexible grid) showed most promise as it was easy for the crew to handle, stowed neatly onto the net drum and maintained a rigid shape during towing. The Bennett SED, with a downward facing escape hatch, had a grid constructed of vertical bars consisting of 16 mm stainless steel wire covered by polyurethane tube and an outer frame constructed of stainless steel tube. More work is required to fine-tune the design and to test efficacy in reducing seal bycatch. A recent project examined the potential of reducing seal interactions by shortening trawl fishing nets. While large trawl vessels have used excluder devices successfully, the use of grids has been considered impractical and unsafe on small vessels that are typical in the South East Trawl Fishery. In a rush to return to sea 2013, a South East Trawl vessel did not have time to sew extensions into their trawl as they normally would. The extensions make the trawl longer and stop fast swimming fish escaping from the trawl. The crew found that having a shorter net did not affect catches of the slow swimming species that they were catching, but instead over time noticed a large decrease in interactions with seals. SETFIA have now formally trialled the use of shortened nets in a paired experiment comparing shortened nets with normal nets. After 900 observed sets there has been no difference in the level of interaction between seals and both types of net (SETFIA unpublished data; Simon Boag pers. comm).	Knuckey (2009) Tuck *et al*. (2013) Simon Boag (SETFIA)
Prawn trawl fisheries and dugong bycatch	These fisheries were not included as a Case Study.	Dugong bycatch unlikely a serious threat in Australian waters (Trawling does not have a direct impact on dugongs, but may alter bottom habitats and disturb dugong feeding. (Grech *et al*. 2008; Donna Kwan and Sylvana Maas pers. comm).	Grech *et al*. (2008) Sylvana Maas (DOE, Migratory Species Section), Donna Kwan, (Convention on Migratory Species)

Fishery	Was this included as a case study?	Trawler bycatch and mitigation device details	Key information sources
United States fisheries	These fisheries were not included as a Case Study.	Provided contact for Dr. Patricia Rosel Dr Patricia Rosel: Stated that there are bycatch issues with mid-water trawl fisheries and primarily pilot whales in the U.S. northeast, but did not know of any physical mitigation measures have been tried to decrease bycatch. Provided contact details for Drs. Debra Palka and Marjorie Lyssikatos who are more familiar with this fishery. Dr Marjorie Lyssikatos: Stated that, to her knowledge, there are no mitigation measures implemented in the Northwest Atlantic New England or Mid-Atlantic mid-water trawl fisheries to reduce interactions with marine mammals. The level of observer coverage in these fisheries has increased in recent years with no subsequent increase in observed bycatch events. Total bycatch statistics for mid-water trawl gear have not been generated in recent years because bycatch is relatively rare event.	William Perrin Convention on Migratory Species Conference Appointed Scientific Counsellor on Marine Mammals, Dr Patricia Rosel - NOAA Federal Dr Marjorie Lyssikatos - NOAA Federal
Californian scientific sardine trawling operations	As we were unable to uncover any further information on the testing of the marine mammal exclusion device utilised in this fishery, this was not included as a Case Study	Zollett (2009) reported that excluder devices for marine mammals had not been tested or implemented in the United States. However, Carretta *et al*. (2013) reported that, in 2007 and 2008, four northern fur seals were incidentally killed in California waters during scientific sardine trawling operations conducted by the National Marine Fisheries Service, (NMFS, Southwest Regional Office, unpublished data). NMFS scientists implemented an initial mitigation plan which included use of 162 dB acoustic pingers (for cetacean bycatch mitigation), a marine mammal watch, and scheduling trawls to occur when the ship first arrived on station to avoid attracting animals to a stationary vessel (Carretta *et al*. 2013). However, two additional northern fur seals were killed in subsequent 2008 trawls. In 2009, a marine mammal excluder device was added to the trawls and no additional deaths were observed during 42 trawls (Carretta *et al*. 2013).	Carretta *et al*. (2013) Zollett (2009)
U.S. west coast fisheries that use a Nordic 264 pelagic rope trawl	This fishery was not included as a Case Study.	A Marine Mammal Exclusion Device (to exclude pinnipeds and cetaceans) was developed for fisheries research vessels that utilise a Nordic 264 pelagic rope trawl. However, as no new innovations were developed and there was limited testing of this device, we did not include this study as a case study.	Dotson *et al*. (2010).

Fishery	Was this included as a case study?	Trawler bycatch and mitigation device details	Key information sources
Gulf of California shrimp trawl fishery	This fishery was not included as a Case Study as no mitigation efficacy research was identified.	Even low levels of bycatch can have catastrophic results for small populations, such as the vaquita porpoise (*Phocoena sinus*). Vaquita are incidentally taken in mesh net and trawl fisheries throughout their range in the upper Gulf of California, where they drown after being entangled or captured. The exclusion device for the vaquita porpoise may be reducing bycatch of this species (Senko *et al*. 2013). WWF, together with Mexico's National Fisheries Institute (INAPESCA) and NOAA, developed and pilot tested a different type of trawl net targeting brown shrimp. It contains an excluder device to reduce vaquita bycatch while still effectively catching shrimp. Last year, the net was tested and is considered ready for use in the Upper Gulf. Fishermen are being trained to use the new alternative gear effectively and efficiently. http://worldwildlife.org/ species/vaquita	Senko *et al*. (2013)
New Zealand Southern Blue Whiting fishery	This fishery was not included as a Case Study as there has been no development of specific mitigation measures for the fishery. The recent introduction of SLEDs following bycatch incidents in 2013 was based solely on research undertaken in the Auckland Islands squid trawl fishery.	The SLED deployed in the NZ Southern Blue Whiting follows the design specification of that used in the Auckland Islands squid trawl fishery.	Richard Wells (Deepwater Group Ltd, New Zealand), personal communication.
New Zealand Hoki Trawl fishery	No. insufficient mitigation research undertaken.	An excluder device, based on the SLED used in the Auckland Islands squid trawl fishery, was briefly trialed in NZ waters. This work was based on the premise that a device that is efficient in allowing New Zealand sea lions to escape from squid trawls would also work in principle for New Zealand fur seals in hoki fisheries: this was not the case (Clements and Associates 2009). There were serious issues with escapement of target species through the SED and large fish becoming trapped across the hard grid bars. No excluder device is currently used in this fishery and any relevant work on an	Clements and Associates 2009

Fishery	Was this included as a case study?	Trawler bycatch and mitigation device details	Key information sources
		excluder design for fisheries targeting hoki has been undertaken by AFMA (Mike Gerner) in Australia’s Winter Blue Grenadier fishery.	

CASE STUDIES OF MITIGATION DEVICES

The following case studies (fisheries) were identified that provide substantial information on the development, application and research into the efficacy of marine mammal mitigation devices:

1) Winter blue grenadier fishery (Commonwealth Trawl Sector, SESSF) and seal exclusion devices (Case Study 1);
2) European (Dutch and Irish) pelagic fleet fishing off Mauritania, Northwest Africa and seal exclusion devices (Case Study 2);
3) Antarctica krill fishery and the development of a range of seal exclusion devices (Case Study 3);
4) Small Pelagic Fishery and seal exclusion devices (Case Study 4);
5) Auckland Islands squid trawl fishery and sea lion exclusion device (Case Study 5);
6) Western Australian Pilbara fish trawl fishery and dolphin excluder device (Case Study 6); and,
7) UK Bass pair trawl fishery and adjacent, overlapping European fisheries - dolphin excluder devices and pingers (Case Study 7).

WINTER BLUE GRENADIER FISHERY (COMMONWEALTH TRAWL SECTOR, SESSF) & DEVELOPMENT OF A SEAL EXCLUSION DEVICE (SED)

Description of fishery

The Southern and Eastern Scalefish and Shark Fishery (SESSF) is a multi-species multi-gear fishery situated off the south-east coast of Australia. The SESSF has the following trawl sectors: Commonwealth Trawl Sector (CTS), East Coast Deepwater Trawl Sector (ECDTS), and Great Australian Bight Trawl Sector (GABTS) (Penney *et al.* 2013).

The CTS extends from State waters out to the EEZ from Barrenjoey Point southward around NSW, Victorian and Tasmanian waters to Cape Jervis in South Australia (Tuck *et al.* 2013). The major component of the CTS is the South East Trawl (SET) fishery, which comprises 59 Boat Statutory Fishing Rights that use predominantly otter board trawl and Danish seine methods.

Most of the vessels in the CTS are ‘wet boats’ (fishing vessels that store fresh fish on ice or brine) that use demersal trawl methods although there are also a few factory boats that operate in the winter blue grenadier *Macruronus novaezelandiae* fishery off western Tasmania using mid-water trawls (Knuckey and Stewardson 2008).

In 1999, the Australian Fisheries Management Authority (AFMA) allowed factory trawlers (using mid-water trawls) into the winter blue grenadier fishery off the west coast of Tasmania (part of the CTS of the SESSF) to ensure the full utilisation of the total allowable catch (AFMA 1999 in Hamer and Goldsworthy 2006). The mid-water trawl fishery (1-2 vessels) operates under the SESSF management plan and is managed by AFMA.

In the early 2000s, a number of large vessels came across from New Zealand to fish in the winter blue grenadier fishery. The number of vessels has since decreased with a single vessel (*Rehua* length 66 m) operating since 2006-07 and a 2nd New Zealand-based boat coming into the fishery last year (Mike Gerner, pers. comm.).

Nature and extent of the marine mammal interaction and bycatch problem

The Australian fur seal, *Arctocephalus pusillus doriferus*, and New Zealand fur seal, *A. forsteri*, are commonly found in south-east Australian waters (Knuckey and Stewardson 2008). There is considerable overlap between the operations of trawl vessels in the SESSF and the foraging area of Australian and New Zealand fur seals (Arnould and Hindell, 2001; Arnould and Kirkwood 2008; Kirkwood *et al*. 2006).

Factory trawlers experienced a high Australian fur seal bycatch mortality rate in their first year of operation, with 89 seals caught from 665 trawl events (Hamer and Goldsworthy 2006; Tilzey *et al.* 2006).

There are currently relatively few seal interactions with mid-water trawl operations in the winter blue grenadier fishery (Penney *et al.* 2013).

Technical details of mitigation devices

Initial development of Seal Exclusion Device

In 1999, in response to particularly high levels of incidental captures of seals on factory trawlers working in the blue grenadier fishery, industry initiated a collaborative project with researchers to reduce seal bycatch in the factory boat component of the Commonwealth Trawl fishery (Tilzey *et al.* 2006). An Industry Code of Fishing Practice (www.fishwell.com.au) was developed which aimed to: minimise the accidental bycatch of seals and other marine mammals by entrapment or entanglement in commercial trawl fisheries; ensure all processor trawlers operating in this fishery follow this Code; and, ensure compliance with the laws and regulations governing fisheries and bycatch, including encounters with marine mammals. The project also trialled the use of Seal Exclusion Devices (SEDs) to assess their effectiveness in reducing seal mortalities (Knuckey and Stewardson 2008).

Specific management actions in the SESSF have focused on reducing fur seal interactions in the winter fishery for blue grenadier where the use of seal excluder devices (SED) has been mandatory since 2005 (Woodhams and Vieira 2012). AFMA require factory trawlers to include a SED in trawl nets as the principal gear modification for mitigating seal bycatch (Tilzey 2002 in Hamer and Goldsworthy 2006). The SED (Figure 1) comprises a stainless steel grid placed in front of the codend and an escape hatch some 5 m ahead of the grid (Hamer and Goldsworthy 2006; Tilzey *et al.* 2006). In principal, the SED allows the uninterrupted passage of fish through to the codend while prohibiting the entry and facilitating the escape of seals, subsequently reducing the risk to seals of drowning (Hamer and Goldsworthy 2006).

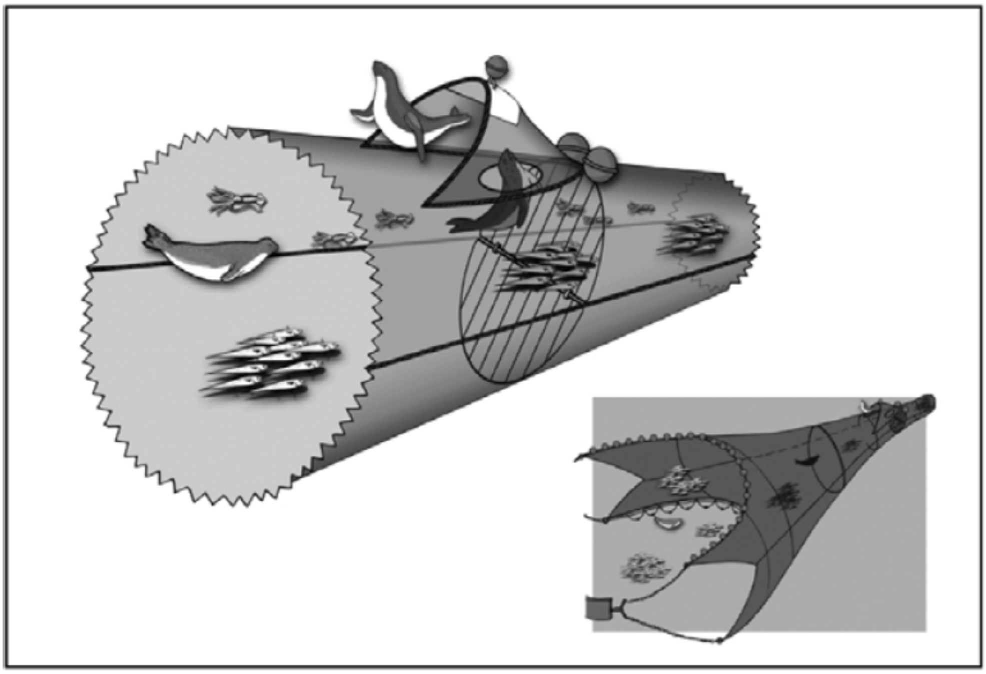


Figure 1: Schematic of seal exclusion device (SED) configuration used in trawls nets by factory trawlers off western Tasmania (Courtesy: Hoki Fishery Management Company NZ). Figure from Hamer and Goldsworthy (2006).

The inclusion of SEDs in fishing gear used by factory trawlers in the winter blue grenadier fishery and the concomitant reduction in the Australian fur seal bycatch rate between 2000 and 2002 led to the conclusion that SEDs were responsible for the observed reduction of seal bycatch and mortality on factory trawlers (Tilzey 2002 in Hamer and Goldsworthy 2006; Tilzey *et al.* 2006). Tilzey *et al.* (2006) identified that the perceived success of the SEDs must be validated firstly by quantifying the incidence of sub-surface net entry by fur seals and secondly by comparing the incidence of bycatch and mortality that occurred during trawl events that had the SED attached with those that did not.

From 2000-2002, a study was undertaken which:

- assessed the potential usefulness of SEDs in reducing seal bycatch in this fishery;
- improved the effectiveness of SEDs in blue grenadier trawl nets in reducing seal mortalities and minimising losses of fish;
- assessed the effectiveness of fishing techniques aimed at minimising seal bycatch;
- gathered biological information from all seal fatalities;
- achieved full observer coverage of freezer-trawler activities during the 2001 and 2002 winter grenadier fishery and monitor seal numbers around vessels and all seal-trawl interactions; and
- gathered information on seal movement/residence-time in the winter grenadier fishery (Tilzey *et al*. 2006).

In 2003, the study further trialled the most promising SED design and the use of only a grid to prevent seal access to the codend; gathered further information on seal movement/residence-time in the fishery; and made further observations on when/how seals entered the trawl net. The findings of this study were presented in Hamer and Goldsworthy (2006) and Tilzey *et al.* (2006).

Hamer and Goldsworthy (2006) reported on the environmental and operational aspects of the fishery associated with increased numbers of seals observed at the surface, and determined the incidence of net entry to establish the effectiveness of the currently used SED at reducing bycatch and mortalities (sub-surface net interactions were examined using a submersible video camera). Blue grenadier were predominantly caught at depths between 300 m and 600 m (Tilzey 1994 in Hamer and Goldsworthy 2006). Although dive data for Australian fur seals was limited, a single record of 102 m maximum depth for an adult male (Hindell and Pemberton 1997) and 164 m mean max depth for adult females (Arnould and Hindell 2001) suggested they were unlikely to forage naturally on blue grenadier due to lack of vertical overlap. However, blue grenadier may become available during fishing operations, when they are hauled into the upper water column within the trawl net and the period that the net is above approximately 200 m depth (during both shooting and hauling) is likely to be when seals are at greatest risk of becoming caught (Hamer and Goldsworthy 2006).

Hamer and Goldsworthy (2006) reported that:

- seal numbers increased when weather conditions deteriorated;
- seal numbers increased when the number of nearby vessels and trawl frequency increased, but decreased when vessel speed increased;
- seal numbers increased as the distance from the nearest breeding colony and haul-out site decreased;
- only one seal was detected entering and exiting the net mouth during monitored tows suggesting that reduced bycatch may not be necessarily attributable to SED use;
- the reduction in seal bycatch recorded in the factory trawler component of this fishery since 1999 was attributed to the introduction of SEDs but this seems unlikely considering all but one net entry resulted in bycatch;
- the reduction in seal bycatch was more likely due to a reduction in the incidence of seal–net interactions;
- seal bycatch mortality on the *FV Aoraki* also occurred during shooting. While this study indicated seals were equally as likely to enter the trawl net during shooting and hauling, the low incidence of bycatch recorded emphasised the need to continue investigating subsurface interactions;
- all seal bycatch occurred during the day and almost half occurred during shooting;
- mortalities were significantly higher during shooting compared with hauling, and mortality rates were similar between tows with the SED attached and those without;
- it appeared that seal bycatch was reduced when haul speeds were low which contradicted the recommendation in the 2007 Code of Fishing Practice, that nets should be hauled as quickly as possible to reduce the time that it remains within the diving range of fur seals (South East Trawl Fishing Industry Association SETFIA 2000/updated 2007);
- it was recommended that net hauling should be as fast as possible below maximum dive depth of the seals (about 200 m) to reduce the length of time available for Australian fur seals to reach the vessel, but should then proceed at speeds slower than the minimum average swimming speeds for fur seals (about 7.2 km/h) to reduce likelihood of seals becoming caught in the upper water column; to facilitate this hauling procedure, an

improved method of determining net velocity through the water column was considered necessary; and, changes to the Code of Fishing Practice would be unwise until an investigation of the relationship between haul speed and seal bycatch incidence was undertaken.

Tilzey *et al.* (2006) experimented with SEDs and different SED designs. Problems of significant fish-loss via the SED escape hatch and net blockage via the SED grid were encountered and solved by changes in SED design. The forward-facing 'top-hatch' SED had a significantly lower occurrence of seal bycatch than other SED designs and nets without a SED. Tilzey *et al.* (2006) considered that a top opening SED represented a considerable advancement over a bottom opening design because it better facilitated both seal exit (seals being more likely to swim upwards) and reduced the likelihood of seal entry via the escape hatch. An overall seal bycatch survival rate of 48% was achieved in nets fitted with SEDs, compared to zero for nets without a SED, largely because the SEDs prevented seals entering the codend where most drownings probably occur (Tilzey *et al.* 2006). However, SED performance remained largely unquantified because underwater video footage was limited and the numbers of seals interacting with the trawl net and successfully exiting the net via the SED escape hatch during this study were unknown. Obtaining significant results on SED performance by comparing replicate sets of trawl shots with and without a SED was difficult, because of the generally low level of seal bycatch and the complex suite of factors influencing seal interactions with the trawl net (Tilzey *et al.* 2006).

The current AFMA 'Gear Requirement' for the freezer processing vessels in the CTS of the SESSF includes a requirement that a SED is used in every trawl shot and that the SED complies with the following specifications:

- A grid is used to prevent seals from entering the codend of the trawl net, being a grid that is made of a rigid material strong enough to repel a seal (such as a 25mm diameter stainless steel rod) with a spacing between bars of no more than 250mm. The grid must conform as closely as possible to the corresponding cross-section dimensions of the net;

- The escape hatch must be no smaller than 800mm in length and 600mm in width at its widest point and be free of obstruction and be located at the top of the net adjacent to the SED;

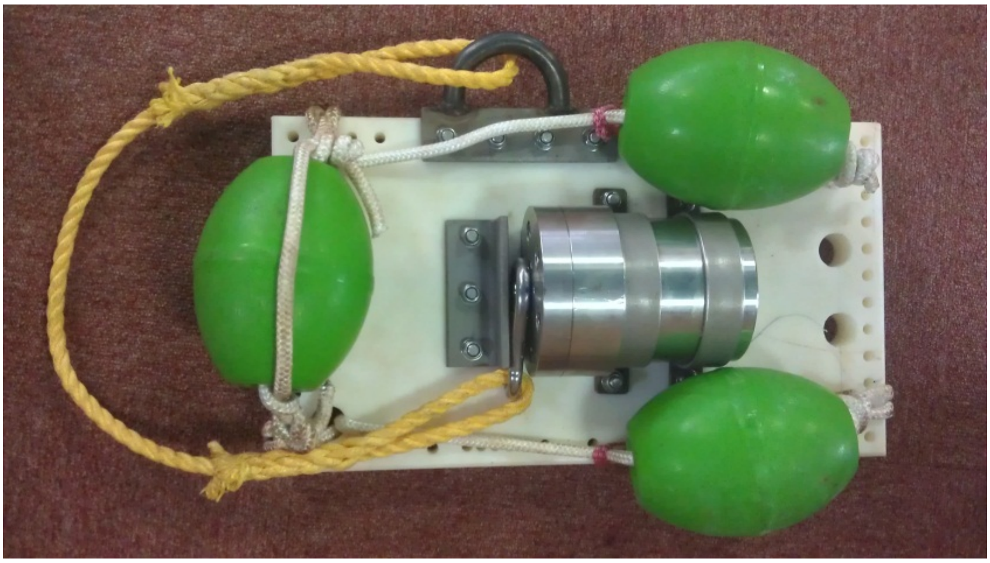
- The use of a 'hood' over the escape hatch is optional. If a hood is used it must be made of mesh no greater than 40mm and have a kite attached to the leading edge of the escape hatch that ensures that the escape hatch egress is maintained; and,

- At least one single 20cm diameter float is attached at the centre of the leading edge of the kite for initial flotation.

Development of SED with hydrostatic net release and acoustic transponder release gate ('Acoustic SED')

There have recently been some new developments with the design of the SED in the winter blue grenadier fishery. There had been problems encountered with SED performance in this fishery due to the larger size of the target species (blue grenadier) getting clogged in the grid when catching high volumes of fish. AFMA has been working with the vessel *Rehua* to improve SED performance in terms of improving seal exclusion as well as fish quality. The new design includes a hydrostatic net release, used to release net binding after the gear has been shot away, as well as an acoustic transponder release of a gate which excludes seals from the codend during hauling of the trawl. The SESSF Gear Directions (outlined above) do not currently include these design features and the acoustic SED is currently operated under a scientific permit (Mike Gerner, pers. comm.). This work is in the process of being formally documented and the following information has been provided, IN CONFIDENCE, by Mike Gerner AFMA.

Hydrostatic net release (see photo below): Nets are often bound with sisal so that the net remains closed until it reaches fishing depth. However, the use of underwater cameras identified that, particularly in rough weather, a net with sisal binding may open on deployment when still within the depth range of seals. Also, if too much binding is used, the net may not open at all. The Hydrostatic release, designed by Petuna-Sealord, releases the net at a depth of 300m and can be adjusted to suit conditions/seal diving depth. This device prevents seals from entering the net on deployment. The hydrostatic binding holds the net together very close to the mouth. This device was trialled in 2013 due to the observation of seals entering the mouth of the net during setting and resulting in mortalities during the 2012 season.



Acoustic transponder release gate (Figure 2): An Australian designed, New Zealand built Acoustic SED (Gated Seal Excluder Device), which was tested in the flume tank in May 2011, consists of a two piece grid sewn into the net in front of the codend. The grid has a hinged top half and fixed lower half. This design allows the top half/gate to be open while capturing fish (at depths beyond the diving range of seals) to facilitate the easy flow of fish into the codend. The device also stops the loss of fish through the seal escape opening, which has been a concern with other designs. Once the net is deployed and sufficient fish have been captured, the gate can be triggered to close, preventing any seals from entering the codend on retrieval to the surface and allowing any seals that may enter the net to escape via an opening in the top of the net. The gate is triggered by an on-board acoustic transponder deployed by hand over the stern of the vessel. This sends a signal to the release device (sewn into the net) which frees the latch and allowing the gate to drop.

In 2009/10, the mesh on the hood was changed from 90mm meshing to 45mm (prawn mesh) meshing. This reduces the likelihood of blue grenadier getting stuck in the hood meshes (i.e. ‘stickers’) where they could provide an attraction to seals during retrieval of the net.

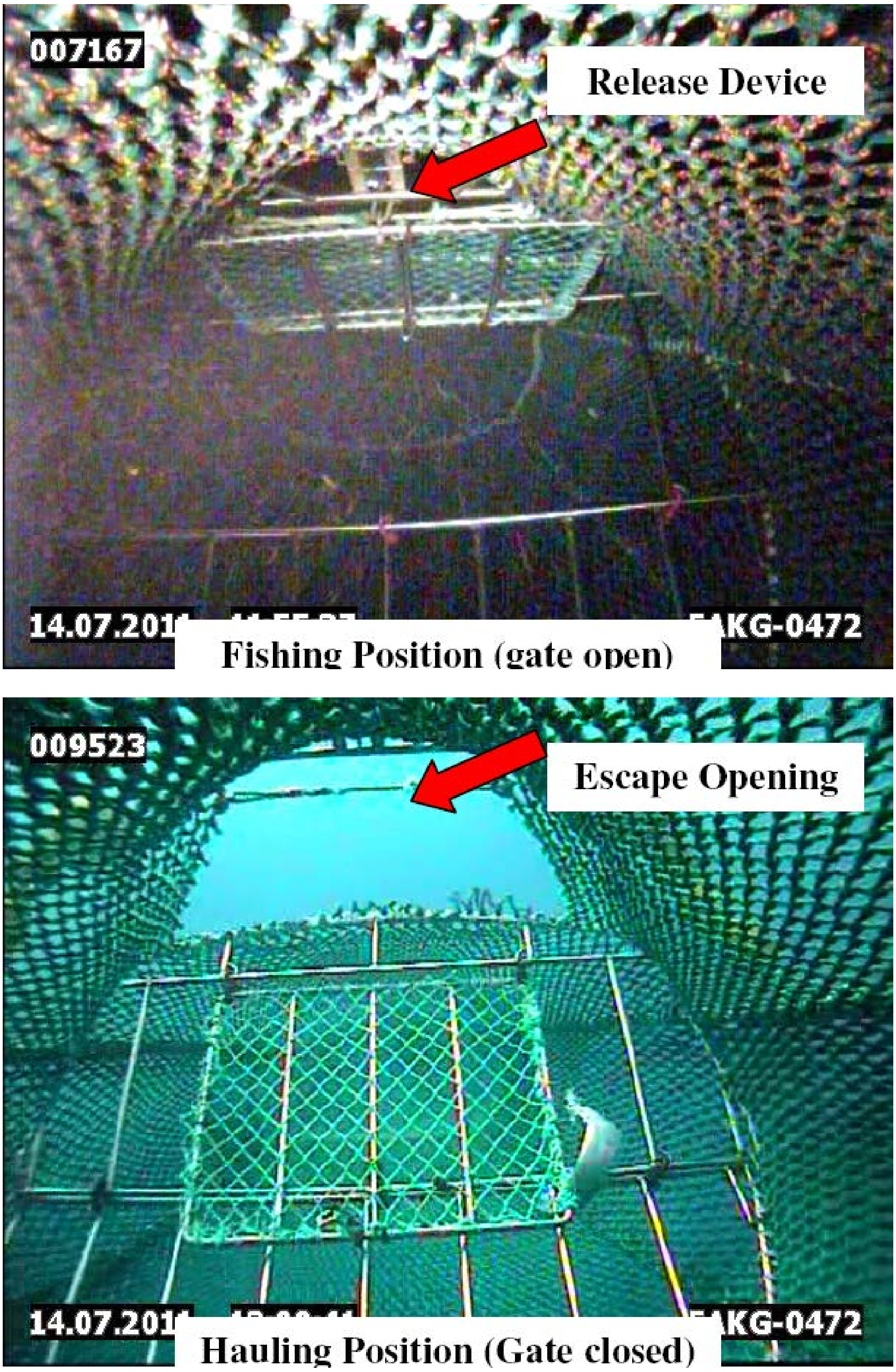


Figure 2: Acoustic-release gate in open and closed positions. The gate is held open by the acoustic actuator while the net is towed through the school of fish, allowing the fish to pass into the codend. Once the boat has finished towing through the school of fish, the gate is released (triggered from the boat) before the net is hauled (through seal diving range depths) and brought onboard.

Trials of the device - information provided by Mike Gerner, AFMA

The acoustic SED was deployed during fishing operations on board the fishing vessel *Rehua* during the Winter Blue Grenadier Season in 2011 and 2012 (Figure 3). The gate has successfully released every shot (except one which was not triggered due to safety concerns for the person triggering the device during rough weather). The device is being released at a depth estimated to be around 250m though this depth seems to be reduced during rough weather when there is more turbulence behind the vessel, obscuring the signal. The SED has allowed the easy flow of fish into the cod end. Rates of up to 10t of fish per minute (and up to 65t passing in one shot) have been observed without blockage or fish loss.

Two years of trials using the acoustic SED have been completed and there has been a reduction in fish loss, the problems of fish clogging the grid have been eliminated. There have been no seal mortalities observed in 2011, though in 2012 twelve seal mortalities were observed with the animals recovered in the codend. These events supported the development of the Hydrostatic release mechanism that was tested in 2013. (Mike Gerner, pers. comm.). The acoustic-release device is being further refined to improve ease of use for vessel operators.

Efficacy of the device

A report on the efficacy of the acoustic SED is currently being produced (Mike Gerner, pers. comm.).

At this stage the video footage has yet to reviewed and reported on (pending funding availability).

Note that, where possible, bycatch rates for mitigation research trials relevant to this Case Study are summarised in Table 11.

Specific vessel operating or structural characteristics

Petuna Sealord are working on building the transponder into the hull of the boat so that the acoustic SED is able to be operated from the wheelhouse to increase efficiency during rough weather and minimise impact on deck crew operation. The use of the Hydrostatic release with the acoustic SED hopes to minimise the capture of seals during the deployment of the net. Further refinements to the Acoustic SED design and use of hydrostatic release hopes to minimise the impact on deck operations and improve reliability of the two systems working together.

Key points:

- Recent work in the winter blue grenadier fishery has included some new and important innovations in SED design. These include a hydrostatic net release, an acoustic transponder release grid gate and installation of smaller sized mesh on the hood.

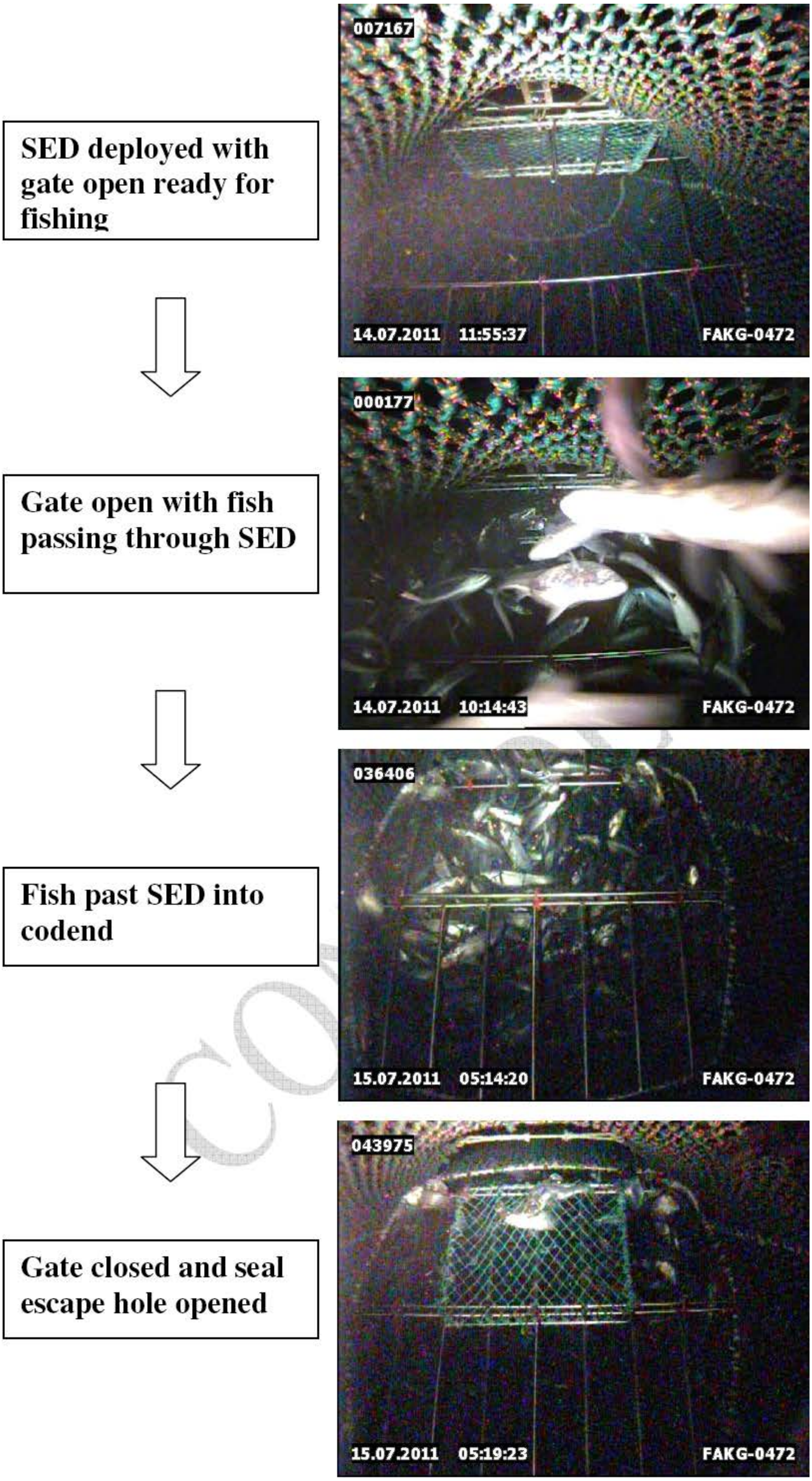


Figure 3: Video shots of the acoustic SED during deployment at depths beyond the diving range of seals (figure provided by Mike Gerner, AFMA).

EUROPEAN (DUTCH AND IRISH) PELAGIC FLEET FISHING OFF MAURITANIA, NORTHWEST AFRICA

Description of fishery

Between 40 and 70 foreign trawlers (Russian, Lithuanian, and Icelandic) including 5–10 European (Dutch and Irish) pelagic freezer-factory trawlers (net openings of 90 × 50 m) operated out of northwest Africa, which together yield more than 500,000 tons of small pelagic fish per year (Zeeberg *et al.* 2006).

Sardinella, sardine, and horse mackerel are the target species of the European (Dutch and Irish) pelagic fleet, which operates nearly year-round with five to ten freezer-trawlers. The pelagic freezer-factory trawlers are amongst the largest fishing vessels in the world with installed horse power for trawling and freezing between 9,000 and 18,000 hp. In the Mauritanian Exclusive Economic Zone (EEZ, 200 nm) they operate within miles of each other, fully exploiting the fish stocks that rank amongst the most productive and most intensively fished areas in the world (Zeeberg *et al.* 2006).

Nature and extent of the marine mammal interaction and bycatch problem

The conservation situation of small cetaceans in western Africa is not well known and few fisheries in western Africa are known to have been surveyed for small cetacean bycatch.

The majority of cetaceans captured in pelagic trawler fisheries are the smaller dolphins that live and forage nearer the sea surface (as opposed to deeper-diving dolphin species) i.e. common dolphins *Delphinus delphis*, bottlenose dolphins *Tursiops truncatus*, and (along the European shelf margin) white-sided dolphins *Lagenorhynchus acutus* (Zeeberg *et al.* 2006). Zeeberg *et al.* (2006) presents pelagic megafauna bycatch rates observed during more than 1,400 trawl sets off Mauritania, northwest Africa, between October 2001 and May 2005. The observed trawl sets represent 4–88% of the fishing effort of the Dutch pelagic freezer-factory trawlers in a particular month.

During this period, cetaceans made up 8% of the megafauna bycatch with 70–720 dolphins captured between 2001–2005 and the main bycatch species being common dolphins (Zeeberg *et al.* 2006). This bycatch occurred almost exclusively at night (Zeeberg *et al.* 2006). Additionally, in summers or years with low sardine abundance, bycatch of non-target species increases because the vessels continue to trawl while searching for the target species. This also happens when searching at night if target species has dispersed and fishers are searching for catch (Zeeberg *et al.* 2006).

There was also a strong seasonal relationship with cetacean incidental bycatch linked to the return of the migrating sardines. Trawlers in spring incidentally captured pods of 10–20 short-finned pilot whales or groups of 5–30 dolphins. The transit of sardines through the region appears to increase megafauna bycatch rates in all types of fisheries, with the combined international trawler fleet (40–70 vessels) accounting for a substantial part of the bycatch of larger, oceanic animals (Zeeberg *et al.* 2006).

Heessen *et al.* (2007) concluded that observations by the crew are likely to be an underestimate of the total number of bycaught megafauna. The working procedures on board Dutch trawlers is described in ter Hofstede *et al.* (2004) (cited in Heessen *et al.* 2007): "*As soon as the fishing skipper supposes that the amount of fish in the net is large enough for processing, most of the net is taken on board. Only the codend, the part where the target fish is gathered, stays in the water.*

The crew connects a fish-pump to the tip of the codend, and the catch can be pumped directly from the net into the storage-tanks on board the ship.

Pelagic megafauna are retained by a specific part of the net, the so-called shark-grid, which consists of large meshes that allow the smaller fish to pass, but prevent the larger animals from entering the codend. As a result, the pelagic megafauna cannot block the fish-pump when the catch is taken on board the ship. Normally the captured large species are released while the net is still in the water." In most cases the bycatch is discarded into the sea while the codend is still in the water but before the fish pumping starts (Heessen *et al*. 2007). This is done from deck by pulling a rope that opens a "zipper gate" at the lower end of the shark panel.

Technical details of mitigation devices

Trawl-gear modification to exclude larger pelagic animals from the catch is a trade-off between megafauna-filtering efficiency and catch—with full processing of 50–200 tons of small pelagic fish commonly taken in a set. The gear designed under this program guides pelagic megafauna deflected by a filter to an escape route along the bottom of the trawl (Figure 6).

These devices were not designed specifically to mitigate dolphin bycatch, but to address bycatch of all megafauna (sharks, manta rays, sea turtles, and dolphins).

Although individual dolphins could potentially escape using a tunnel, cetaceans are less likely to enter a narrow (3–4 m) release route because of 'claustrophobia', which has been observed among cetaceans in marine mammal parks and purse seine fishery for tuna (Zeeberg *et al.* 2006). The most practical way to reduce cetacean bycatch, then, is to have an exit in the net's top panel because dolphins had been observed to seek an exit in the upper part of the trawl (Zeeberg *et al.* 2006). The design of the escape tunnel (Figure 4) is thought to enable the cetaceans to reverse and accelerate upwards to reach the water surface (Zeeberg *et al.* 2006).

In addition to several types of cetacean "*barriers*" (i.e. vertical ropes in the front part of the trawl), acoustic deterrents are under development to prevent dolphins from entering the net opening, or guide them out during hauling (Zeeberg *et al.* 2006).

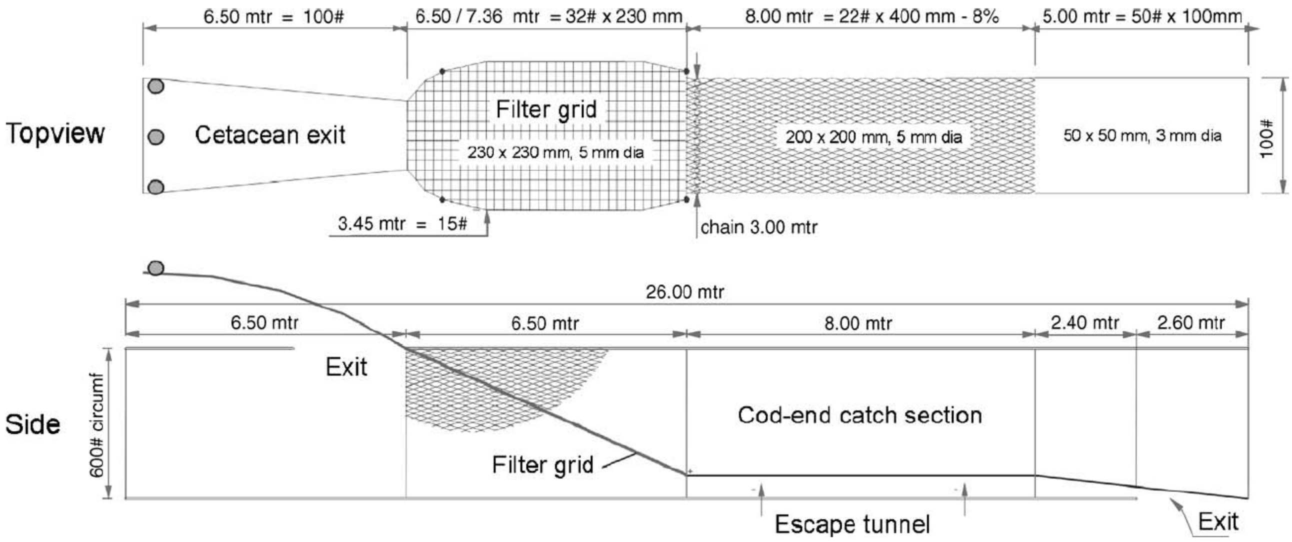


Figure 4: Technical specifications of the aft section of a mid-water trawl (about 50–70m in front of the cod end), showing the position of a filter grid connected to an escape tunnel. The filter grid slopes top-downwards with a ca. 20◦ inclination that forces larger non-targets downward to the tunnel entrance; before the grid is a cetacean exit (from Zeeberg *et al.* 2006).

Trials of the device

Zeeberg *et al.* (2006) tested a tunnel exclusion device in the Mauritania (West Africa) trawl fleet. To ensure acceptance by the fishing industry, experiments were aimed to achieve zero loss of target fish with at least a halving of the bycatch rate. First tests in fully commercial trawl sets with this "tunnel excluder" have been promising and a prototype is presently in experimental use by the Dutch trawlers off Northwest Africa (Figure 4). Underwater video recordings have demonstrated the functionality and rigging performance of the prototype, showing manta rays, hammerheads, and turtles exiting with ease. Improvements have focused on the diameter and stability of the tunnel opening, minimizing loss of target fish, and reduction of entanglements of sharks, manta rays, and bill fish. The inclination of the filter grid at ca. 20◦ balances the throughput of fish and the deflection of especially sun fish, which tend to be immobilized against the grid. Gear modifications are detailed in de Haan and Zeeberg (2005) cited in Zeeberg *et al*. (2006). The present prototype achieves a 40–100% reduction of the bycatch of the megafauna species most vulnerable to bycatch. However, while cetaceans made up only 8% of the retained bycatch, zero were released alive.

Efficacy of the device

Note that, where possible, bycatch rates for mitigation research trials relevant to this Case Study are summarised in Table 11.

In 2005-2006, the excluder was tested in order to study its effectiveness. The trawler crews collected observations and some additional underwater observations were made (Heessen *et al.* 2007). The observations were made on board four Dutch-owned freezer trawlers fishing in Mauritanian waters. Data were collected for a total of 1072 hauls made during 16 trips, altogether consisting of 350 fishing days, in the period 26 April to 15 November 2006. These vessels alternately fished with and without the excluder (Table 2). All vessels recorded the following data by haul: start and end time of haul, position, surface water temperature, and catch data. Information on bycatch of large fish and cetaceans were recorded, including details on species, their number and their size. If possible, pictures were taken to facilitate proper identification. Also, the position where the bycatch animals were found in the net was recorded. The use of the excluder did not significantly influence the catches of the target species (Heessen *et al.* 2007).

Table 2: Overview of the vessels and hauls for which these vessels provided information on bycatch (from Heessen *et al*. 2007).

	Trips	Fishing days	Hauls without excluder	Hauls with excluder	Total hauls
SCH 24	5	112	267	74	341
SCH 81	4	91	199	120	319
SCH 188	4	87	179	72	251
H 171	3	60	84	77	161
Total	16	350	729	343	1072

The number of hauls for which reports were received for each month, split into hauls with and without excluder, were reasonably well spread over the season (Figure 5; Heessen *et al*. 2007).

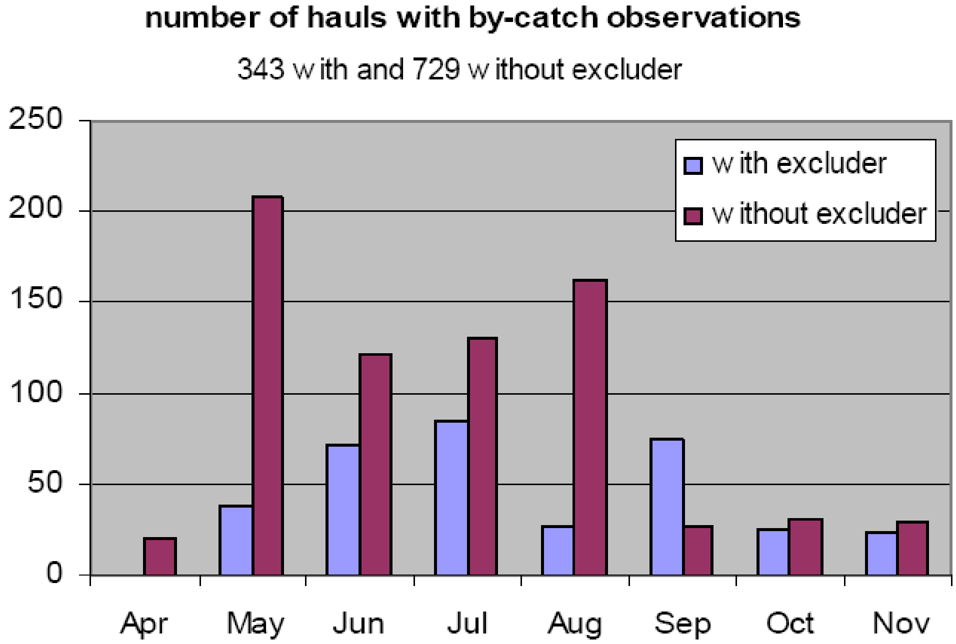


Figure 5: Number of hauls, with and without excluder, for which by-catch observations were provided (from Heessen *et al*. 2007).

For the observed hauls with and without the excluder deployed, Table 3 provides information on the observed bycatch of the large megafauna species including how many hauls a certain species or species-group was observed, and how many specimens were reported to have been caught.

Table 3: Overview of the by-catch observations: number of hauls, with and without excluder, in which certain large by-catch species were observed, and the total number of specimens reported. In addition the percentage of the hauls in which these by-catches occurred is indicated for each group (e.g. in 10 out of 343 (= 2.92%) observed hauls with excluder hammerhead sharks were caught), and the average by-catch in number per 1000 hauls (from Heessen *et al*. 2007).

	Numbers				**Percentage**		**Average per 1000 hauls**	
	with excluder		without excluder		with	without	with	without
	hauls	specimens	hauls	specimens	hauls	hauls	specimens	specimens
devil ray ("manta")	0	0	11	14	0.00	1.51	0.0	19.2
hammerhead shark	10	42	20	36	2.92	2.74	122.4	49.4
other sharks	2	6	6	12	0.58	0.82	17.5	16.5
billfish	8	28	21	100	2.33	2.88	81.6	137.2
sunfish	19	36	28	66	5.54	3.84	105.0	90.5
turtle	2	2	3	3	0.58	0.41	5.8	4.1
dolphin	1	4	4	15	0.29	0.55	11.7	20.6
pilot whale	0	0	1	1	0.00	0.14	0.0	1.4
hauls observed	343		729					

The numbers recorded during 2006 by the vessel crews most likely only refer to the bycatch that has been brought on deck (Heessen *et al.* 2007). Data collected between 2001 and 2004 by scientific observers had higher bycatch rates (Zeeberg *et al.*2006). The scientific observer data also included estimates of the numbers retained by the shark-grid, but released through the operation of the "zipper system", before the net was hauled on board or the observers usually asked the crew to take the whole catch on board. When large fish and cetaceans are released through the zipper-system, it is highly unlikely that they will survive, since most of the fish will have died from the high pressure in the net, whereas the cetaceans will already have drowned. The zipper-system is only used when a shark-grid is being applied. If large megafauna retained by the shark-grid are not, or not always, included in the bycatch records this will possibly have caused a serious bias in the bycatch rates for hauls without excluder.

From 12-25 July 2006 underwater video observations on two different prototypes of the Large Animal Reduction Device (LARD) were conducted on board the freezer trawler “Cornelis Vrolijk” H171 while fishing for Sardinella off the Mauritanian coast (Heessen *et al.* 2007). As is usual on board Dutch freezer trawlers, two pelagic trawls were used in order to minimize delays in case of trawl damage. One of the two trawls was rigged with a LARD. Daytime underwater observations of the performance of the LARD were made during 7 out of a total of 39 hauls. During these seven cases only a single release of a small hammerhead shark was observed, while another one became entangled in the LARD interior. During the remaining 32 hauls the pelagic trawl equipped with a shark-grid was used.

During the same trip used to do the underwater observations of the LARD, a number of hauls were made without using the LARD, but using a “shark blocking panel” instead. For these hauls, most of the bycatch occurred at night and included a number of dolphins (18 to 40 in total). In most cases the bycatch was discarded into the sea (using the “zipper gate”), while the codend was still in the water but before the fish pumping started. The bycatch of non-targets in a trawl rigged with a shark blocking panel in the codend demonstrated that dolphins, hammerhead sharks and large rays are mainly caught during the night (Heessen *et al.* 2007). The bycatch of dolphins illustrates the urgent need for research on the likelihood for escape of these animals through a LARD. Such research, however, can only be successful if the instruments could be modified to enable observations during night hauls. Observations indicated that some of the target fish (*Sardinella*) escape through the larger meshes in the tapered net sections.

At the start of the observation period, only one LARD was available and the second device, originally intended for use on board freezer trawler “Willem van der Zwan” SCH 302, did not arrive until the end of the period and could, therefore, only be observed on board the “Cornelis Vrolijk” H171 on the last day of the research period. The issues identified for the research presented in Heessen *et al*. (2007) were:

12. the filter of the first LARD was repaired before the observation period and enlarged in width. This meant that a proper comparison with previous bycatch registrations could not be made;
13. the design of the codend sections of the two LARDs was not identical, since an arrangement behind the LARD to avoid fish from swimming forward (so-called “fish flaps” or valves) was only built in the second LARD;
14. the mesh-size of the tunnel was different;
15. both prototypes did not contain the desired and recommended weight on the junction of the filter grid and escape route. This affects the efficiency of filtering targets.
16. We conclude that the LARD tested was not fully effective in reducing bycatch of small cetaceans.

Key points:

- The Large Animal Exclusion Device (LARD) in this fishery was developed to address bycatch of all megafauna (sharks, manta rays, sea turtles and dolphins).
- There is an urgent need for research into the likelihood of dolphin escape through a LARD.

- Vertical rope ‘barriers’ in the front part of the trawl and acoustic deterrents were under development but no information was found regarding their efficacy in reducing dolphin bycatch in this fishery.

ANTARCTICA KRILL FISHERY AND THE DEVELOPMENT OF A RANGE OF SEAL EXCLUSION DEVICES

Description of fishery

Commercial krill (*Euphausia superba*) trawl fishing began in the early 1970s and the prospect of a free-for-all fishery for Antarctic krill led to the signing of a unique fishing treaty in 1981. The Convention on the Conservation of Antarctic Marine Living Resources (CCAMLR) is designed to protect the Antarctic ecosystem from the consequences of rapidly-expanding fisheries, and to aid recovery of the great whales and some of the overexploited species of fish.

Nature and extent of the marine mammal interaction and bycatch problem

Discussions on the level of Antarctic fur seal (*Arctocephalus gazella*) mortality associated with the krill trawl fishery first took place at the 2003 meeting of CCAMLR's Working Group on Incidental Mortality Associated with Fishing (WG-IMAF) (Reid and Grilly, 2014). This was a new issue for this group as no incidental fur seal catches had previously been reported from the krill fishery.

In 2004, data provided by the United Kingdom part of the CCAMLR Scheme of International Scientific Observation indicated that 292 fur seals were caught during krill fishery trawl operations in Subarea 48.3 in the 2003/04 season (Reid and Grilly, 2014).

Technical details of mitigation devices and trials of the devices

In 2004, the United Kingdom reported to CCAMLR on the bycatch of Antarctic fur seals in the krill fishery around South Georgia, and on the different mitigation methods that were being developed and deployed to avoid fur seal deaths in the fishery (Hooper *et al.* 2005).

The number of entrapped seals observed in 'Area 48' during the 2004/05 krill fishery season was considerably less than the previous year, yet still high enough to warrant concern (Reid and Grilly, 2014). The CCAMLR Scientific Committee reiterated their recommendations that every vessel should employ a SED and that observers should be required on krill trawls to collect reliable data on mortalities and efficacy of mitigation devices. The Scientific Committee largely considered the paper Hooper *et al.* (2005) in which various SEDs and their success rates were outlined. Observer reports were only received from four of nine trawl vessels in Area 48 in 2005 and this inconsistent level of observer coverage was considered insufficient to permit resolution of seal bycatch issues.

Mitigation measures for fur seal bycatch were tested for krill vessels fishing around South Georgia in the 2004 fishing season (Hooper *et al.* 2005). The range of measures were categorised into four approaches: physical barriers (panels of netting) excluding seals from entering the net; physical barriers (panels of netting) positioned within the net accompanied by escape channels or openings; manufactured seal-exclusion devices in front of the codend that were composed of a separator grill that deflected seals to an escape opening; fishing gear configured with panels of a mesh size adequate to allow seals to escape (i.e. the forward part of the roof of the net had three large mesh panels inserted into it of mesh size 16 m and a further 2 panels of mesh size 4 m which appeared to allow the seals to escape alive and unharmed). It was considered that in all the above four cases, the incidence of seal entanglements during the 2004 season was either eliminated or greatly reduced (Hooper *et al.* 2005).

The range of mitigation devices outlined in Hooper *et al.* (2005) were:

- The *Atlantic Navigator* was equipped with a seal exclusion device (Figure 6) which was positioned within the net and consisted of a metal grid sloped at an angle to divert seals out through an escape panel. The device was fabricated and configured on board the vessel.

Despite the device, seal entanglements were recorded for the first two trawls. As a result, the gear was modified by enlarging the hole and changing the orientation so the seals escaped through the floor of the net rather than the roof and no further captures were reported. [NB. The authors do not discuss the possibility that dead animals may have fallen out of the SED escape hole on hauling]. This vessel keeps the net at fishing depth for prolonged periods and uses a pump to remove the krill which means the number of shooting and hauling operations is reduced and this may also reduce the incidence of seal entanglement.

Figure 6: Seal-exclusion device on the *Atlantic Navigator*. From Hooper *et al*. (2005).

- The *InSung Ho* deployed a device that was constructed from 240 mm nylon mesh and positioned immediately anterior to the net. This device acted as a barrier suspended over the mouth of the net. The apex of the barrier was attached on either side where the headrope and groundrope connected to the warps. Two mesh planes, 44 m in width and 20 m in length, extended back to cover the mouth of the net, one situated above the headrope and one below the groundrope respectively. Part way through the season, modifications were made so that the device was spliced into the perimeter of the net just posterior to the mouth and this improved design ensured there were no gaps through which the seals could gain access to the net. The barrier extended back into the body of the net by approximately 20 m and functioned similar to a giant ‘bag’ (Figure 7). Only two subsequent seal entanglements occurred. A seal was discovered inside the ‘bag’ during trawls 72 and 95. In both cases the seal was released alive and unharmed.

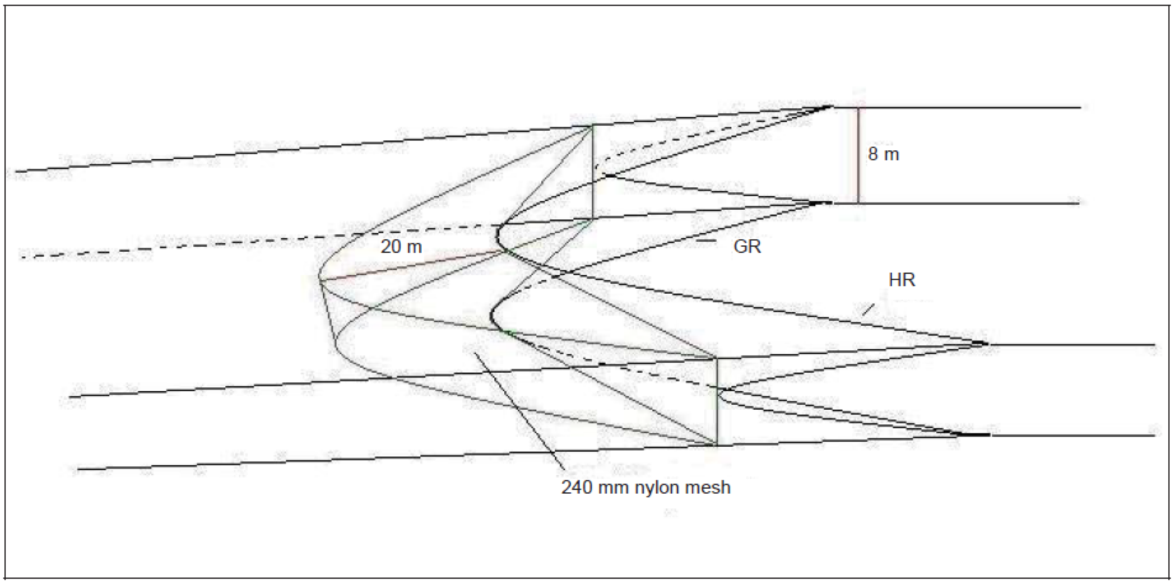


Figure 7: Modified mesh barrier deployed on the *InSung Ho*. HR – headrope, GR – groundrope. From Hooper *et al*. (2005).

- Two different nets were used by the *Top Ocean*. Modifications were made to both nets to create a series of mesh barriers and escape openings (i.e. "measures") which were trialled.

The first net had:

(i) Measure 1: an inclined mesh barrier spliced into the inside of the net to guide seals upward towards an escape opening. This was constructed from 140 mm polypropylene mesh and positioned immediately after the escape opening. The escape opening in the roof of the net was initially 0.5 m in diameter but the opening was increased to 1 m in diameter to allow seals to escape more easily (Figure 8);

(ii) Measure 2: an additional three 1.6 m mesh escape openings positioned in the roof of the net (Figure 8); and,

(iii) Measure 3: a large mesh barrier measuring 162 m^2 (13.5 x 12 m), positioned 47 m from the mouth of the net (Figure 8).

The second net had:

(i) Measure 1: a mesh funnel spliced into the inner panel anterior to the codend to guide seals towards an escape opening 0.5 m in diameter in the roof of the net. The funnel was constructed from 240 mm nylon mesh and was located inside the 15 mm inner mesh liner and within the 140 mm mesh of the outside net (Figure 9); and,

(ii) Measure 2: To improve its effectiveness, a large mesh barrier was also inserted 47 m from the mouth of the net measuring 162 m^2 (13.5 x 12 m). A 1.6 m mesh opening was placed in the roof of the net immediately in front of the barrier (Figure 9) and the funnel and original escape opening were removed.

The most successful measure was measure 3 on the first net. All other measures resulted in some reduction in bycatch, but not its elimination. When the vessel operators considered that net 1, measure 3 was the most successful, measures 1 and 2 were removed from the first net and the second net was also configured with measure 3.

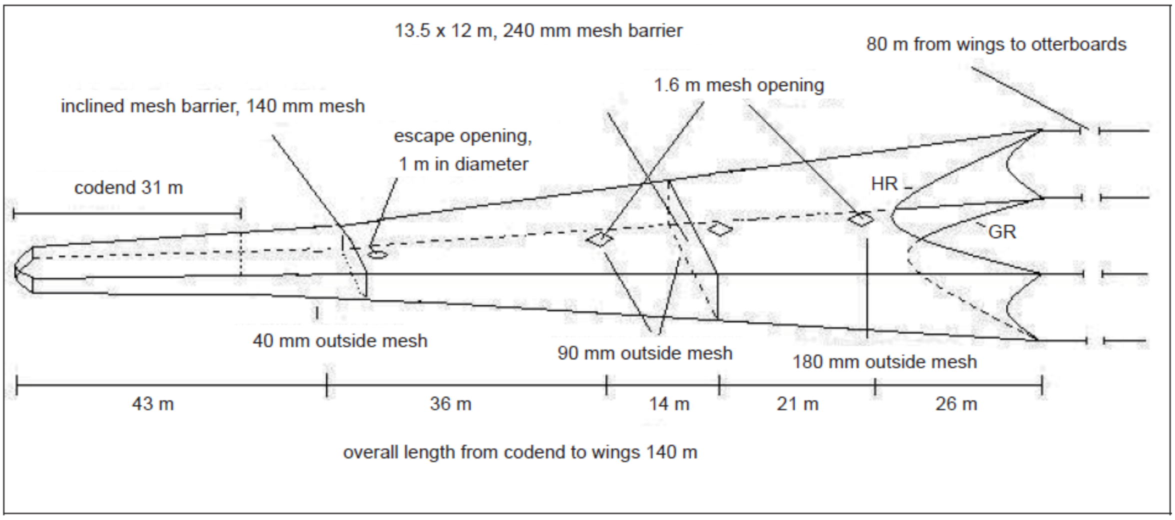


Figure 8: Mitigation measures of the first net deployed by the *Top Ocean*. HR – headrope, GR – groundrope. From Hooper *et al.* (2005). Details of the different design elements for net 1 (Measures 1-3) are provided in the text.

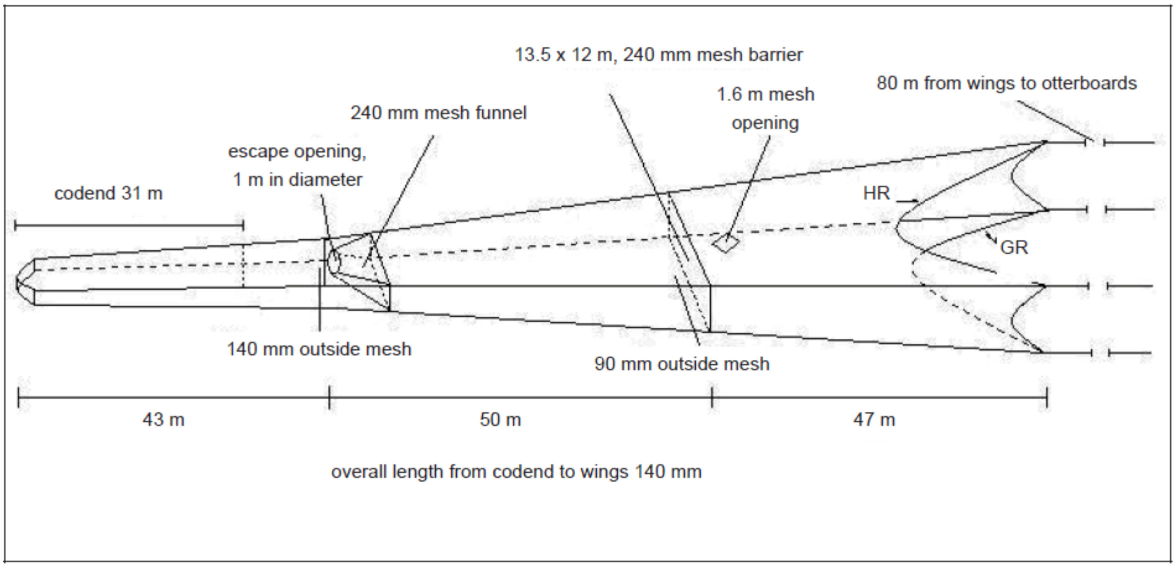


Figure 9: Mitigation measures of the second net deployed by *Top Ocean*. HR – headrope, GR – groundrope. From Hooper *et al.* (2005). Details of the different design elements for net 2 (Measures 1 & 2) are provided in the text.

- The Japanese net systems are referred to as NISSUI and MARUHA. The NISSUI system was installed in the nets used on the Koyo Maru No. 8 (Figure 10). The NISSUI system was developed by Nippon Suisan Kaisha Ltd. A section of roof panel netting, measuring 6 x 4 m is removed, and replaced with a panel of a larger mesh size of 1.6 x 1.6 m, thus permitting the seals to escape. The seals are deflected towards the panel by insertion of a section of net constructed from 300 mm mesh and configured obliquely, guiding the seals to the escape panels. The 300 mm mesh allows the krill to pass through to the codend. The MARUHA system was developed by Maruha Trawl Corporation and incorporated into nets used on the Chiyo Maru No. 5. An inner net is arranged within the body of the main net (Figure 11). The initial section of the inner net had a mesh size of 200 mm, followed by a section of 150 mm. The inner net acted as an excluding device, preventing the seals from entering the codend. A panel with a single section of mesh, size 1.5 x 2.1 m, was located in the upper panel (Figure 11), providing a means of escape.

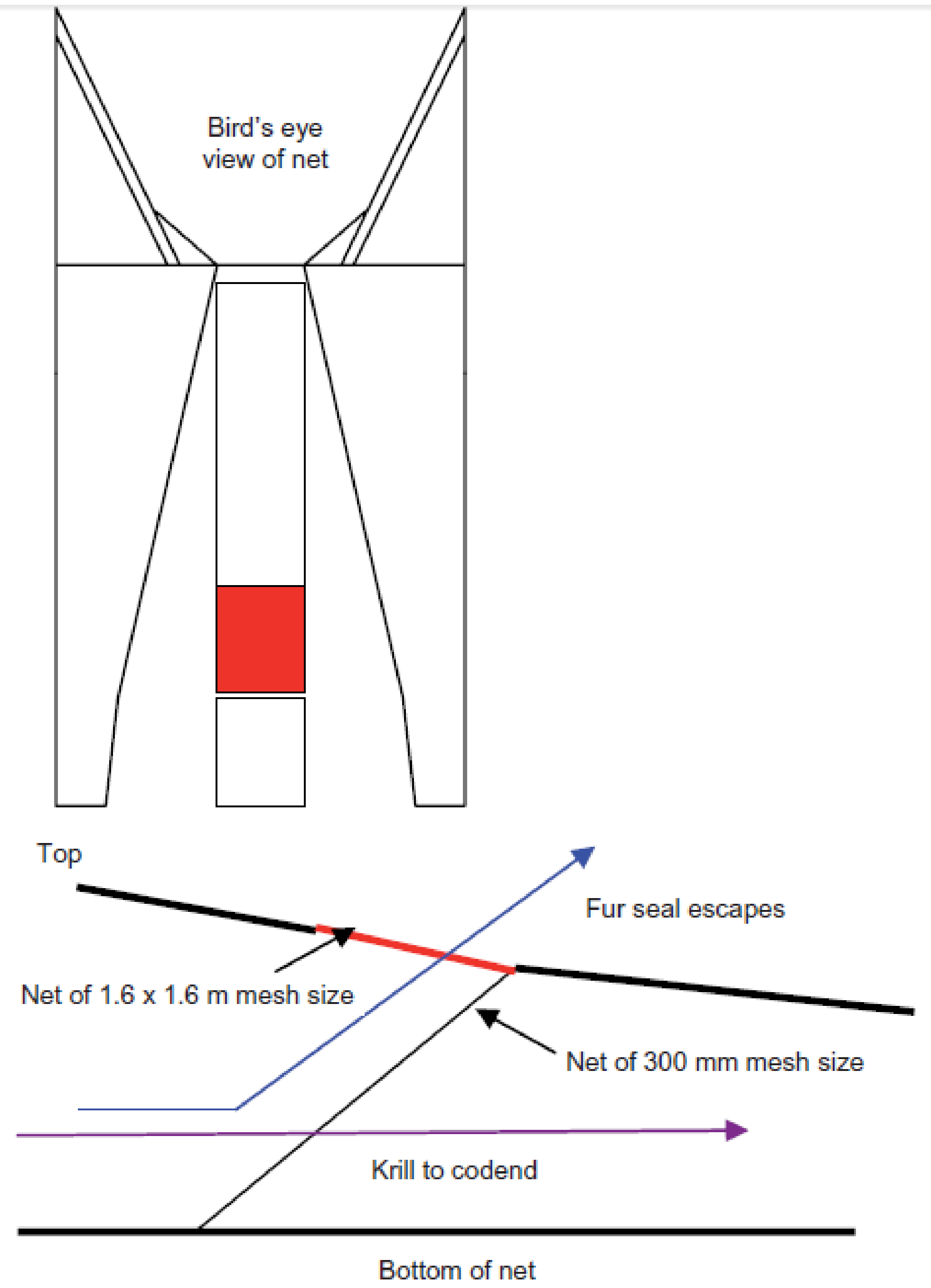

Bird's eye
view of net
Top
Fur seal escapes
Net of 1.6 x 1.6 m mesh size
Net of 300 mm mesh size
Krill to codend
Bottom of net

Figure 10: Net plan of the NISSUI system. From Hooper *et al.* (2005).

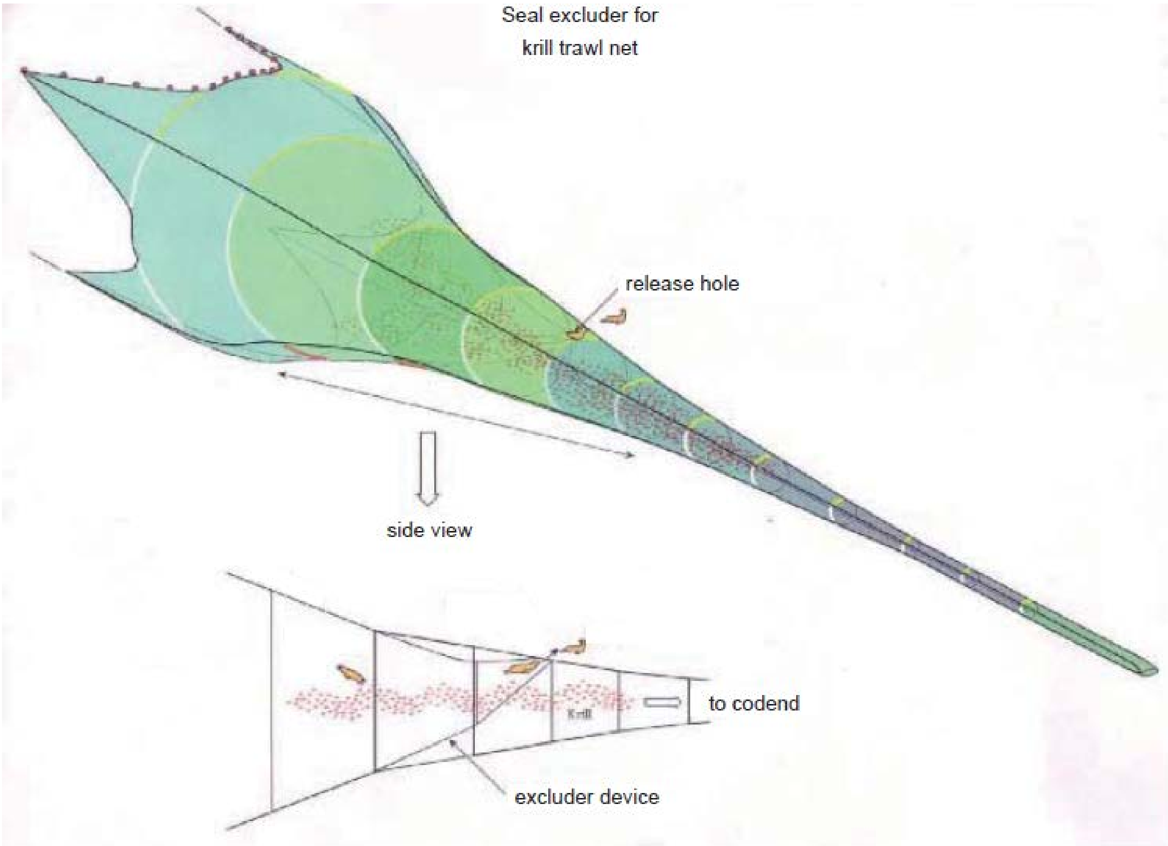


Figure 11: Net plan of the MARUHA system. From Hooper *et al.* (2005).

Trials on the efficacy of the device

Note that, where possible, bycatch rates for mitigation research trials relevant to this Case Study are summarised in Table 11.

During the 2005/06 krill fishery season observer data were available from 15% of the total fishing effort in the krill fishery and one Antarctic fur seal was reported killed (Reid and Grilly, 2014). While this was greatly reduced from previous years, without 100% coverage the extrapolated mortality rate remained uncertain.

No marine mammal mortalities were reported for the 2007 krill fishery season (Reid and Grilly, 2014). The Scientific Committee stressed the continued need for monitoring of incidental mortalities and for an improved reporting process on the use of mitigation devices within the trawl fishery in order to document which measures were successful. Six mortalities were recorded in Subarea 48.3 in 2008. The Scientific Committee suggested the krill fishery notification pro forma should be amended to include specific information on gear configurations such as mesh size, net opening, presence and design of SEDs. The Commission agreed to apply the general mitigation measure contained in Conservation Measure 25-03 and also introduce the mandatory use of marine mammal exclusion devices on trawls in the krill fisheries in Area 48 (CM 51-01), Division 58.4.1 (CM 51-02) and Division 58.4.2 (CM 51-03). The Conservation Measures were adopted by the Commission and are currently still in force.

CCAMLR has endorsed the recommendations of its Scientific Committee regarding the reduction of seal bycatch in the krill trawl fishery through the use of excluder devices (Anon 2006; NMFS 2011).

Specific vessel operating or structural characteristics

CCAMLR do not specify a standard exclusion device as there are a number of different fisheries utilising different net designs (Keith Reid, CCAMLR Science Manager, pers. comm.). Each fishery deploys mitigation devices that suit the characteristics of the fishery and vessels.

Key points:

- A range of seal exclusion devices have been developed for the Antarctic krill trawl fishery.
- Each device is tailored according to the characteristics of the fishery and vessels in that fishery.

SMALL PELAGIC FISHERY AND SEAL EXCLUSION DEVICES

Description of fishery

The Australian Small Pelagic Fishery (SPF) targets Australian sardine (*Sardinops sagax*), Blue mackerel (*Scomber australasicus*), Jack mackerels (*Trachurus declivis, T. murphyi*) and Redbait (*Emmelichthys nitidus*). These target species occur in the diet of some odontocetes (toothed whales and dolphins). The SPF uses purse-seine and mid-water trawlers to catch fish (Moore and Skirtun, 2012). The SPF extends from southern Queensland to southern Western Australia and is currently divided into two sub areas East and West of latitude 146°30'00" (www.afma.gov.au).

Mid-water trawling was trialled off the east coast of Tasmania during 2001 using the pair trawl method, the success of which led to the introduction of a purpose built mid-water trawler into the fishery in late 2002 (Lyle and Willcox 2008).

Nature and extent of the marine mammal interaction and bycatch problem

As the SPF region covers all the breeding locations and known foraging ranges of Australian fur seals, New Zealand fur seals and Australian sea lions in Australia, and there have been known interactions between seals and other trawlers in the SPF, all three species are at risk from interactions with any proposed fishery in the SPF region. Interactions with fur seals and dolphins in the SPF were identified as an issue of concern in 2004–05. Management has focused on gathering data to understand the level of interaction, research into mitigation measures and the introduction of seal excluder devices. AFMA established the Cetacean Mitigation Working Group to help develop long-term management strategies.

Interactions with marine mammals (fur seals and cetaceans) were identified as a key environmental concern for the mid-water trawl fishery (Moore and Skirtun 2012). AFMA commissioned a study conducted from January 2006 to February 2007 using underwater video information for almost 100 trawls, representing over 700 hours of video footage (Lyle and Willcox 2008). This study quantified the nature and extent of interactions and evaluated potential mitigation strategies and found that fur seals entered the net in >50% of mid-water trawl operations, with an observed mortality rate of 0.12 seals per shot for nets using bottom-opening SEDs (Lyle and Willcox 2008). Given the high level of interactions with fur seals (despite deployment of SEDs), this study indicated that more effective SEDs were needed for the mid-water trawl (Moore and Skirtun 2012).

Of the 184 seal interactions with mid-water trawl gear reported during 2001-2010, 175 were incidentally caught during scientific projects aimed to determine the type and frequency of interactions and to assess the performance of various excluder devices as a means to mitigate seal and dolphin interactions (Tuck *et al.* 2013). Most of the seals were believed to be Australian fur seals, with 145 (79%) reported as surviving the interaction. There have been no reported incidental interactions between fur seal and the mid-water trawl fisheries of the SPF since 2007 (based on observer coverage of <13% mid-water trawl shots per annum since 2007) (AFMA 2011, AFMA 2012, Tuck *et al.* 2013). The lack of reported interactions coincides with a reduction in effort in the fishery, a decline in observer coverage as well as no mid-water trawl fishery catches in 2011 (Tuck *et al.* 2013).

The lack of cetacean interactions reported for the SPF mid-water trawl fishery since 2009 corresponds to a reduction in fishing effort rather than a low level of interactions with cetaceans. Prior to this, from 2001-2009, there were 25 reported dolphin mortalities in this fishery. AFMA require certain mid-water trawl vessels to comply with a seal and dolphin management plan that mandates mitigation measures be used to minimise interactions with these species, however the success of these measures has not been properly determined for cetaceans (Tuck *et al.* 2013).

Technical details of mitigation devices

Seal Exclusion Devices trialled by Lyle and Willcox (2008)

At the commencement of the fishery in Tasmania, a ‘soft’ rope-mesh Seal Excluder Device (SED) and a high level of observer coverage was used (Lyle and Willcox 2008). In 2004, 14 dolphin mortalities occurred in two separate incidents east of Flinders Island. After this, full observer coverage was applied to the fishery and other dolphin bycatch mitigation methods applied, including that the gear would not be set if dolphins were sighted around the vessel, and the vessel would steam at least 10 kilometres away from areas where dolphins were present before setting the gear. However, a further 3 dolphin mortalities occurred in mid-2005.

Three SED configurations were trialled by Lyle and Willcox (2008): (i) bottom opening, small escape hole, (ii) bottom opening, large escape hole, and (iii) top opening. The bottom opening SED was comprised of two panels, producing a 2.3 x 2.3 m steel grid, with 10 vertical steel bars spaced at 21 cm. The SED was angled forwards at about 15-25^{o}, with the escape opening located at the base of the SED. The ‘small escape hole’ configuration, with an approximate 1 x 1 m escape opening, was trialled initially. The hole was subsequently enlarged to 1.9 m wide, producing the ‘large escape hole’ configuration. Escape holes were either left open, or had a flap of netting or short lengths of rope attached to the leading edge in an attempt to discourage the loss of target species while not hindering the exit of large bycatch species. The top opening SED was constructed of four panels, to produce a grid that was 5 m high by 2.1 m wide with steel bars spaced at 23 cm, which was angled backwards at 45º. A 1.8 m wide by 0.55 m deep escape opening was positioned on top of the net, immediately in front of the SED. A cover flap of trawl netting was attached to the leading edge of the escape opening. The bottom opening, small escape hole configuration was used continuously until early June 2006 when the escape opening was enlarged (large escape hole configuration) following several seal mortalities. The large escape hole configuration was used to the end of January 2007. The top opening configuration was then trialled for about a month but owing to operational problems, specifically difficulties in retrieving the SED onto the net drum, it was deemed operationally unsuitable for the vessel and replaced with the bottom opening configuration at the end of the study period (Lyle and Willcox 2008).

From Jan 2006 – Feb 2007, Lyle and Willcox (2008) obtained underwater video information for almost 100 trawls, representing over 700 hours of video footage. No interactions with dolphins were observed or reported over the entire study period, highlighting that such interactions are rare and unpredictable.

Seafish Tasmania - SED developed by Maritiem (2012)

A seal exclusion device (SED) was designed for use on the factory trawler that Seafish Tasmania proposed to operate in the SPF (Figure 12). The SED, designed by Maritiem, had a soft fibre grid made of a flexible and strong material called Dyneema twine (Maritiem 2012). Dyneema is similar in the way its feels and looks to the nylon used in the trawl, but without any stretch and of the same strength as steel for the same diameter. It was considered that a hard SED (e.g. constructed of steel bars) would not be practical, as it would not withstand the forces applied to the trawl, particularly during the time of shooting and hauling back. A hard grid would also not be suitable for the factory vessel (*FV Abel Tasman/Margiris*) because this vessel used a net drum and did not have a ramp - a hard material like steel would not be practical for use on a net drum and would bend out of shape. The recommended soft grid was of a mesh size of 200x200mm. Previous research showed that this size was adequate to stop the expected bycatch species to pass through it. It was proposed that the SED would be mounted on the bottom panel of the cod end on the forward side and on the top of the cod end on the aft side, with a release at the top of the cod end (Maritiem 2012).

It was considered that the angle of the device in the cod end was important. If parallel to the seams of the cod end is 0° and perpendicular to the seams [vertical] is 90°, it was recommended that the grid was positioned at an angle of between 15° and 25° (Maritiem 2012), which increases the grid length. It was thought that lengthening the grid, achieved by using a small angle, improves the capacity of the grid to allow target species to pass through into the codend (Maritiem 2012). Underwater camerawork has shown that the targeted fish is usually swimming forward towards the direction of the mouth of the trawl, is 'overtaken' by the trawl, and subsequently slowly move backwards into the trawl. In this position, a grid with as low an angle as possible will make it more likely that the species go through the grid 'of their own choice', when the space between this panel and the top of the cod end becomes increasingly narrow, rather than be washed through it by the flow in the cod end. Larger species that are not able to go through the 200x200mm panel will stay above it and ultimately find their way out of the opening at the end of the grid, on the top side of the cod end (Maritiem 2012).

To avoid targeted species being lost through the opening on the top panel of the cod end, a cover was designed to go over the opening that, with the use of floats and the speed of the trawl, would open at an angle of approx. 45° (Maritiem 2012). Bycatch species trying to escape out of the trawl would actively swim forward to clear this cover, once outside of the cod end. Targeted species would not be able to swim forward and would be deflected by the cover back into the cod end, towards and through the grid. The opening on top has the added advantage that species who do not make it out of the trawl, are unlikely to be automatically released during the hauling process and, therefore, these mortalities can be monitored (Maritiem 2012). It was proposed that the excluder would be positioned between the intermediate [or conical] part of the trawl and the straight cylinder part of the trawl, at approx. 50m from the end of the cod end (Maritiem 2012). It had been agreed to use additional flotation around the hood and that a camera was to be set up on the top of the panel to monitor animal activity on the vessel side of the SED. The additional floatation would allow large animals to move through as well as maximise the function of the hood to retain any potential deceased animals so they could be brought on board the boat. The underwater camera gear would have the ability to record the outside of the net to view the function of the hood and could be repositioned to also record the inside of the net to view the grid inside the net (Mike Gerner, pers. comm.).

Due to the declaration that prohibited the use of a large factory trawler in this fishery, this SED was never trialled on the large factory trawler in the SPF.

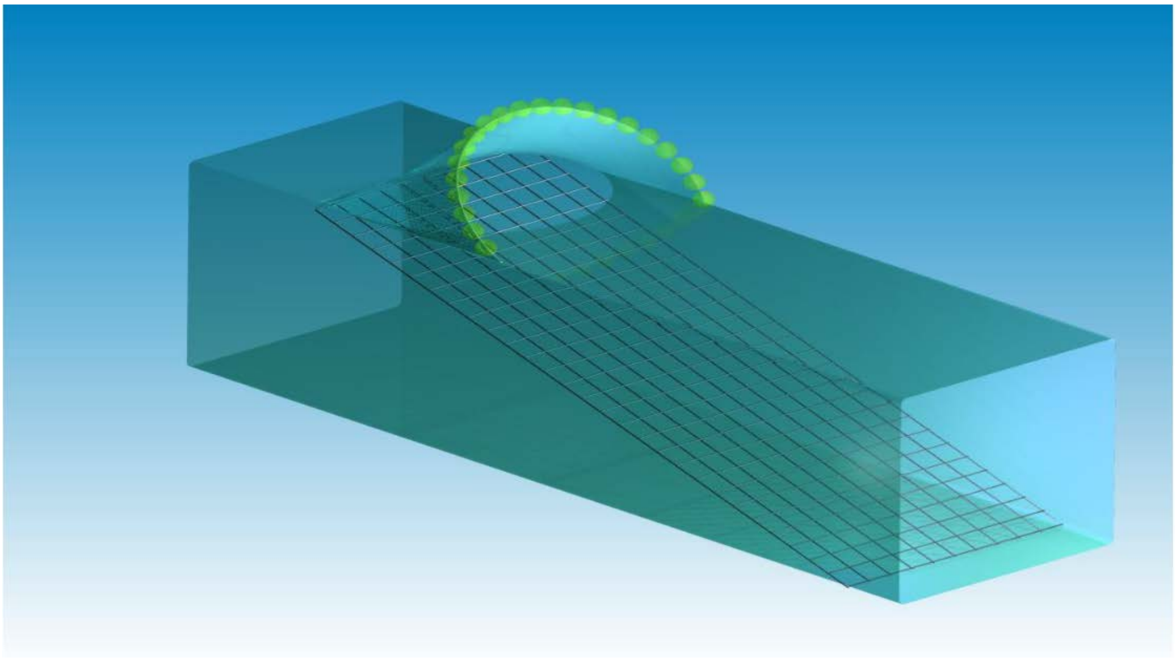


Figure 12: Visualisation of the SED that was proposed for the *FV Abel Tasman* in the SPF fishery.

Auto-trawl system

The auto-trawl system that was to be utilised by Seafish Tasmania on the FV Abel Tasman results in the trawl gear maintaining its shape when turning so that the net never closes up. The auto-trawl system is controlled via telemetry and sensors. Although it is intuitive that ensuring the net entrance does not collapse during trawling operations will be effective in reducing marine mammal entrapment in trawl nets and maintaining the effective operation of excluder devices, auto-trawl systems have never been evaluated as a marine mammal bycatch mitigation measure. There is no currently no evidence that the use of auto-trawl equipment will be effective in minimising the capture of marine mammals.

Trials of the device - Lyle and Willcox (2008)

From the commencement of mid-water trawl operations in the SPF, the trawl net included a ‘soft’ rope-mesh SED (Browne *et al*. 2005). No marine mammal bycatch was reported until October 2004, at which time 14 dolphin mortalities occurred in two separate hauls east of Flinders Island. Modifications were made to the exclusion device (enlarging and moving the escape opening from the underside to the top of the net) in an attempt to make it easier for dolphins to exit the trawl. In addition, a code of conduct was adopted which included not setting the trawl if dolphins were visible around the vessel and moving at least ten kilometres from the area prior to setting the gear. In response to the dolphin mortalities, AFMA implemented 100% observer coverage of fishing operations and established the Cetacean Mitigation Working Group (CMWG) which had a primary role of identifying strategies to mitigate cetacean bycatch for inclusion in the SPF Bycatch Action Plan and to provide advice on research needs to develop mitigation measures.

Further dolphin and seal mortalities were recorded (11 dolphins and three incidents of seal mortality in the trawl net in 2005/06, Lyle and Willcox 2006). An underwater camera system was deployed on the trawl net in the vicinity of the SED between June and September 2005 to better understand the behaviour of marine mammals in relation to the fishing gear (Browne *et al*. 2005). This pilot study indicated a high incidence of seal interactions whilst the net was fishing. Seals were observed entering and exiting through the SED escape opening to feed in the net (Browne *et al*. 2005). Browne *et al.* (2005) identified several aspects of SED design for improvement with the most notable being the material and orientation of the mesh barrier. While the rope mesh used in the SED did not appear to cause harm to the seals it was not effective in guiding them out of the net. The mesh was not sufficiently rigid and under the weight of a seal, deformed considerably, sometimes leading to partial entanglements. Furthermore, the vertical orientation of the barrier provided no passive assistance in directing the seals out through the escape opening. As a consequence the cargo mesh barrier was replaced with an inclined steel grid.

The Lyle and Willcox (2008) study implemented recommendations from Browne *et al.* (2005) and aimed to quantify and characterise the nature and extent of the marine mammal bycatch in the SPF, and advance the development of mitigation strategies for mid-water trawlers to reduce mortalities of marine mammals in the trawl gear. The objectives of the Lyle and Willcox (2008) study were to determine the type and frequency of interactions between dolphins and seals and mid-water trawl gear based on underwater video observations; determine the incidence of dolphin and seal capture in mid-water trawl nets and, where feasible, investigate potential contributing factors; trial and assess the performance of various exclusion devices as options to mitigate dolphin and seal mortalities; and identify factors such as changes in net geometry during trawl fishing operations that present potential risks to dolphins and seals.

Lyle and Willcox (2008) reported that:

17. Underwater video information for almost 100 trawls, representing over 700 hours of video footage was obtained (January 2006 – February 2007);
18. Fur seals entered the body of the trawl in over half of all monitored shots, though interaction rates peaked at over 70% during autumn and winter and were below 25% at other times of the year. Seasonality may, in part at least, be the result of habituation, since seals appeared to become increasingly adept at entering the net to forage during periods of sustained fishing activity within localised areas;
19. An estimated 151 seals were sighted inside the net in the vicinity of the SED and most seals entered via the net mouth and only a small proportion (13%) entered through the escape opening;
20. Conversely, the greatest majority (64%) exited the net via the escape opening, relatively few (22%) exited out of the net mouth;
21. Seals entered the net throughout the trawl operation (i.e. setting, during the fishing phase, during turns, hauling and while the catch was being pumped out). The highest rate of interactions occurred whilst the net was being set;
22. numerically the majority of seals (62%) entered the net whilst it was fishing at depth (trawling typically occurs in shelf waters < 150 m), this particular operational phase accounting for the bulk (73%) of the trawl duration;
23. Since trawling typically occurs in shelf waters (< 150 m), at depths within the dive capability of fur seals, the trawl effectively remains accessible to seals throughout the entire operation;
24. Most interactions occurred at night, reflecting the concentration of trawl effort during the hours of darkness. When standardised for effort, this diurnal pattern was no longer evident, suggesting that the probability of interactions occurring was unaffected by time of day;
25. The performance of bottom and top opening SED configurations were examined - due to operational limitations the authors were unable to adequately trial the top opening design;

26. SED configuration had no influence on interaction rates. However, by increasing the size of the escape opening, such that there was no floor in the net immediately in front of the excluder grid, a three-fold reduction in lethal interactions was achieved;

27. By comparison with other Australian trawl fisheries the overall seal mortality rate is high in this fishery, around 0.19 seals per shot, though when the large escape opening was used this dropped to 0.12 per shot, which is comparable to the upper range for the winter blue grenadier fishery;

28. All seal mortalities eventually fell out of the escape exit prior to the net being brought on-board the vessel, suggesting that many would not have been observed without the camera system and hence the scope of the bycatch issue would have been understated, even with a high level of observer coverage, and;

29. There is considerable scope for further refinement in SED design, including the need to examine the suitability of a top escape opening and to investigate options to reduce the ingress of marine mammals and loss of fish out of the escape opening. Such refinements as the inclusion of an escape hatch and/or a hood over the escape hole warrant consideration.

In the SPF, Lyle and Willcox (2008) recorded 19 seal mortalities on video, with individuals observed to become progressively less responsive over time, eventually being pinned against the grid for long periods prior to dropping out through the escape opening. The observation that all of the seals that died in the net ultimately dropped out through the bottom-mounted escape opening before the net was retrieved on-board has obvious ramifications for reporting of marine mammal bycatch (Lyle and Willcox 2008).

Fish loss out of the escape opening, along with providing a potential access route for marine mammals into the net, represent important issues for industry. Modifications including flaps, "hoods" or escape hatches have been applied to SEDs in other trawl fisheries (e.g. Wilkinson *et al.* 2003; Tilzey *et al.* 2006) to reduce both fish loss and net entry rates. There is a clear opportunity and need for such refinements to be applied in the SPF (Lyle and Willcox 2008).

It is still possible for a dead animal to fall out of a top opening escape hole (e.g. Lyle and Willcox, 2008, observed three fur seals passively exit via the SED with a top opening escape hole).

The predominant mid-water trawler in the SPF uses a bottom opening SED with a large escape hole and steel grid (AFMA 2011). The 2009 SPF Bycatch and Discard Workplan identified a trial of upward excluding SEDs which has not proceeded due to lack of funding and virtually zero mid-water trawl effort in the fishery (AFMA 2011).

Efficacy of the device

Note that, where possible, bycatch rates for mitigation research trials relevant to this Case Study are summarised in Table 11.

Mortality rates were significantly higher for the small escape hole (20%) compared with the large escape hole (7%) configuration ($\chi2 = 5.31$; d.f. = 1, P = 0.02) (Lyle and Willcox 2008; Table 4). i.e. the odds of mortality occurring were significantly higher, by a factor of 3.21 times (95% confidence interval 1.15 – 8.98), when the small escape hole was used as compared with the large opening. The combined mortality plus high risk rate was also significantly greater when the small escape hole was used ($\chi2 = 4.86$; d.f. = 1, P = 0.03) (Table 4). There was insufficient information available to evaluate the performance of the top opening SED in terms of reducing bycatch mortality.

Table 4: Seal interactions by SED configuration with mortality and high risk interaction rates (from Lyle and Willcox 2008).

	SED configuration			
	Bottom opening, small escape hole	Bottom opening, large escape hole	Top opening	Total
No. of shots	40	48	10	98
No. of seals	65	83	3	151
No. of mortalities	13	6	0	19
Mortality rate	0.200	0.072	-	0.126
Mortalities per shot	0.325	0.125	-	0.194
No. high risk	4	4	0	8
High risk rate	0.061	0.048	-	0.053
High risk per shot	0.100	0.083	-	0.082

The lack of cetacean interactions reported for the SPF mid-water trawl fishery since 2009 corresponds to a reduction in fishing effort rather than a low level of interactions with cetaceans. Prior to this, from 2001-2009, there were 25 reported dolphin mortalities in this fishery. AFMA require certain mid-water trawl vessels to comply with a seal and dolphin management plan that mandates mitigation measures be used to minimise interactions with these species, however the success of these measures has not been properly determined for cetaceans (Tuck *et al.* 2013). Three measures were identified: 1. Monitor the trial and use of upward excluding Seal Excluder Devices in the Commonwealth Trawl Sector and adapt as appropriate for SPF midwater trawl boats; 2. develop and implement individual vessel management plans for midwater trawl operators to minimise capture of threatened species; and 3. Develop triggers to identify shifts or expansion in effort within the fishery, including increased interaction with threatened species. Although it was identified that an upward-opening SED should be trialled for the mid-water trawl fishery to mitigate dolphin and seal mortalities, this did not go ahead due to lack of funding and the minimal trawl effort in the fishery (AFMA, 2011; Tuck *et al.* 2013).

Specific vessel operating or structural characteristics

The SED that was designed for use on the *FV Abel Tasman/Margiris* contained a ‘soft’ grid. It was considered that a hard grid (made of a hard material such as steel) would not have been suitable for this freezer-factory vessel because the vessel used a net drum and did not have a ramp hauling and stowage of the trawl.

Key points:

- Following a study that trialled three different SED designs, it was identified that an upward-opening SED should be trialled for the mid-water trawl fishery to mitigate dolphin and seal mortalities. However, due to lack of funding and the minimal trawl effort in the fishery in recent years, this did not go ahead.
- Seafish Tasmania commissioned the design of a soft-grid SED but there have been no at-sea trials of this device. It was thought that the auto-trawl system (which results in the trawl gear maintaining its shape when turning so that the net never closes up) that was to be utilised by Seafish Tasmania on the *FV Abel Tasman* could also reduce the risk of bycatch of seals and dolphins.

AUCKLAND ISLANDS SQUID TRAWL FISHERY AND DEVELOPMENT OF SEA LION EXCLUDER DEVICE (SLED)

Description of fishery

The Auckland Islands Squid Fishery (SQU6T) is one of New Zealand's largest and more valuable fisheries. The fishery began in the early 1970s with the discovery of commercial quantities of arrow squid *Nototodarus sloanii* to the north and east of the subantarctic Auckland Islands. An annual trawl fishery rapidly developed, using a combination of bottom and mid-water trawls across the Shelf at bottom depths of about 150 – 250m. The fishery usually commences in February and may run through to April each year, depending on squid catch rate and the estimated number of sea lions potentially killed incidental to the fishery.

Nature and extent of the marine mammal interaction and bycatch problem

The New Zealand sea lion, *Phocarctos hookeri*, is New Zealand's only endemic pinniped and is considered to be the world's rarest sea lion. In 2008, it was classified as Vulnerable (A3b) on the IUCN Red List based on a 30% decline in pup production at some of the major breeding colonies in the preceding 10 years (Gales 2008). Since 2010, it has been given a Nationally Critical status on the New Zealand Threat Classification system (Baker *et al.* 2010).

Over the last twenty years, commercial trawl fisheries have been implicated in the observed decline of the New Zealand sea lion population due to the incidental mortality of sea lions in trawl nets (Robertson and Chilvers, 2011; Hamilton and Baker 2014). Annual estimates at all breeding locations in the Auckland Islands showed New Zealand sea lion pup production (i.e. the best index of relative overall population size for this species) decreased from a peak of 3 021 pups in 1997/98 to a low of 1 501 in 2008/09 (Childerhouse 2013). Most incidental mortality of New Zealand sea lions has occurred in the Auckland Islands squid fishery although mortality has also been recorded in the Auckland Islands scampi fishery, the Auckland Islands non-squid/scampi target fisheries, the southern blue whiting fishery operating near Campbell Island and the Stewart-Snares shelf trawl fisheries (Thompson *et al*. 2013).

The level of New Zealand sea lion incidental mortality in the Auckland Islands squid fishery has been monitored by government observers since 1988 (Wilkinson *et al.* 2003). High numbers of incidental mortalities have been recorded in the past with peaks in the mean estimated number of captures in 1995/96 and 1996/97 of 131 and 142 respectively (Thompson *et al.* 2013; Figure 13). The observed capture rates for 1995/96 and 1996/97 were 0.024 and 0.039 sea lions per trawl respectively (Thompson *et al.* 2013).

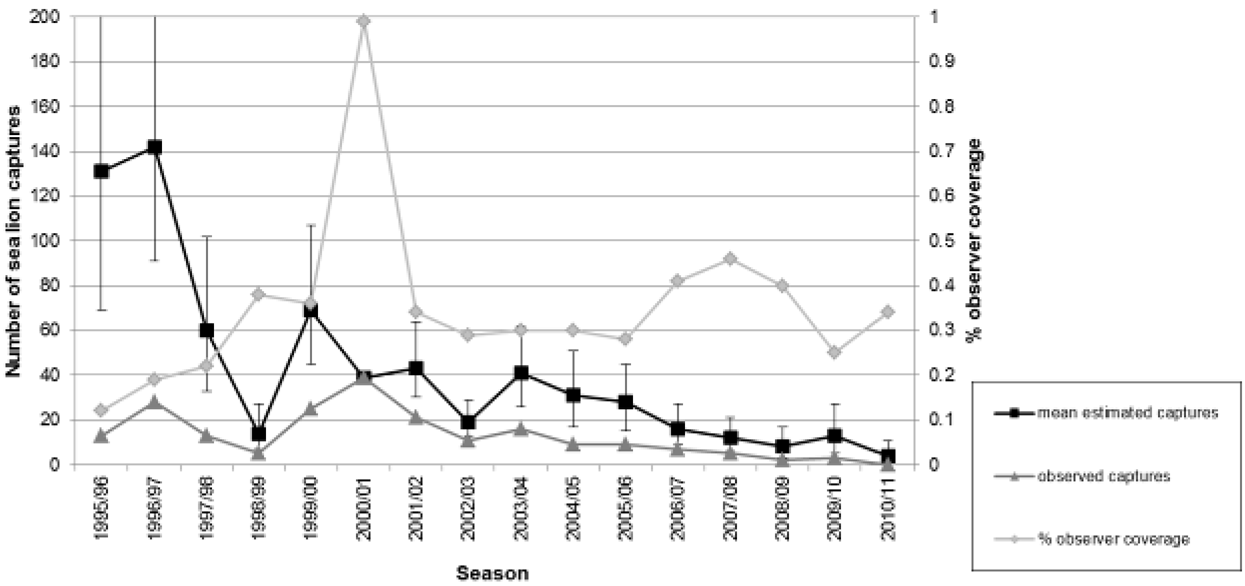


Figure 13: The observed number of captures (grey triangles) and mean estimated captures (black squares; error bars = 95% confidence interval) of New Zealand sea lions in the Auckland Islands squid fishery from 1995/96 to 2010/11. The % observer coverage (light grey diamonds) is also shown. Data taken from Thompson *et al.* (2013) and figure from Hamilton and Baker (2014).

Technical details of mitigation devices

Due to high levels of bycatch of New Zealand sea lions in the Auckland Islands squid trawl Fishery, a sea lion exclusion device (SLED) was developed that aimed to direct New Zealand sea lions out of the trawl net system prior to entering the codend where the target catch is retained (Roe and Meynier 2012; Wilkinson *et al.* 2003). Similar to a SED, the SLED comprises an additional section of netting inserted between the lengthener and codend of a trawl net with an angled two or three part metal grid that aims to direct sea lions to an escape hole in the top of the net and exclude them from the trawl cod end (Abraham 2011; Middleton and Breen 2011; Roe and Meynier 2012).

There have been several improvements to the basic design of the SLED over the last 10-15 years. These have included:

- Adding a hood and kite to the top-mounted escape hole (MPI 2012) (Figure 14);
- reducing the space between the grid bars from 26 cm to 23 cm to reduce the probability of smaller NZ sea lions passing through the grid and becoming trapped in the cod end of the trawl net; and,
- modifying the SLED kite with additional floats on the top of the SLED hood to ensure the kites and hood operate properly in all conditions and thus the escape hole remains open during fishing (MPI 2012).

In 2007, the annual audit of SLEDs and their use in the Auckland Islands Squid Fishery showed the most common cause of Operational Plan compliance failure were kites that were not rigid enough, grid bar spacing failures, incorrect grid angle and non-continuous stitching around grid perimeter (Clement and Associates 2007).

Since 2004/05, there has been widespread use of government-approved, standardised SLEDs in the Auckland Island Squid Fishery (MAF 2012). Although not mandatory, the use of SLEDs is required by the current industry body, applied fleet wide and monitored by fishery observers (MAF 2012).

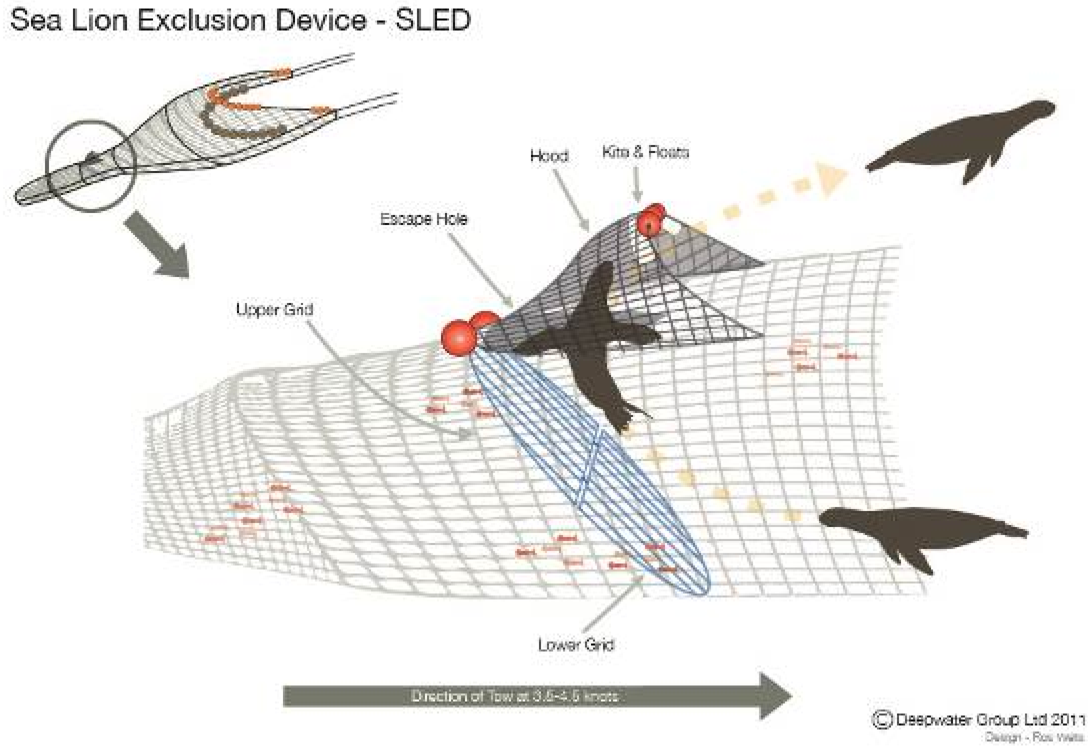


Figure 14: Standard New Zealand Sea Lion Excluder Device used within the squid fishery (SQU 6T) around the Auckland Islands (diagram provided by Deepwater Group; from Hamilton and Baker 2014). The SLED consists of a mid-section of netting with a metal grid and an opening (escape hole) above it. The grid directs sea lion to the escape hole, enabling them to exit the net. The forward-facing hood above the escape hole is designed so that only actively swimming sea lion escape the net. The hood is held open by floats, and a strip of material known as a kite.

Efficacy of the device

Note that, where possible, bycatch rates for mitigation research trials relevant to this Case Study are summarised in Table 11.

The number of observed New Zealand sea lion captures has dropped substantially in the Auckland Islands squid fishery following the widespread introduction of SLEDs in 2004/05 (Figure 13). SLEDs are therefore considered to be effective in allowing most New Zealand sea lions to exit a trawl but some are retained and drowned and there has been concern that some may escape but not survive the encounter e.g. due to life-threatening injuries from collisions with grids (MAF 2012).

Following the introduction of SLEDs, the mean estimated number of New Zealand sea lions captured in the Auckland Islands Squid Fishery per year declined from 14-142 for 1995/96 to 2001/02 (i.e. pre SLED deployment) to 4-31 for the period 2004/05 to 2010/11 (i.e. post SLED deployment) (Thompson *et al.* 2013). In 2010/11 there were no observed captures and four mean estimated captures (0-11 95% CI) (Thompson *et al.* 2013) and no observed captures in the 2011/12 season (MPI unpubl. data; NB: estimated capture statistics yet to be published for the 2011/12 season).

The reported continued decline in the New Zealand sea lion population estimates from 2004/05 (when SLEDs were in widespread use) to 2008/09 (when the lowest pup production was reported) led to uncertainty and scepticism about the efficacy of SLEDs and whether ‘cryptic’ mortality was occurring with claims that some animals could have suffered head trauma from hitting the SLED’s hard grid that may have compromised their post-escape survival (Robertson and Chilvers 2011). There has also been some concern regarding the possibility that some New Zealand sea lions that die in the trawl net may fall out of the escape hole during hauling which could lead to underestimates of mortality (Roe 2010; Roe and Meynier, 2012; Hamilton and Baker 2014).

It is considered very unlikely for a dead animal to fall out of a top-mounted SLED escape hole that has also been fitted with a hood like the SLEDs deployed in the Auckland Islands squid trawl fishery (MPI 2012). Unfortunately, the use of cameras to verify this has not been effective in the Auckland Islands squid trawl fishery because of the poor visibility at fishing depth due largely to water turbidity (Richard Wells pers. comm.).

To assess the efficacy of SLEDs in reducing incidental mortality of New Zealand sea lions in the Auckland Islands squid trawl fishery, a number of research projects and reviews of data have been undertaken.

Initially the focus was on whether SLEDs allow sea lions to escape from trawl nets and whether animals survive if they pass through a SLED. This included the following work:

- an experimental approach where sea lions were deliberately trapped after passing through a SLED;
- assessments of the survivability of sea lions passing through a SLED based on reported reviews of necropsy results and video monitoring; and,
- attempts to obtain additional video footage of SLEDs during fishing operations (Hamilton and Baker 2014).

A second body of work, which focussed on tests to determine whether head trauma is likely when sea lions come into contact with stainless steel SLED grids, included:

- re-analysis of video footage from an Australian study of fur seals passing through a Seal Exclusion Device (SED);
- a biomechanical study that simulated the impact of sea lions hitting the metal grid of a SLED; and,
- modelling of the risk of sea lions suffering mild traumatic brain injury after striking a SLED grid.

Do SLEDs allow sea lions to escape from trawl nets and do these animals survive?

An experimental approach where sea lions were trapped after passing through a SLED:

30. To assess whether SLEDs allowed for the escape of sea lions and whether sea lions survived the process, a Government-led experiment was carried out where New Zealand sea lions were deliberately trapped and drowned after passing through a SLED (Wilkinson *et al.* 2003). The closed 'cover-net' was installed over the escape hole to retain and, if they had escaped alive, necessarily drown animals that had successfully negotiated the SLED. For a small number of these sea lions, video footage was obtained of the animal passing through the SLED (Wilkinson *et al.* 2003). The sea lion carcasses were subsequently necropsied to assess injuries (Gibbs *et al.* 2001 in Wilkinson *et al.*2003; Gibbs *et al.* 2003).

Wilkinson *et al.* (2003 - peer-reviewed publication):

- During the 1999 and 2000 fishing seasons, six New Zealand sea lions were incidentally caught by fishing vessels installed with SLEDs and, of these, five were directed out of the SLED and retained in a cover net;

- In 2001, 33 NZ sea lions were caught by vessels with closed cover nets and 30 of these animals (i.e. 91%) passed through via the SLED and were retained in the cover net. Only three of these animals were successfully videotaped. The video footage of three animals indicated that the animals would have survived if the cover net had not been present although Wilkinson *et al.* (2003) did not provide details describing the animals' behaviour and why this conclusion was reached;

- Based on the observed "escapes" and assessment of survival, the probability of survival after exiting was calculated to be 36% (based on the NZ Ministry of Primary Industries guidelines on how results of SLED trials would be evaluated);

- Despite the visual assessment that the three New Zealand sea lions that exited would survive the process, examination by a veterinary pathologist of the retained and frozen carcasses concluded that at least one and possibly two of these animals exhibited severe internal trauma which, it was considered, would have led to the subsequent death of the animals (Gibbs *et al.* 2001 in Wilkinson *et al.* 2003; Gibbs *et al.* 2003), and;

- Necropsies of all 30 animals retained and frozen in 2001 concluded that at least 55% of them had suffered trauma that would have compromised their post-exit survival (Gibbs *et al.* 2001 in Wilkinson *et al.* 2003; Gibbs *et al.* 2003). However, Gibbs *et al.* (2003) also acknowledged that freezing of the carcasses, which also involved rough handling of carcasses (including dropping some animals 6 metres into the fishing vessels hold for storage), may have induced changes that could be confused with true lesions and that the problem needed to be investigated by conducting necropsies on sea lions before they were frozen.

An assessment of survivability of NZ sea lions passing through a SLED - review of necropsy results

Although SLEDs direct the majority of sea lions encountered by trawl nets out of the net, a small number of sea lions are still captured and hauled aboard by vessels deployed with SLEDs and probably die by drowning or trauma (Roe and Meynier 2012). Drowning occurs when the sea lion is unable to negotiate the SLED within its breath-holding ability or there is a failure with the SLED escape route (e.g. the hood collapses and subsequently closes the escape hole; Roe and Meynier 2012). In some cases small animals have been able to squeeze between the SLED grid bars, and were retained in the cod end of the net.

Freezing sea lion carcasses caught in the fisheries around the Auckland Islands is necessary due to the time frame from when animals are caught by vessels (often at sea for several weeks) and the transport distance back to port and veterinary laboratories (Roe and Meynier 2012).

A series of reviews were conducted to assess data for animals that passed through the SLED following concerns that some observed lesions and trauma may be an artefact of the freezing process (Roe 2010; Roe and Meynier 2012). Necropsy data are collected for all animals retained as bycatch in the fishery. The reviews were of necropsy data for 163 animals – 15 captured with no information on whether a SLED was used or not, 50 captured in a net with no SLED and 98 captured in a net using a SLED. It should be noted that, from 1996/97 to 1999/00, the aim of the necropsies was to obtain morphometric information and not to assess the types or severity of injuries (Roe 2010).

To look at effects of freezing and thawing, an experiment was conducted in 2008 and 2009 using five chilled and five frozen New Zealand fur seals that were all recovered from trawl nets without exclusion devices in the Cook Strait hoki fishery. Although these were small samples sizes, this experiment showed that some lesions originally thought to be due to trauma were artefacts of freezing (Roe and Meynier 2012).

Roe and Meynier (2012) conducted a review of necropsy data to determine whether it was possible to apply a consistent set of trauma criteria across all necropsied NZ sea lions using archived records (i.e. 'revised criteria'). The use of a SLED did not seem to affect either the overall reported trauma severity or the prevalence of head bruising and also that the pattern of bruising involving the sternum, shoulders and axillae appears to be unrelated to SLED use (Roe and Meynier 2012). Based on the revised criteria, 49% (80/163) had moderate or severe trauma that could have compromised the likelihood of survival if the animal had been able to exit the net (Roe and Meynier 2010). However, many 'injuries' that were observed on dead animals were thought to have occurred well before death and the assessment was also compromised by the knowledge that some lesions originally thought to be due to trauma were actually artefacts of freezing (Roe and Meynier 2012). Therefore, it was considered that there was no evidence in the necropsy data that necropsied animals died as a direct result of trauma or that they sustained trauma that would have been severe enough to affect their survival if they had been able to escape rather than drown in the net (Roe 2010).

Although based on a very small sample size, Middleton and Breen (2011) considered the original assessment by Wilkinson *et al*. (2003) that the three animals videoed in cover nets after escaping via the SLED were likely to have survived, must be assumed to stand. This determination of survival was questioned by Gibbs *et al*. (2001 - in Wilkinson *et al*. 2003) solely on the basis of necropsy results. However, it has now been established that the lesions considered to be evidence of "acute blunt trauma" in these animals are likely to be artefacts of freezing and a reliable assessment of survivability via necropsy is not possible for this fishery due to the post-capture handling of carcasses (including the necessity of freezing carcasses).

The assessment of necropsy data has been complicated and drawn out over several years which may have contributed to some remaining public perception in New Zealand that SLED impacts cause life-threatening trauma in New Zealand sea lions. However, the current expert opinion is that the observed trauma on reported animals was due to artefacts of freezing and not collisions with fishing gear.

Additional video footage of trawl nets in the Auckland Islands squid fishery:

Although there has been extensive additional video monitoring of trawl nets in the Auckland Islands squid fishery to assess SLED deployment and engineering characteristics (Richard Wells, pers. comm.), this additional footage has not been useful for assessing New Zealand sea lion use of SLEDs or post-SLED survival of sea lions. Hamilton and Baker (2014) reviewed some of this video footage (of which approximately 600 hours was recorded) and found that it was not possible to get a clear impression of SLED efficacy at fishing depths as visibility was very poor due to the limitations of the lighting, water depth, fine debris and squid inking suspended in the water column.

Is head trauma likely when sea lions come into contact with stainless steel SLED grids?

31. Re-analysis of video footage of fur seals passing through a Seal Exclusion Device (SED):

32. The behaviour and responses of fur seals to SED interactions in the SPF may provide some information to help assess the possible nature of New Zealand sea lion and SLED interactions and, in particular, the potential of head trauma injuries that may result from head-first collisions

with a metal grid (Lyle 2011). Therefore, Lyle (2011) undertook a review of underwater video footage from 2006/07 (Lyle and Willcox 2008) of interactions between fur seals and SEDs deployed in the Australian SPF. This review aimed to record the nature (i.e. whether seals struck the grid, the speed at which they struck and where on the grid the impact occurred) and potential consequences of collisions with a rigid steel grid (Lyle 2011).

Interactions with the SED were described for 132 seals although the clarity and quality of the footage influenced how much information could be obtained for each interaction (Lyle 2011). The review of the fur seal video footage showed that about one third of the seals that entered via the mouth of the trawl approached the SED head-first and most of them experienced a head-first collision with the grid (usually the upper half of the SED grid) and usually the angle of the head was more or less perpendicular to the grid (Lyle 2011). Impact velocities were also estimated with first interaction head-first impacts occurring at a slightly faster speed (average of 3.5 m/s with a range of 2.9-6.1 m/s) than subsequent head-first collisions (Lyle 2011). There was no significant difference in the mortality rates between seals that had at least one head-first collision with the SED grid and those that did not contact the SED head-first (Lyle 2011). From observed video footage, mortalities within the nets were obvious with individuals lying motionless against the SED for periods of up to several hours (Lyle 2011).

Lyle (2011) did not discuss the implications of the assessment of the video footage on the extent and nature of impact injuries or the subsequent survival of fur seals as there had been no post-interaction or post-mortem examination of the seals during the original study.

Biomechanical study – simulating the impact of sea lions hitting the metal grid of a SLED:

Ponte *et al.* (2010) used a validated method for measuring head impact injury in human pedestrians (‘crash tests’) with scaling and extrapolating to account for the relative head and brain mass of the New Zealand sea lion to assess the likelihood of Mild Traumatic Brain Injury (i.e. ‘concussion’) to a sea lion as a result of a head impact with SLED stainless steel grid. For particular impact locations on the SLED grid, the likelihood of a brain injury, based on swim speed and effective sea lion head mass, was determined using the ‘crash test’ results (Ponte *et al.* 2010).

The ‘crash test’ results indicated that a sea lion impacting with the grid may incur some sort of brain injury and the risk of life-threatening brain injury may be higher than 85% for a female sea lion in a 10 m/s (based on trawl speed of 2 m/s and estimated burst speed of an adult sea lion of 8 m/s) collision with the SLED grid at the stiffest location tested (Ponte *et al.* 2010). However, this impact speed probably represents the worst case scenario, especially if Lyle’s (2011) fur seal interaction speeds are considered indicative of New Zealand sea lion interactions, and may be more dependent on individual sea lion behaviour than the grid design (Industrial Research Ltd 2011).

Modelling the risk of sea lions suffering mild traumatic brain injury after striking a SLED grid:

Using modelling simulations and the results from the ‘crash-test’ methodology (Ponte *et al.* 2010) and the re-analysis of video footage of fur seals interacting with SEDs (Lyle 2011), Abraham (2011) developed a simulation-based probabilistic model to estimate the risk of a sea lion suffering a mild traumatic brain injury when striking a SLED grid. Abraham (2011) estimated the probability that a sea lion interacting with a SLED (single collision) suffers Mild Traumatic Brain Injury was less than 5%.

Ministry for Primary Industries (2012) consider that the research and assessments on SLED efficacy (reviewed above), provide robust evidence that SLEDs greatly increase the survival probability of those sea lions that enter a trawl net. The weight of evidence is that SLEDs are effective in reducing the incidental mortality of New Zealand sea lions in the Auckland Islands squid fishery.

Summary/Conclusion

For the Auckland Islands squid fishery, mitigation management aimed at reducing the incidental mortality of New Zealand sea lions includes spatial and/or temporal closures of the fishery, the introduction of agreed Operational Plans, the imposition of mortality limits for sea lions that can trigger the close of the fishery for that year, and the widespread deployment of SLEDs (MAF 2012). Any sea lion that is caught in a trawl net that has no SLED deployed will die by drowning whereas SLEDs provide an opportunity for sea lions to escape trawl nets (Hamilton and Baker 2014). There are claims that incidental mortality from fisheries continues to be the main anthropogenic cause of mortality for New Zealand sea lions largely based on implications that animals could suffer traumatic internal and head injuries from hitting the SLED's hard grid that may compromise their post-escape survival (Robertson and Chilvers 2011). However, there is good evidence that most sea lions would survive encounters with SLEDs (Hamilton and Baker 2014). A comparison of necropsy data from sea lions drowned in nets with and without SLEDs indicated that trawl nets installed with a SLED did not seem to affect either the overall reported trauma severity or the prevalence and pattern of apparent bruising (Roe and Meynier 2012). Based on necropsies of sea lions that passed through a SLED, expert external reviews discounted the possibility of abdominal or thoracic injury compromising the chances of survival, and concluded that necropsies could not be reliably used to estimate head injuries because freezing sea lions after capture (a logistical necessity) can mimic and potentially obscure lesions (Roe 2010; Roe and Meynier 2012). Biomechanical modelling to estimate the impact of head-first collisions between sea lions and SLED grids (Ponte *et al*. 2010; MPI 2012) indicated that it was extremely unlikely that an impact with a SLED would cause brain trauma at a level to cause death (Abraham 2011). In addition, the probability of a Mild Traumatic Brain Injury (i.e. concussion) that could result in the animal drowning after exiting the SLED was very unlikely to exceed 10% (Abraham 2011). This work was based on video footage of fur seals interacting with a Seal Exclusion Device (Lyle 2011) and it was considered that the likely speed and location of collisions that were inferred and the estimated collision speeds were consistent with the observed swimming speeds for New Zealand sea lions (MPI 2012). Although an additional cause of drowning could be that a sea lion exiting the net is at the extreme end of their breath-holding capabilities, this has been taken into account when undertaking population modelling to derive the Fisheries-Related Mortality Limit (MPI 2012).

In the absence of the ability to obtain useful video monitoring data of sea lion and SLED interactions for the bottom and mid-water Auckland Islands squid fishery and, based on the research and assessments reviewed above, the evidence is that SLEDs significantly reduce the risk of mortality of sea lions in trawl nets and the efficacy of SLEDs has contributed to reduced rates of observed mortality of sea lions (with high observer coverage) in the fishery in recent years (Hamilton and Baker 2014). Although the research and assessments of SLEDs have produced some inconclusive outcomes and have not been able to clearly demonstrate the post-SLED survivability of a sea lion, there is also an absence of evidence to support the hypothesis that sea lions sustain life-threatening injuries when they pass through a SLED (Hamilton and Baker 2014).

Specific vessel operating or structural characteristics

Due to the fishing depths in this mid-water trawl fishery, useful video footage of sea lion interaction with SLEDs is difficult to obtain.

Although not mandatory, the use of government-approved, standardised SLEDs is required in the Auckland Island Squid Fishery by the current industry body (MAF 2012).

Key point:

- The evidence is that SLEDs have reduced the bycatch mortality of New Zealand sea lions in the Auckland Islands squid trawl fishery.

WESTERN AUSTRALIAN PILBARA FISH TRAWL FISHERY AND DOLPHIN EXCLUDER DEVICE

Description of fishery

The Pilbara Fish Trawl Fishery (PFTF) is situated in the Pilbara region in the north west of Australia. It occupies the waters north of latitude 21°35’ S and between longitudes 114°9’36 E and 120° E. The PFTF contains 11 permits with combined effort allocations being consolidated onto 3 full time vessels (WA Department of Fisheries 2011).

The PFTF is an otter trawl fishery targeting demersal scalefish species. Retained by-product in the fishery includes bugs (*Thenus orientalis*), cuttlefish and squid (WA Department of Fisheries 2011).

PFTF vessels use a single stern trawl net towed close to the substrate to target demersal scalefish (e.g. Lutjanidae, Lethrinidae and Epinephelidae, Newman *et al*. 2012 in Wakefield *et al*. 2014). Most fishing occurs in depths of between 50-100 metres.

Nature and extent of the marine mammal interaction and bycatch problem

There has been considerable focus and investment toward collecting data on the bycatch of listed species, specifically dolphins, turtles, sea snakes and sawfish and sharks, in this fishery over the last decade, but this review focuses on dolphins.

Stephenson and Chidlow (2003) documented bycatch in the PFTF from 100 days of observer coverage in 2002, spread over the (then) five vessel fleet. Bycatch data were obtained from 427 trawl shots representing 1,581 hours of trawling and an observer coverage rate of 7.7%. Bottlenose dolphins were observed around and in (using video cameras) almost every trawl shot. A total of four incidental dolphin deaths were reported. In parallel, research on the effectiveness of exclusion grids and escape hatches fitted to trawl nets (Stephenson *et al.* 2008) was undertaken in conjunction with an assessment of pingers (Stephenson and Wells, 2008) to reduce dolphin interactions. These studies highlighted dolphins deliberately entering trawl nets to forage and purposely making contact with the nets (from clinging to the headrope to bouncing along the net) during almost all trawl shots (> 98% trawls). The incidental catch of bottlenose dolphins in this fishery in 2006 equated to an annual mortality of approximately 43 dolphins per year (Stephenson *et al.* 2008).

Further work on modified net designs by Allen and Loneragan (2010) and Jaiteh *et al*. (2012), also observed dolphins around (99%) and in (98%) trawl nets during fishing, albeit from a limited number of video-observed trawls that represented 0.9 to 1.1% observer coverage (36 – 44 observed trawls (Allen and Loneragan, 2010). The renewal of a Wildlife Trade Operation accreditation by the Commonwealth Government for the PFTF in 2011 included additional conditions to investigate further reductions of dolphin and turtle interactions and potential mortalities (http://www.environment.gov.au/coasts/fisheries/ wa/pilbara-trawl/pubs/wto-march2011.pdf). The bottlenose dolphin *Tursiops truncatus*, was the only species of marine mammal observed to interact with PFTF trawl nets during the subsequent observer programs (Wakefield *et al*. 2014). They were also the only species that deliberately entered trawl nets, typically for foraging, socialising or frequently and intentionally making contact with the nets. Despite dolphin depredation of trawl caught scalefish being observed in a large majority of trawls (> 75%), the incidental capture of dolphins was rare (~0.005 trawl-1). There were only seven dolphins observed to come within close proximity to exclusion gear inside trawl nets (Wakefield *et al*. 2014).

Allen *et al*. (2014) used data from skippers' logbooks and independent observers to assess common bottlenose dolphin bycatch patterns between 2003 and 2009 in the PFTF. Both datasets indicated that dolphins were caught in all fishery areas, across all depths and throughout the year. Over the entire datasets, observer reported bycatch rates (n = 52 dolphins in 4,124 trawls, or 12.6 dolphins/1,000 trawls) were approximately double those reported by skippers (n = 180 dolphins in 27,904 trawls, or 6.5 dolphins/1,000 trawls).

Technical details of mitigation devices

Since 2006 the use of exclusion grids and escape hatches in trawl nets has been mandatory. The Bycatch Reduction Devices (BRD) deployed in the fishery since 2006 consisted of a semi-flexible metal grid and a bottom-opening escape hatch with a loose skirt of netting covering the hatch to prevent the loss of target species (Allen *et al*. 2014). In June 2008, the BRDs were moved forward in the net from just before the codend to the start of the net extension - this was done to prevent dolphins from backing down into the extension and to provide a shorter escape route between the BRDs and the opening of the net (Allen *et al*. 2014).

A number of different excluder devices have been trialled in the fishery since that time, which have included both top and bottom opening net configurations. These devices were not designed specifically to mitigate dolphin bycatch, but to address bycatch of all megafauna (dolphins, turtles, sea snakes, sawfish, rays and sharks).

Semi-flexible exclusion grid

A semi-flexible exclusion grid constructed from a combination of braided stainless wire and pipe (Figure 15 and Figure 16), appeared to reduce the bycatch of dolphins by almost half (Stephenson *et al.* 2008). Dolphins were able to swim out the mouth of the net, or exit through a bottom-opening escape hole, after interacting with the grid. However, an undetermined number of dolphins could potentially exit the net underwater in poor condition with unknown chances of survival (Stephenson *et al.* 2008). In this study it was recommended that video footage should be collected to gain information on the fate of dolphins that encounter the grid. There were two instances (by an observer and another by a skipper) where a dolphin was reported to have had its tail fluke caught in the grid. Reducing the bar spacing, to less than 155 mm, was suggested to reduce the likelihood of this occurring (Stephenson *et al.* 2008).

Use of this excluder was observed over 1,384 shots. With the grid deployed the dolphin catch was 9 in 1,156 shots, a reduction from the dolphin catch rate in 2005 without grids, which was 15.2 per 1,000 shots (Stephenson *et al.* 2008). Dolphins were generally caught in daylight hours, with 84% of the dolphins caught between 7:00 and 20:00. This temporal pattern was not related to the time of winch-up as fishing and winch-up occurred over the whole 24 hour period. Net depth (50-80 m) did not affect dolphin capture rate. A higher relative frequency of dolphin captures was observed in shallower water, but that was related to the fishing effort expended not the net depth (Stephenson *et al.* 2008).

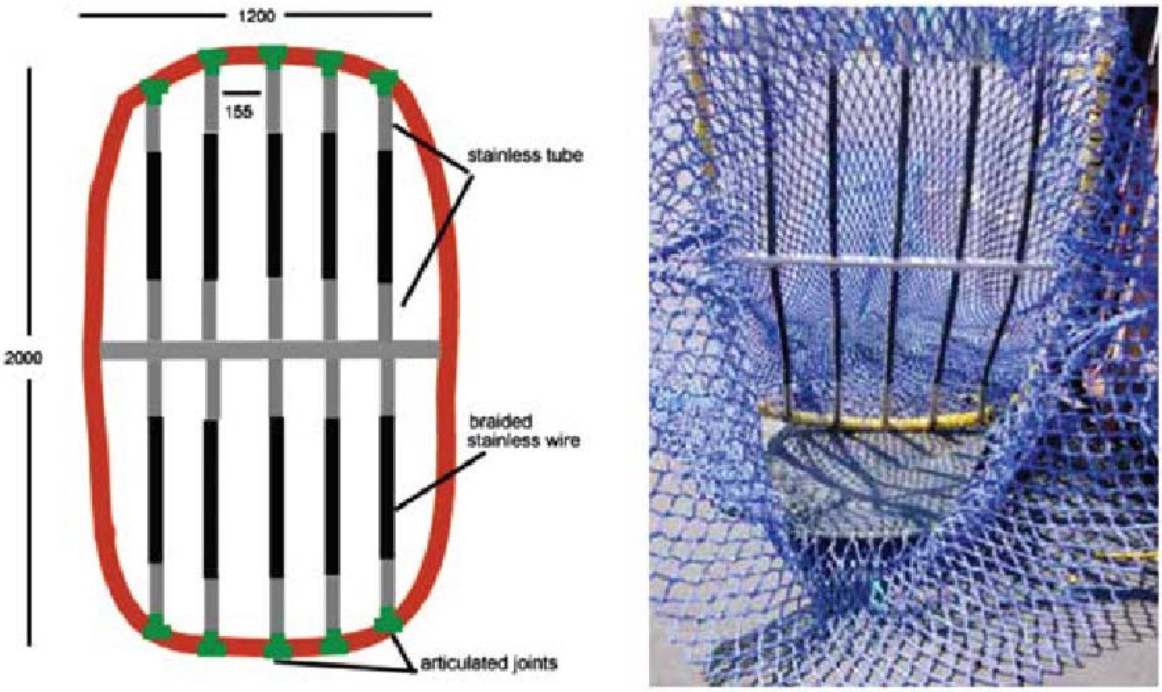


Figure 15: Semi-flexible grid constructed from stainless tube and braided stainless wire (from Stephenson *et al.* 2008).

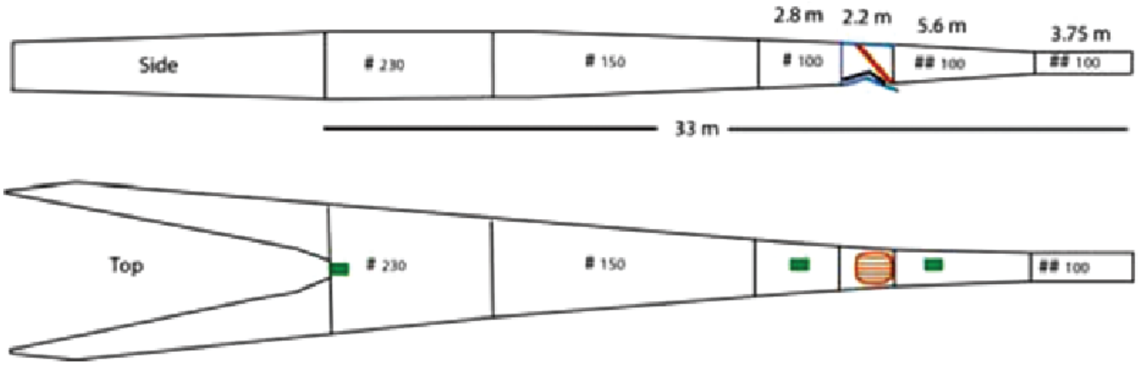


Figure 16: The design of the net used during the selection grid trials showing the grid (red), cover net at the bottom opening escape (blue), the Kevlar flap (black), and the location of the cameras (green) as well as the mesh sizes (## denoted double mesh) for the different panels of the net (from Stephenson *et al.* 2008).

Study comparing three different exclusion grid configurations

In 2012, three different exclusion gear configurations in trawl nets (Figure 17) were evaluated in trials conducted on all three vessels fishing in the PFTF (Wakefield *et al*. 2014). The body panel sections of the trawl nets used on all three vessels were constructed from three types of netting, which included 229 mm (9 inch) stretched mesh in the wings and first body panel, 152 mm (6 inch) in the second body panel, and 114 mm (4.5 inch) in the last body panel that was connected to the grid extension panel. Each body panel was about ten metres in length when stretched. The stretched mesh distance of the grid extension panel from the posterior edge of the last body panel to the grid and associated exclusion gear (escape hatch and/or escape slit) was 2 to 4 m.

The grid extension panel was followed by the codend extension panel (10-20 m long) and codend (10 m long, Figure 17). The standard construction of the trawl net used in this fishery from which modifications were based on, included a semi-rigid downward angled exclusion grid, which was constructed of six stainless steel tubes spaced at 150 mm apart with a side tube length of 795 mm (Figure 17a). An escape hatch was cut into the bottom of the trawl net at the base of and forward to this grid with a mesh cover opening backward to facilitate the subsurface expulsion of megafauna and benthos during trawling (Figure 17a). The mesh panels on this net consisted of 105 mm (stretched) diamond mesh in the grid and codend extension panels and 110 mm (stretched) diamond mesh in the codend.

This standard trawl net configuration is referred to as the 'downward excluding net'. The first of the two modified trawl nets consisted of an exclusion grid that was rotated to achieve an upwardly inclined grid (Figure 17b). The escape hatch and mesh cover for this net was shifted to the top of the net immediately forward of the grid (Figure 17b). The grid was made rigid and the spacing of the stainless steel tubes was increased to 200 mm with the length of the side bars increased to 1030 mm (Figure 17b). The mesh sizes used in this modified net were identical to the downward excluding net. Flume tanks trials of this net determined that additional floats were needed on the top of the grid to optimise the nets fishing performance (Figure 17b). This modified trawl net is referred to as the 'upward excluding net'.

The second modified net used the same rigid grid as the upward excluding net, but with the declining orientation of the downward excluding net (Figure 17c). As with the downward excluding net, the escape hatch was cut into the bottom of the net at the base and forward of the grid, with a similar mesh cover opening backwards (Figure 17c). However, the grid and escape hatch were stitched into 50 mm square mesh which served to keep this section of the net cylindrical, which in turn improved water flow through the net (Figure 17c, Brewer *et al*. 2004). A longitudinal escape slit (~3 m long) was cut into the top of the square mesh net within one metre of and forward to the exclusion grid. This slit was intended to facilitate the subsurface escapement of predominantly air-breathing animals, based on the assumption that they would tend to push upwards to escape (Allen and Loneragan, 2010). The slit was held together with magnets along its edges to keep it closed during trawling and after an animal had passed through it.

This top opening slit design was refined through trials in a flume tank that involved using a megafauna replica (with similar dimensions to a dolphin), in an attempt to minimise the amount of force required to open the slit but still well within the capabilities of a megafauna species that may be encountered in the trawl net. This second modified trawl net is referred to as the 'experimental net'.

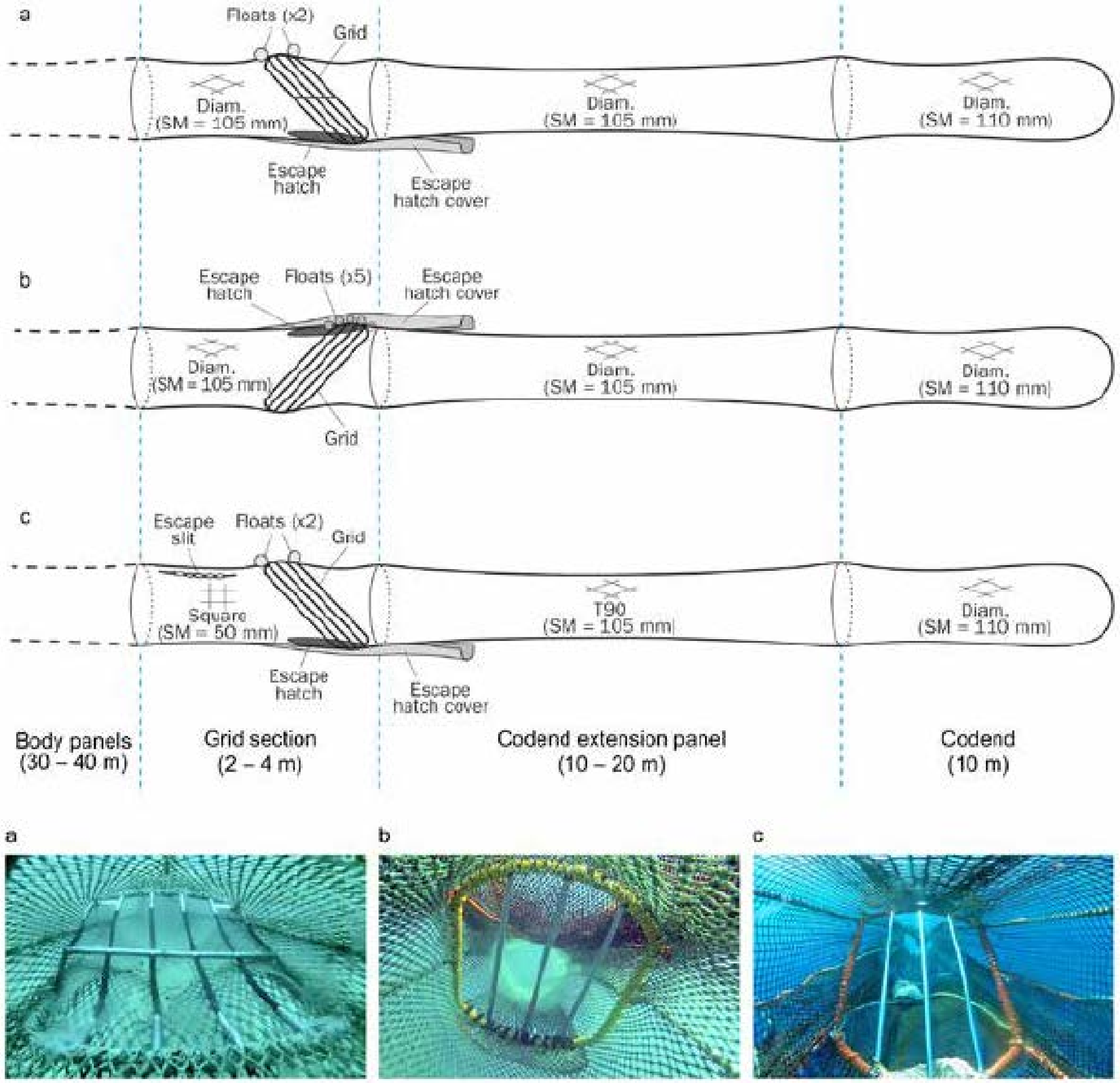


Figure 17: Schematic diagrams (above) and in situ images taken from the net camera systems with the camera positioned behind the grid facing forward (below), for the three different net configurations, i.e. (a) downward excluding net, (b) upward excluding net and (c) experimental net (SM, stretched mesh) (from Wakefield *et al.* 2014).

Trials of the device

Semi-flexible exclusion grid

Stephenson *et al*. (2008) tested the semi-flexible cetacean exclusion device, and used underwater video footage in an attempt to clearly determine its success. During the 1,384 shots observed, video footage was obtained for 446 shots. The footage showed images of behaviour of dolphins entering and exiting the net or on the outside of the net in nearly all of the 446 tapes. The video footage indicated that in almost all cases the dolphins backed down into the net to a position about 3 m from the grid and later swam upstream out of the net. Very few dolphins were seen swimming head-first towards the grid, and those that did turned around before reaching the grid and swam out the mouth of the net. Seven dolphins were recorded interacting with the grid or escape opening. Three were assumed to have escaped alive and four were in distress and were assumed to have died (Stephenson *et al.* 2008). The underwater video footage of the behaviour of the dolphins, showing them backing towards the grid, appears to indicate that the dolphins readily detected the selection grid. The pressure wave generated by the grid was probably effective in allowing animals to detect its proximity to the grid (Stephenson *et al.* 2008).

Study comparing three different exclusion grid configurations

To observe the effectiveness and efficiency of mitigating dolphin and other megafauna species interactions with the three different exclusion gear configurations being trialed (Figure 17), all trawl vessels in the PFTF were fitted with dual-lens above water and subsurface within-net camera systems. Observer coverage during the trials was high, with 85.2% of trawl catches above water (1,916 trawls), 71.7% of day-trawls (n = 774 trawls) and 53.9% of day-trawl hours (n = 1,013 hours) below water observed. Captures of megafauna were rare, despite very high levels of attendance in and around trawl nets by bottlenose dolphins (> 75% of trawls).

A total of 10 dolphins were observed landed during the trials at an overall mean catch rate of 0.0052 animals per trawl (Wakefield *et al.* 2014). A further seven dolphins (*Tursiops truncatus*) observed underwater came within close proximity to exclusion gear inside the trawl nets during five trawls at an interaction rate inside the nets of 0.009 dolphins per day-trawl (Wakefield *et al.* 2014). All seven of these dolphins appeared to be distressed at this point (following the terminology used by Stephenson *et al*. 2008). The most conspicuous behaviour observed for this species at this stage was short bursts of swimming in a direction upstream toward the mouth of the net, i.e. short (< 10 seconds), infrequent and non-sustained bursts of swimming. These distressed dolphins (n = 7) did not always make obvious movements upwards toward the top of the net. Four of these seven dolphins were observed to asphyxiate and be retained within the net ahead of the exclusion grid. All four of these dolphins were observed in the catches by the deck camera systems and all were recorded in statutory logbooks as dead. Two of the remaining three dolphins exited from the upward excluding net through the top opening escape hatch within relatively short periods of time (i.e. 0.3 and 5.0 minutes). These two dolphins were considered to have a high chance of survival based on their conspicuous swimming movements during escapement. The dolphin that exited the net in the shortest time approached the exclusion grid head first and exited through the escape hatch head first, whereas the orientation of the dolphins during the other six interactions all approached the grid tail first. These orientations usually involved the tail of the dolphin passing through the grid and becoming lodged. During the last of these observations, the dolphin appeared to asphyxiate and was retained within the net forward of the grid for 27 minutes. Whilst that trawl was near the water's surface during hauling and under excessive turbulence, the tail of that dolphin was observed to become dislodged from the exclusion grid, the net rotated 180° and the dolphin fell out of the net through the top opening escape hatch that was now orientated downward. This was the only observation of an asphyxiated dolphin exiting through an escape hatch.

Overall, there were no megafauna or scalefish observed to exit the trawl nets through the top opening escape slit, which was designed to facilitate escapement of predominantly air breathing animals. However, there was a single dolphin observed to attempt to enter the trawl net through this escape slit.

Efficacy of the device

Note that, where possible, bycatch rates for mitigation research trials relevant to this Case Study are summarised in Table 11.

Semi-flexible exclusion grid

There was a significant difference in dolphin catches between vessels when the semi-flexible exclusion grid was deployed – differences that were considered due to different types of gear being used by the vessels (Stephenson *et al.* 2008).

Allen *et al*. (2014) categorised dolphin bycatch data based on three broad net types:

(i) before the introduction of the BRDs (August 2003 until February 2006; excluding BRD trials) - 8.9 bycatch dolphins per 1000 trawls (Skipper's logbook) and 18.8 bycatch dolphins per 1000 trawls (Independent observer data);

(ii) BRD trials from the previous period, after the compulsory introduction of the BRDs and before BRDs were moved forward (primarily March 2006 to May 2008) - 5.2 bycatch dolphins per 1000 trawls (Skipper's logbook) and 10.3 bycatch dolphins per 1000 trawls (Independent observer data); and

(iii) after the BRDs were moved forward in the net (June 2008 until September 2009) - 3.9 bycatch dolphins per 1000 trawls (Skipper's logbook) and 11.3 bycatch dolphins per 1000 trawls (Independent observer data).

Study comparing three different exclusion grid configurations

During the six-month observer period there were 2,250 trawls completed by the three commercial vessels and catches from 85.2% of these trawls were independently observed using the deck camera systems (Wakefield *et al*. 2014).

The subsurface interactions in the trawl nets for dolphins were unable to be used to investigate mitigation efficiencies among different exclusion gear configurations, as there were insufficient numbers of interactions across all net types (i.e. interactions were rare) (Wakefield *et al.* 2014).

Catches of dolphins during the trial were well within catch ranges reported historically in logbooks since exclusion grids were mandated. The number of dolphin mortalities reported in logbooks from March 2006 to June 2012 ranged from 1 to 12 per quarter. There were an additional 1 to 3 dolphins per quarter that were reported to be returned alive. The numbers of dolphin mortalities reported in logbooks during the three exclusion grid trials were well within this range, i.e. 6 and 8 for the third and fourth quarters of 2012, respectively. The numbers of dolphin mortalities reported in statutory logbooks has averaged 16.7 per year and ranged from 11 to 24 per year since the mandatory use of exclusion grids. (Wakefield *et al.* 2014).

Specific vessel operating or structural characteristics

Mitigation of dolphin bycatch is complicated as animals are observed depredating around and in almost all trawls, actively provisioning on discards and deliberately entering and purposely coming in contact with trawl nets (Allen and Loneragan 2010; Jaiteh *et al.* 2012).

Wakefield *et al*. (2014) reported on discussions with fishers around potential circumstances resulting in the entrapment of dolphins. These involved the collapsing of the mouth of the trawl net from reduced trawl speed or sharp turning of the vessel during hauling, which may have prevented escapement during the trial of the three exclusion grid configurations. It was suggested that this could have resulted in a small number of the 14 dolphin mortalities recorded in statutory logbooks during the six month observer program. Two of the three vessels use monitoring sensors (MARPORT Canada Inc.) on their otter boards to provide immediate feedback to the fishers on the board's orientation (pitch, roll, depth) and performance to prevent net collapse. However, it appears the few instances when net collapse occurred were when a relief skipper was onboard. Thus, in an attempt to reduce the catches of dolphins, a vessel operating Code of Practice could be developed to help prevent net collapse and to document other standard operational procedures to ensure a consistent standard of mitigating dolphin interactions is maintained. The extensive evidence provided from the high level of subsurface within-net observations at the exclusion grid, suggested that the initial causes of dolphin distress are occurring toward the mouth of the net. Therefore, it would be beneficial to obtain in situ observations of dolphin behaviour in this forward part of the trawl nets in an attempt to determine the potential circumstances that lead to distress, and to develop and trial further mitigation measures and strategies in this part of the net (Wakefield *et al.* 2014).

Key points:

- Dolphins were mostly observed to back down into the net to a position near the grid and later swim upstream out of the net. Very few dolphins were seen swimming head-first towards the grid, and those that did turned around before reaching the grid and swam out the mouth of the net.
- Net monitoring systems that are designed to maintain the shape of the trawl gear when turning, thus ensuring the entrance to the net remains open at all times, may assist in reducing entrapment of dolphins in trawl nets.

UK BASS PAIR TRAWL FISHERY AND ADJACENT, OVERLAPPING EUROPEAN FISHERY

Description of fishery

The European sea bass, *Dicentrarchus labrax*, is important to commercial fisheries. The largest targeted sea bass fishery takes place between November and April in the western English Channel and Bay of Biscay, where mainly French, but some Scottish and Danish mid-water pair trawlers target sea bass shoaling offshore prior to spawning.

The UK bass pair trawl fishery employs trawl nets towed near the surface by a pair of relatively small trawlers (30-40m range; MAFF 2002) (Figure 18). The UK pelagic pair trawl fishery for bass is operated typically by just two pair teams (mainly Scottish boats) and runs sporadically from November to April. Boats may switch between gears for various other species, even within trips, depending on bass catch rates. Annual fishing effort is typically measured in tens to a few hundred fishing operations (Range 0-493) (Northridge *et al.* 2011).

There are reportedly up to 50 pairs of French boats operating the same gear, but mostly working in the Biscay area (Northridge 2007).

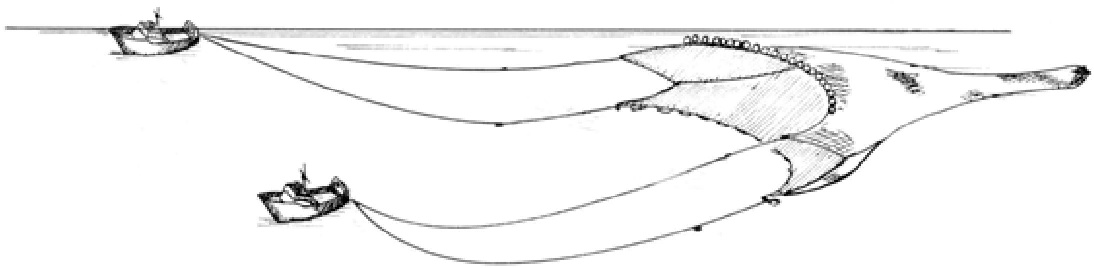


Figure 18: Schematic representation of a pair trawl operation (Northridge 2007).

Nature and extent of the marine mammal interaction and bycatch problem

Observations from previous years have shown that the bycatch rate in unmodified pelagic pair trawls in the UK bass pair trawl fishery is very high, with mean bycatch rates of around 1 short-beaked common dolphin (*Delphinus delphis*) per tow (Northridge *et al.* 2011). Estimates of dolphin bycatch in the Southwest have been made annually since 2001 for the winter bass pair trawl fishery (Table 5).

Table 5: Common dolphin bycatch in the UK bass pair trawl fishery (Northridge *et al.* 2011). LCL (lower confidence level), UCL (upper confidence level).

Winter Season		Point Estimate or Census	LCL	UCL
2000 to	**2001**	**190**	**172**	**265**
2001 to	**2002**	**38**	**23**	**84**
2002 to	**2003**	**115**	**88**	**202**
2003 to	**2004**	**439**	**379**	**512**
2004 to	**2005**	**139**	**139**	**146**
2005 to	**2006**	**84**	**84**	**85**
2006 to	**2007**	**70**	**55**	**117**
2007 to	**2008**	**0**	**0**	**0**
2008 to	**2009**	**2**	**2**	**2**
2009 to	**2010**	**28**	**28**	**28**

It has been thought that further evidence of bycatch in pelagic trawls can be obtained from necropsies of stranded animals. Under contract to DEFRA, the Natural History Museum, Institute of Zoology and the Scottish Agricultural College have carried out post-mortem examinations on a sample of all stranded cetaceans which occur on the UK coasts. Data obtained from 1 January 2000 to 30 September 2002 showed that bycatch, most probably from pelagic fishing operations, was identified as the cause of death in 65% of the stranded common dolphins that were subject to post-mortem examination and where cause of death was established (DEFRA 2003).

From a 2004 -2009 study, de Boer *et al*. (2012) showed that the overlap between pelagic fisheries and a short-beaked common dolphin 'hotspot' led to direct mortality through bycatch and, together with recent range-shifts, may have contributed to a localised decline of this species in this winter hotspot since 2007.

Mitigation devices

The main mitigation work for the sea bass trawl fisheries in the English Channel and Bay of Biscay has been undertaken by European (IFREMER - French Research Institute for Exploitation of the Sea) and Scottish (Sea Mammal Research Unit, SMRU, University of St. Andrews, Scotland) researchers. As there has been work on both exclusion devices and pingers to mitigate dolphin bycatch in these fisheries, the following sections have been grouped to review these mitigation methods separately.

Technical details of mitigation devices - exclusion devices

Sea Mammal Research Unit (SMRU), St Andrews, Scotland

The possibility of employing an exclusion grid was investigated based on the assumption that such a device, if deployed near the front end of the extension piece would enable dolphins to escape before they had travelled much further towards the cod end, in the expectation that they would be alive at this point (MAFF 2002). An examination of the trawl net plans suggested that such a point is roughly 100-150 meters from the mouth of the trawl. At the mouth of the trawl the mesh size of the net is 9m, with gradually decreasing mesh sizes to around 6 cm at the beginning of the extension piece. The nearest meshes that an animal of this size might reasonably still be expected to escape from, i.e. about 80cm. are just 50m from the entrance of the extension piece.

Several key aspects of design were discussed at a workshop of experts in January 2002, including rake angle, grid spacing, construction material, outlet size and placement, guide nets and outlet cover (MAFF 2002). Through all of these discussions it was recognized that there are many alternative options that might be taken during the design of a selection grid and that only experience would determine the best options for this fishery. It was unknown how bass might behave in such a situation, a grid never having been tried in a bass fishery before. In order to monitor the outlet, it was agreed to try to establish a cabled link between a high definition underwater camera and a monitor and recorder in the wheelhouse, a distance of some 500m (MAFF 2002).

In 2001, SMRU was awarded a grant to design and test an exclusion grid to reduce common dolphin bycatch in the bass pair trawl fleet. The gear was developed and tested at sea with the co-operation of the Scottish Pelagic Fishermen's Association but no cetaceans were encountered during the trial (DEFRA 2003). Among 37 tows observed during March 2002, only 2 tows (5%) had any dolphin bycatch (8 animals in total), and these were the only two bycatch tows observed throughout from January to April 2002 (66 tows observed in all). This compared with dolphin bycatch in 11 out of 52 (21%) tows in March 2001. These very much lower bycatch rates meant that any dolphins in the nets were unable to be observed and, therefore, there was no direct evidence of how dolphins behaved in relation to the grid (Northridge *et al.* 2011).

During the 2004-2005 season, it was found that dolphins can and do use a 2m by 3m escape opening fitted into the net midway along its length (Northridge 2006). A barrier immediately behind the escape opening allowed fish to pass but was not passable by dolphins. Nine dolphins were observed escaping while 32 were recovered from the nets having drowned. This represents a minimum 22% escape rate. Most of the animals that drowned had done so some distance in front of the escape hatch and barrier, so it was assumed they were not aware of the escape hatch, had detected the barrier and stopped further forward in the net, and tried to escape there. A few other animals had reached the barrier but failed to notice or use the escape hatch. Northridge (2006) concluded that escape routes need to be more numerous and more obvious.

Although trials with exclusion devices showed some promise between 2003 and 2006, these were curtailed in 2006 after negative intervention by an animal welfare organisation. Instead, work focused on the use of acoustic deterrents to reduce bycatch (Northridge *et al.* 2011).

'Necessity' project (Netherlands, UK, France and Spain)

A preliminary model of a barrier to prevent dolphins from entering a trawl net (tuna and sea bass fisheries) was tested in a flume tank (Meillat *et al.* 2006). Various selective devices were adapted to this model:

1) A large square mesh barrier (1600 mm mesh side) fitted at the assembly point between the 800 mm side meshes and the first 4 m side meshes ("shark teeth" level). The barrier is 20 meshes wide and 9 meshes high. The objective of this device was to catch tuna while letting dolphins escape through the large 4 m side meshes.

2) A BRD (By-catch Reducing Device) also known as « Fisheye », a tunnel like device with an opening towards the front of the trawl; this device could enable the large size individuals (dolphins) to escape from the trawl while holding back the catches of target species.

3) A semi-rigid grid placed in the extension of the pelagic trawl: the target species can flow through while the dolphins are prevented from entering. These can escape through a longitudinal opening provided at the top of the extension in front of the tilted grid. So as to reduce the risk of seeing too many commercial species escape, the opening is covered with a netting panel partly sewn onto the trawl; this cover is expected to free the opening as dolphins work their way through it when it remains closed to commercial species (Meillat *et al.* 2006).

A workshop, hosted by IFREMER at the Lorient flume tanks in February 2005, discussed the above models and compared designs with the various excluder devices investigated by the partners, by net manufacturers and for France by the fishermen (Meillat *et al.* 2006). The list of models tested during the workshop is given in Table 6 as well as the models selected for at-sea testing.

Table 6: List of gear and gear modifications to test at model scale in the flume tank (top table) and, following the February 2005 Lorient workshop, the devices selected for testing at sea (bottom table) (Meillat *et al.* 2006).

List of gear and gear modifications to test at model scale (Cetaceans trials NECESSITY Project) Ifremer Flume tank / Boulogne sur Mer (2-3 February, 2005)											
FULL SCALE TRAWL						MODEL					
PARTNER	COUNTRY	FISHERY INVESTIGATED	GEAR TYPE	MANUFACTURER	HEADLINE x WING LINE	FULL TRAWL or PART OF THE TRAWL	MODIFICATION	MODEL SCALE	SIZE OF THE MODEL		
									Length	Width	Height
1 RIVO	Netherlands	Horse mackerel	PTM	MARITIEM	151m x 129m	Full	Rope Barrier (3m between ropes) or "Net barrier (square mesh 2x2m)	1/32	8	2	1
6 IFREMER + 4 USTAN	France	Tuna + Seabass	PTM	LE DREZEN (France)	83m x 65m	Full	Net barrier (1600 mm square meshes)	1/25	7	1.5	0.9
		Seabass	PTM	LE DREZEN (France)	83m x 65m	Full	Net barrier (1600 mm square meshes) + Flexible exclusion grid with net cover on the top + BRD By-catch Reducing Device	1/25	7	1.5	0.9
						Part	Exclusion grid	1/2	5	0.8	0.8
LE DREZEN + Xavier TIMBO	France	Seabass	PTM	LE DREZEN (France)	151m x 108m	Back Part	Inclined net barrier (300mm square mesh) + exclusion panel (breakable twine) on the top	1	15	4	2
							the same with 250mm square mesh	1	15	4	2
								1/4	3.75	1	0.5
14 BIM	Ireland	Mackerel	PTM	SWAN NET GUNDRY		Part	Net barrier V shape 200mm mesh side	1/5	10	1.5	1.5
19 AZTI	Spain	Hake	PTB	NABERAN	165m x 157m	Full	still to be decided	1/80	2	0.60	0.40

	Devices to test at sea (Cetaceans trials NECESSITY Project) Boulogne sur Mer (2-3 February, 2005)		
ORGANISATION	**Species**	**Period**	**DEVICES**
RIVO	Horse mackerel , mackerel	March, 2005 September 2006	Rope Barrier (3m between ropes) or "Net barrier (square mesh 2x2m)
BIM			
LE DREZEN + Xavier TIMBO	Seabass	March April 2005	Inclined net barrier (300mm diamond mesh) + exclusion panel (breakable twine) on the top
			Inclined net barrier (300mm diamond mesh) + exclusion panel (breakable twine) on the top + net cover
			Inclined net barrier (300mm diamond mesh) + escaping hole + net cover
IFREMER	Seabass	March April 2005	Net exclusion grid with "deflector" +net cover on the top (3 to 4m x 1.2m)
			BRD By-catch Reducing Device
			Flexible exclusion grid + net cover on the top
USTAN	Seabass	January to April 2005/2006	BRD By-catch Reducing Device
			Solid grid Rope "grid" Escape holes + covers (elastic rope, vinyl strips, use of velcro)
AZTI	Hake	March, or autumn 2005	Rope grid + escaping hole with net cover

Trials of the exclusion devices

'Necessity' project

For the at-sea testing, the following cruises were conducted by the Fisheries Technology Laboratory based in Lorient (Larnaud *et al.* 2006):

1. In August 2004 (NECECET2), the season when white tuna is fished off Brittany coasts, to test the initial configuration, i.e. a 1600 mm square mesh anti-dolphin barrier (20 mesh sides by 9 mesh sides) fitted at the joining of the 800 mm side meshes and the first 4 m side large meshes (at “shark teeth” level). The dimension of the barrier meshes was calculated to let the tuna fish flow through while it would act as an acoustical “barrier” for dolphins. Sub-sea video equipment was used to observe both the way the barrier acted under fishing conditions and the behaviour of the various individuals facing the obstacle. Bad weather hampered this testing;

2. In March/April 2005 on a pair of commercial trawlers (NECECET PRO), the season when bass is fished in the English channel. Three devices were tested to establish whether they enabled catch of seabass in good conditions, if there was no technical or handling problems, and, if possible, to show that they were able to let dolphins escape. An underwater video system and simple camcorder in a diving housing (to obtain complementary images) were used to monitor the devices. Only a few dolphins were

observed around the boats during the campaign and no dolphin was caught during the trawls. The devices were:

a. a barrier consisting of a 300 mm side square mesh tilted panel fitted in the baitings. The device reacted properly, though it pursed at its upper part which may prevent the dolphins from escaping, increase clogging phenomenon when facing large catches

b. a vertical barrier of 300 mm side square meshes (7.5m x 6m) placed in the body of the pelagic trawl (in the part constituted by 100mm side meshes). The barrier did not hinder the implementation of the trawl, no clogging phenomenon was observed and the trawl was able to fish in good conditions,

c. a semi-rigid oval grid fitted in the extension of the pelagic trawl. This device was considered easy to implement on the trawl, the trawl was able to fish in good conditions, although clogging of sea bass occurred on the grid.

From these trials, the fishermen and technologists agreed that a vertical barrier (4 to 5 m width) is better than a tilted one and 300 mm side square meshes seems suitable to fish and to stop dolphins. The flexible grid is easy to handle and it seems that fishing is good even though clogging phenomenon was observed in case of large sea bass catches (Larnaud *et al*. 2006).

It was subsequently decided (following another workshop) to give up the trials on the grid (as it was considered to be too close to the codend) and to develop a new device (Meillat *et al*. 2006).

3. In February 2006, a pair of commercial trawlers in the Bay of Biscay (Larnaud *et al.*2006) trialled the new device composed of 1 square mesh net barrier (400 mm mesh side) with dimensions 14 m x 8 m with 2 escape holes (3.0 m x 3.0 m) in the front of the net barrier and at the top. The escape openings were fitted with bungee cords with 35 cm spacings. The barrier was fitted between the 100 mm and 200 mm mesh parts of the trawl. The trial found that:

   - The device was ineffective in spite of the large (uncovered) escapement openings;
   - Sea bass escapement could have been limited by covering the escapement openings, but this had no importance considering the lack of efficiency of the device on dolphin escapement;
   - Though it was set at the level of the 200 mm meshes, the device seemed to be positioned too far in the cod-end considering that most of the dolphins were exhausted when they reached this barrier.

   As a result, a larger size barrier was developed which consisted of 800 mm square-meshes that would be mounted at the junction between the 800 mm meshes and the 4 m meshes with the aim of enabling dolphin escapement through the large size meshes. The trials indicated that this kind of device may be efficient, but this still remains to be proved (Larnaud *et al.* 2006).

Efficacy of the exclusion devices

Note that, where possible, bycatch rates for mitigation research trials relevant to this Case Study are summarised in Table 11.

None of the excluder devices tested to date have proven to be fully effective. Most of the mitigation work has subsequently focused on the use of pinger devices to deter dolphins from trawl nets.

Specific vessel operating or structural characteristics - deployment of exclusion devices

Excluder devices in bass pair trawl fisheries (summary from Rihan 2008):

- Excluder devices were trialled in the UK bass pair trawl fishery in 2003/2004 with limited success
- The EU CETASEL project tested parallel ropes in the mouth of the trawl to prevent entry but the results were inconclusive
- More research under the EU NECESSITY project included the testing of:
    i. Rope and tunnel barriers placed in the front part of the trawl
    ii. A 300mm square mesh tilted panel
    iii. A vertical barrier of 300mm square mesh placed in the body of the trawl
    iv. A semi-rigid oval grid
    v. Large mesh escape panels with netting covers
- Results have shown most devices to be ineffective in reducing dolphin bycatch although sporadic nature of bycatch has made assessment difficult
- Exclusion devices have resulted in a 20% reduction in bycatch at best and, at worst, no reduction and loss of marketable catch
- There have been some handling difficulties particularly in big trawls
- The positioning of the exclusion device is critical for dolphin bycatch mitigation.

Technical details of mitigation devices - pingers

Definition of 'pinger': Small self-contained battery operated device that emits regular or randomised acoustic signals at a range of frequencies that typically are loud enough to alert or deter animals from the immediate vicinity of fishing gear.

Dolphin Dissuasive Device (DDD) - SMRU

The Dolphin Dissuasive Device (DDD) is a pinger device that has been specially designed to work in the noisy environment of a pelagic trawl and to be activated only when dolphin clicks are detected (Northridge 2006). It is much larger and more powerful than regular pingers designed for use in gillnets (peak source levels are around 165dB re 1 μPa at 1m).

The device:

- was developed in conjunction with UK based acoustic company
- was the basic principle of emitting a wide band deterrent signal in response to echo locating animals
- has the following basic parameters: Transmits 300 ms signals; Randomised inter-pulse period but not > 15 s apart; Various sweep signals between 20 –80 kHz; Significant harmonic energy up to 160 kHz; 165 dB peak, approx 157 RMS; Detection range of 10 to 150m (Rihan 2008).

CETASAVER pinger - European 'Necessity' project

IFREMER and a French company called Ixtrawl developed a prototype pinger, the Cetasaver, to mitigate incidental catches of common dolphins in trawl fisheries operating in the Bay of Biscay (Morizur *et al.* 2008; Figure 19). This device was developed following behavioural tests performed on groups of common dolphins. Tests conducted at sea for the European project 'Necessity' showed that the trajectories of animals could be changed by using this pinger. The Cetasaver emits a conical direction beam with an opening between 75 and 15 degrees. This directionality can be less disruptive to the environmental noise level and should be directed towards the opening of the trawl and the frequency ranges from 30 to 150 kHz. The signals are modulated and pulsed. The average sound level is 178 dB which gives 139 dB at the entrance to the trawl (type Le Drezen 151m). The optimal area location of the deterrent on the trawl was determined.

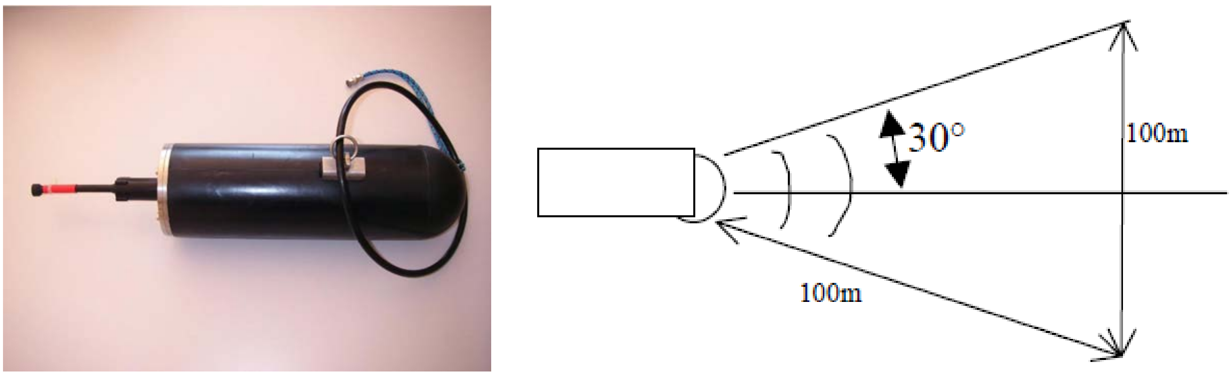


Figure 19: The Cetasaver and the geometric characteristics of the emitted beam (Morizur *et al.* 2008).

Trials of the pinger devices

SMRU work

SMRU undertook a preliminary trial, using standard pingers from gillnet fisheries, to see whether pingers had the potential to reduce the bycatch of common dolphins in this fishery (DEFRA 2003). Pingers were deployed on the trawl of one of the two UK bass pairs, with pingers deployed on 15 out of 52 tows observed during March 2001. Dolphin bycatch rates were not reduced by the use of pingers in this experiment.

SMRU sourced a louder pinger device, the Dolphin Dissuasive Device (DDD). Since 2006, the DDD-03H has been tested in the winter bass mid-water pair trawl fishery in the Western English Channel (Northridge *et al.* 2011).

Northridge *et al.* (2011) worked with three different pair trawler teams from 2008/09 to 2010/11 to monitor hauls using observers. One pair team (with <15m boats) was involved throughout the project, a second pair team only operated in the 2008/09 season and a third pair team operated in 2009/10 and 2010/11. Most tows were equipped with two DDDs but different models were used (DDD-02Fs and DDD-03Hs). Bycatch levels have been greatly reduced in this fishery since the winter of 2006/2007 when DDD-02Fs began to be used (Table 7; Figure 20).

Table 7: Observations and observed bycatch by season (Northridge *et al.* 2011) before and after the introduction of Dolphin Dissuasive Device pingers. DDDs were introduced into the UK Bass Pair Trawl fishery in the Western English Channel in the winter of 2006/07.

Winter Season Ending	Days	Trips	Hauls	Dolphins	Rate per tow
2001	57	10	92	52	0.565
2002	50	14	91	9	0.099
2003	76	16	113	27	0.239
2004	98	26	136	169	1.243
2005	133	39	176	176	1.000
2006	61	21	53	77	1.453
2007	15	5	34	8	0.235
2008	0	0	0	0	0.000
2009	23	10	28	2	0.071
2010	133	41	188	28	0.149
TOTALS	**646**	**182**	**911**	**548**	**0.602**

Overall the bycatch rate in tows with DDDs during 2007-2009 was 0.178 dolphins per tow, compared with 0.772 dolphins per tow overall for the previous seasons (2001-2006), a 77% reduction in bycatch rate (Northridge *et al.* 2011). The lower rate may be attributed to the use of pingers, but the absence of any significant number of control tows (tows without DDDs) with associated bycatch prevents surety regarding this point because it is conceivable that after 2006 the bycatch rate had simply declined independently of the use of pingers.

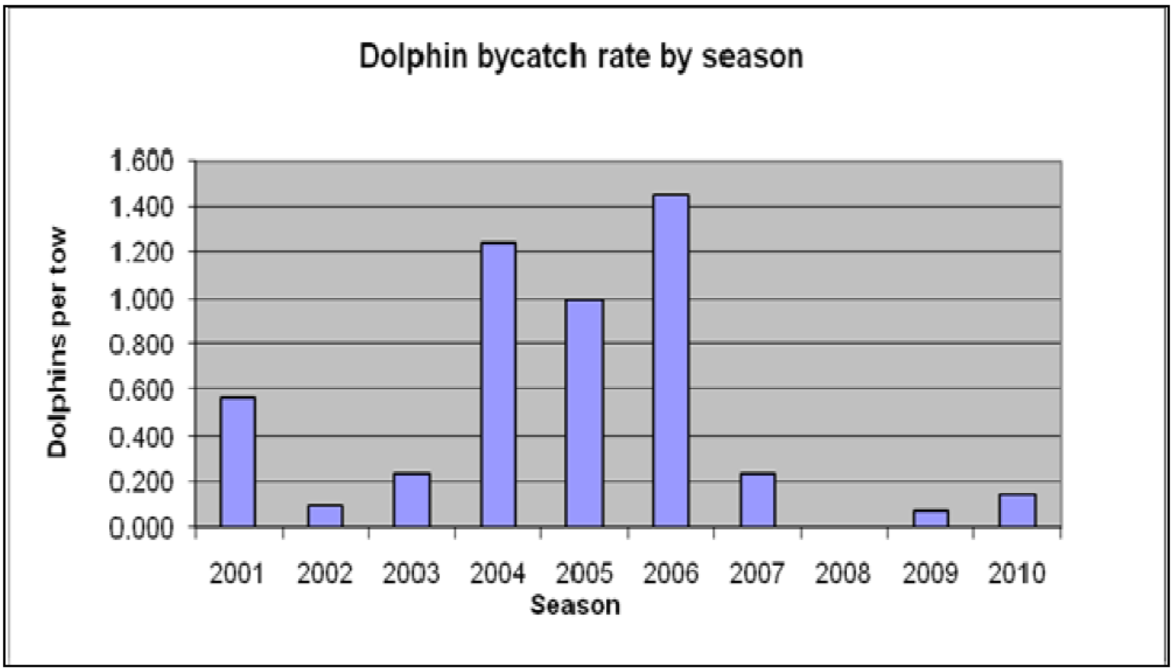


Figure 20: Bycatch rates by fishing season (Northridge *et al*. 2011) before and after the introduction of Dolphin Dissuasive Device pingers. DDDs were introduced into the UK Bass Pair Trawl fishery in the Western English Channel in the winter of 2006/07.

All the vessels involved in the bass trawl fishery in recent years (three pair teams) have voluntarily requested pingers and observers every season to ensure that detailed records are maintained of any dolphin bycatch and the deployment patterns and functioning of the devices (Northridge *et al.* 2011). After the introduction of DDDs to this fishery in the 2007 season (in Dec 2006) most observed tows have been conducted using DDDs, though not necessarily always in a consistent manner (Northridge *et al*. 2011). During the 2007 and 2009 seasons 62 tows were monitored, and DDDs were used on 56 of these. Three of the 56 tows with DDDs in place resulted in dolphin bycatch of 10 (7+1+2) common dolphins. In two of these tows one or both pingers were not working and, in the third, the observer reported that the pingers had been placed in a suboptimal position on the gear close to the surface. The manufacturer recommends that the devices should always be deployed in at least 10 m of water for the acoustic signal to propagate properly (Northridge *et al.* 2011).

During 2009-10, two pair teams were observed for the duration of the fishery and 188 tows were observed, with 9 dolphin bycatch events involving 28 animals (Northridge *et al.* 2011). DDD-03s were only available for one of the vessels in the new pair team, which resulted in observations of 23 ‘control’ tows by this pair team without DDDs, during which 4 bycatch incidents were recorded involving 10 dolphins, a rate of 0.435 animals per tow. A further 34 tows with DDDs resulted in no bycatch. There was a significant difference between the bycatch rate with and without DDDs ($p<0.002$ using a bootstrapped binomial test). However, the other pair team, using the older DDD-02s, yielded more equivocal results in the 2010 season based on 131 observed tows – 123 using DDDs and 8 not using DDDs. The 123 ‘DDD tows’ resulted in 5 bycatch events involving 17 dolphins and the 8 tows without active DDDs had 1 bycatch event involving 1 animal (Table 8). Although the number of animals per tow is not significantly different between these two sets of data, a consideration of bycatch events suggests that the DDDs may have an effect in reducing dolphin bycatch. The probability of encountering 5 or fewer bycatch incidents among a sample of 123 tows where the underlying probability of bycatch is 1/8 was estimated at 0.014 based on a bootstrap simulation. However, the total number of animals caught per tow was still no lower when the DDD-02s were used by one pair team. This result was surprising because it was thought, from previous observations, that the DDDs, if used correctly, may be close to 100% effective. It was subsequently discovered that the older DDD-02 devices were not holding their charge suggesting that signal strength had been compromised during the trials and that DDDs should not be used for longer than three seasons in this fishery (Northridge *et al*. 2011).

Despite the malfunctioning devices used in the 2009-10 season, it was estimated that some 39 fewer dolphins died in bass pair trawls (28) than would have done if no devices had been used (67) (Table 9). If all tows had used new DDDs, Northridge *et al.* (2011) considered that a zero bycatch in 2009-10 would have been achieved. The results of three seasons' monitoring (2006-7; 2008-9 and 2009-10) showed three potential problems with implementing these devices as a mitigation measure:

1) Devices may not always be properly charged or working when deployed;

2) Devices may be placed too close to the surface; and,

3) Devices may be degrade after three years and are unable to hold adequate charge (Northridge *et al.* 2011).

It was recommended that a code of best practice in this fishery should address these points and ensure that DDDs are fully charged, functioning and deployed on the lower wing ends or bridles of the trawl (Northridge *et al.* 2011). Important lessons have been learned about the optimal positioning of DDDs inside the trawl and about battery management to ensure that they continue to function correctly. Any issues have been addressed collaboratively with considerable input from skippers and crews, who are now familiar with the procedures required to minimise or possibly, with further fine tuning, eliminate dolphin bycatch in this fishery (Northridge *et al.* 2011). Although DDDs appear to be effective in reducing dolphin bycatch, there are still challenges to address including determining the most effective configuration for mid-water trawls (Northridge *et al.* 2011).

There have been concerns expressed that cetaceans could habituate to pingers over time, and therefor effectiveness of pingers will decline. However, habituation is not currently thought to pose a problem in this fishery and it is likely that any decline in the effectiveness of pingers would be identified by the use of observer programmes (DEFRA 2003). Concerns have also been expressed that the wide use of pingers in certain fisheries may result in the exclusion of cetaceans from habitat that may be significant to their survival. However, where pingers have been used there is no evidence that this occurs. If pingers were to be used intensively in coastal areas there may be problems with cetaceans being unable to access (or leave) bays or inlets (DEFRA 2003).

Although the use of these louder pingers has proven successful in reducing cetacean bycatch, there remains some unease about the widespread deployment of such loud devices (~165 dB re 1μPa@1m) in case cetaceans are displaced from large areas which could potentially reduce their foraging success (Northridge *et al.* 2011). Experiments were conducted using DDDs and a quieter device (Aquamark 100) to determine how significant any exclusion might be. Results from the experiments in two separate years using DDDs were equivocal although there was some evidence of decreased cetacean activity when a single DDD was in the water out to at least 1.2 km from the device and possibly as far as 3 km or more. The Aquamark appeared to have an effect up to about 400 m, though this particular result is preliminary pending further analysis (Northridge *et al.* 2011).

A possible avenue for research may be to examine in detail how animals behave in the vicinity of fishing fleets, particularly common dolphins that appear to be attracted to fishing vessels such as pair trawlers as this lethal attraction is poorly understood (Northridge *et al*. 2011).

Table 8: Results of DDD trials in the UK Bass Pair Trawl fishery in the Western English Channel 2009/10 (Northridge *et al.* 2011).

Trawler Pair Team	1	2	1	2
DDDs in Use?	Yes (DDD-02F)	Yes (DDD-03H)	None	None
No of Tows Observed	123	34	8	23
Dolphins	17	0	1	10
Bycatch Events	5	0	1	4
Dolphins per Tow	0.138	0.000	0.125	0.435

Table 9: Observed and expected dolphin bycatch in the UK Bass Pair Trawl fishery in the Western English Channel based on 2009-10 observations (Northridge *et al.* 2011).

Mitigation Measure Used or Supposed	Tows this season	Dolphins	Bycatch Tows
Tows using DDDs	157	17	5
Tows not using DDDs	31	11	5
Season's totals	**188**	**28**	**10**
Expected if no DDDs had been used	188	67	30
Expected if all tows used new DDDs	188	0	0

BIM (Bord Iascaigh Mhara/Irish Sea Fisheries Board) conducted a trial in February 2009 to test the response of common dolphins to recordings of killer whale vocalizations as a first step to see if such sounds could be used in an interactive pinger to mitigate cetacean bycatch in pelagic trawl fisheries. However, no effect on common dolphin behaviour was observed during this trial or a further trial conducted in January 2010 (ICES 2011 in Northridge *et al*. 2011).

European 'Necessity' project

Effect of different models of pinger devices on the behaviour of common dolphins

For trawl application, two possible locations for the fixation of the deterrent system were investigated (Van Canneyt *et al.* 2007):

- the area of the 200-400 mm mesh (side mesh) tunnel which matches best the angle criteria;
- the shark teeth area which matches best the 200 metres reaction distance. The shark teeth area is also a transition between large meshes and small meshes.

In the northern Bay of Biscay during August 2005 (one week) and August 2006 (two weeks), IFREMER and CRMM observed the effect of different models of pinger devices (commercial and prototypes) on the behaviour of common dolphin groups (Van Canneyt *et al.* 2007). Seven models of commercial deterrent devices were tested, including some models having the technical characteristics given by the European council 812/2004 (FMDP 2000®, Pinger® and Aquamark 200®) and 3 models with higher source level and longer pulse duration (High Impact Black Saver® and Dolphin Dissuasive Device models - DDD01®, DDD02®, DDD02F®). During the tests, each first immersion (depth between -1 and -3 m) was carried out at a minimal distance of 300 m from the dolphin groups (over 300 m for the DDD models, after the brisk reaction observed during 2005 first test). Then, according to the dolphins behavioural response, the immersions were either done nearer to the group or further away. Data were collected for 16 days at sea and 20 groups of common dolphins. For the models FMDP2000 ®, Aquamark 200 ®, Pinger ® and High Impact Black Saver ®, no change of behaviour was observed whatever the distance and it was concluded that these pingers were inefficient in deterring common dolphins. Among the commercial models, only the DDD models induced an obvious change in dolphin behaviour though with a variable response level. Trials were also conducted with Cetasaver_3 on six groups of common dolphins (Van Canneyt *et al*. 2007). Three directivity tests were carried out by pointing the pinger beam in the same direction as the dolphins. Under frontal conditions (i.e. the dolphin swimming direction and the emitted sound direction were 180 ° apart), Cetasaver_3 induced dolphin reaction up to a 200 metre distance. This system was found to operate like an acoustic barrier on all the groups tested and the dolphins did not come within the 200 metre reach in frontal experiments. Some groups modified their trajectory by 180°, others by 90°.

Tests carried out with variations of the Cetasaver unit

The commercial pinger DDD is able to modify the behaviour of groups resulting in a deterring effect. However the DDD pinger is an omnidirectional device in the horizontal plane. From the directional systems tested, the Cetasaver_3 was selected and its scaring effect was tested on 6 different groups. Trials with a Cetasaver_7 (Cetasaver_3 slightly modified with a shorter pulse duration) were planned in the French sea bass fisheries during winter 2006-2007 (Morizur *et al.* 2007). A special kit to fix the Cetasaver was created by Ifremer by taking into account fishermen and net maker input. This kit has a size of 2m x 1.5 m and is made of small mesh nets in order to avoid any entangling of the Cetasaver with the trawl nets. Four Cetasaver_7 were built and deployed during winter 2006-07 in the sea bass fisheries (Morizur *et al*. 2007).

In this experiment, with the Cetasaver deployed the bycatch events were reduced by 2 and the bycatch rate was decreased by 80 % (Table 10). However, the number of events are probably too low for these results to be conclusive (Morizur *et al.* 2007). The main results at this stage were:

- The Cetasaver does not modify the sea bass catch (e.g. trip 5 with 3.5 tons for control tows and 3.5 tons for test tows).
- The Cetasaver_7 does not suppress all the bycatch.
- The Cetasaver_7 seems to be efficient on trawls for mitigation but the reduction rate is not well determined (Morizur *et al.* 2007).

Similar results would likely be obtained with a Cetasaver_3.

Table 10: Results obtained by the observers on board of pelagic pair vessels in the bass fisheries with Cetasaver (Morizur *et al*. 2007).

Cetasaver	**Number of trips**	**Number of pairs**	**first trip**	**last trip**	**Tows total number**	**Dolphins total number**	**Selected tows**	**bycatch Events number**	**Dolphins total number**
with	**10**	**4**	**6-Jan-2007**	**7-March-2007**	52	2	**52**	**2**	**2**
without	**10**	**4**	**6-Jan-2007**	**7-March-2007**	61	11	**56**	**4**	**11**

Experiments completed in Cork (Ireland) with Cetasaver_7 in mid April 2007 proved that the Cetasaver_3 and Cetasaver_7 might not work on all groups of common dolphins. This recent information may explain why all the bycatch is not suppressed in the trials made with the Fishing Industry (Morizur *et al.* 2007).

In 2007 and 2008, numerous trials of the Cetasaver were conducted using a pelagic trawl in commercial conditions, most often in the presence of scientific observers (Morizur *et al.* 2008). Successions of test and standard tows were performed in order to get a rigorous comparison. The observations were conducted in the bass fisheries during seasons 2007 and 2008 and involved a total of 121 hauls with pinger and 129 without pinger. Incidental captures were respectively found in 5 and 10 hauls with comparative numbers of bycaught dolphins of 6 and 20. The results show a reduction in common dolphin bycatch of around 70% during the two years. The bootstrap analyses show the need to double the number of observations to reach a significant difference through the confidence intervals in numbers of dolphins.

Efficacy of the pinger devices

A decline in observed bycatch in UK pair-trawl fisheries has been reported since 2007, following the introduction of pingers as a mitigation device (Northridge and Kingston, 2009 in de Boer *et al*. 2012). Trials with pingers used by French trawlers indicated a 70%-reduction in common dolphin bycatch (Morizur *et al*. 2008). However, at-sea trials off Ireland indicated that pingers may not provide a consistently effective deterrent signal for common dolphins (Berrow *et al.* 2009). Low bycatch figures reported since 2007 may also be explained by less fishing-effort from 2007 onwards due to high fuel prices and low sea bass availability (Northridge and Kingston, 2009 cited in de Boer *et al*. 2012).

Specific vessel operating or structural characteristics - deployment of pingers

French fishermen prefer to see the Cetasaver set on the rear part of the trawl compared to the DDD set on the wings of the trawls because there is less interference with the netsonder because of the geometry of the beams (Morizur *et al.* 2007).

Key points (Rihan 2008)

Exclusion devices:

- None of the excluder devices tested to date has proven to be fully effective (~20% reduction)
- The sporadic nature of bycatch makes assessing devices difficult
- Positioning of any excluder device within trawls is critical
- Rigging and handling can be problematical in big pelagic trawls
- High losses of commercial fish catch can make some designs unacceptable

Acoustic deterrent devices (pingers):

- Behaviour of cetaceans around pelagic trawls needs further study
- Of the commercial gillnet pingers, only the DDD has shown some effect in pelagic fisheries
- A ~80% reduction in bycatch in the bass pair trawl fishery has been observed
- Trials of the Cetasaver device has shown a 70% reduction in bycatch
- Interactive device works but effective deterrent signal needs to be found
- Background noise from vessels and gears is an issue

SUMMARY OF BYCATCH RATES FROM MITIGATION RESEARCH TRIALS

Table 11: Bycatch rates for mitigation research trials conducted in Case Study fisheries.

Fishery	Marine mammal bycatch species	Mitigation device	Bycatch rate without mitigation	Bycatch rate with mitigation	Reference
Australian winter blue grenadier fishery (Case Study 1)	Australian fur seal, *Arctocephalus pusillus doriferus*, and New Zealand fur seal, *A. forsteri*	Seal exclusion device (SED): a rigid grid with bars of no more than 250mm; top opening no smaller than 800mm x 600mm; optional hood made of mesh no greater than 40mm with a kite attached to the leading edge of the escape hatch and at least one single 20cm diameter float	0.125 (83/665) dead seals per shot in 1999; 0.050 (46/921) dead seals per shot in 2000-2003 (no SED)	0.050 (32/629) dead seals per shot in 2000-2003 for midwater trawls with SED open (from Table 5, Tilzey *et al.* 2006) **See footnote 1.**	Tilzey *et al.* 2006
		new Acoustic SED (hydrostatic net release and acoustic transponder release grid gate on SED)	no reported data	no reported data **See footnote 2.**	Mike Gerner (AFMA), pers. comm.
European (Dutch and Irish) pelagic fleet fishing off Mauritania, Northwest Africa (Case Study 2)	smaller dolphins that live and forage nearer the sea surface i.e. common dolphins *Delphinus delphis*, bottlenose dolphins *Tursiops truncatus*, and (along the European shelf margin) white-sided dolphins *Lagenorhynchus acutus*	Large Animal Reduction Device, LARD, designed to address bycatch of all megafauna (sharks, manta rays, sea turtles, and dolphins) in these fisheries.	Bycatch rates cannot be calculated from data provided in Zeeberg *et al.* (2006); 0.0206 (dolphin bycatch specimens per haul; from Heessen *et al.* 2007); 0.0014 (pilot whale bycatch specimens per haul; from Heessen *et al.* 2007)	bycatch rates cannot be calculated from data provided in Zeeberg *et al.* (2006); 0.0117 (dolphin bycatch specimens per haul; from Heessen *et al.* 2007): 0.0 (pilot whale bycatch specimens per haul; from Heessen *et al*. 2007) **See footnote 3.**	Zeeberg *et al.* 2006; Heessen *et al.* 2007

Fishery	Marine mammal bycatch species	Mitigation device	Bycatch rate without mitigation	Bycatch rate with mitigation	Reference
Antarctica krill fishery (Case Study 3) - vessel-specific mitigation devices/ measures	Antarctic fur seal, Arctocephalus gazella	Vessel *Atlantic Navigator* - SED consisting of a metal grid sloped at an angle to divert seals out through an escape panel in the floor of the net	5.5 entanglements per trawl (Hooper *et al*. 2005)	0.0 entanglements per trawl (Hooper *et al.* 2005)	Hooper *et al.* 2005; Reid and Grilly 2014
		Vessel *InSung Ho* - device constructed from 240 mm nylon mesh spliced into the perimeter of the net just posterior to the mouth - this barrier functioned similar to a giant 'bag'	1.38 entanglements per trawl (Hooper *et al.* 2005)	0.15 entanglements per trawl (Hooper *et al.* 2005)	Hooper *et al.* 2005; Reid and Grilly 2014
		Vessel *Top Ocean* - net installed with large mesh barrier measuring 162 m² (13.5 x 12 m), positioned 47 m from the mouth of the net (i.e. measure 3)	1.94 entanglements per trawl (Hooper *et al.* 2005)	0.23 entanglements per trawl (Hooper *et al.* 2005)	Hooper *et al.* 2005; Reid and Grilly 2014
		NISSUI net system - section of roof panel netting, measuring 6 x 4 m, removed and replaced with panel of a larger mesh size of 1.6 x 1.6 m permitting seals to escape. Seals deflected towards the panel by insertion of a section of net constructed from 300 mm mesh and configured obliquely.	no reported data	no reported data	Hooper *et al.* 2005; Reid and Grilly 2014
		MARUHA net system - inner net arranged within the body of the main net with initial section having a mesh size of 200 mm, followed by a section of 150 mm. The inner net acted as excluding device preventing seals from entering codend. A panel with a single section of mesh, size 1.5 x 2.1 m, located in the upper panel, provided means of escape.	no reported data on bycatch rates	no reported data on bycatch rates	Hooper *et al.* 2005; Reid and Grilly 2014

Fishery	Marine mammal bycatch species	Mitigation device	Bycatch rate without mitigation	Bycatch rate with mitigation	Reference
Australian Small Pelagic Fishery (Case Study 4)	Australian fur seal, New Zealand fur seal, common dolphin, bottlenose dolphin		0.004 dead seals per shot; 0.024 dead dolphins per shot; (from 2003-April 2005: 739 shots in midwater trawls & 116 shots observed = 15.7% observed; 3 seals reported dead; 18 dolphins reported dead)	no comparable data **See footnote 4.**	Tuck *et al.* 2013
		bottom opening SED, small escape hole	no reported data on bycatch rates	0.325 dead seals per shot (Lyle and Willcox 2008)	Lyle and Willcox 2008
		bottom opening SED, large escape hole	no reported data on bycatch rates	0.125 dead seals per shot (Lyle and Willcox 2008)	Lyle & Willcox 2008
		top opening SED	no reported data on bycatch rates	insufficient information (Lyle and Willcox 2008)	Lyle and Willcox 2008
Auckland Islands squid trawl fishery (Case Study 5)	New Zealand sea lion, *Phocarctos hookeri*	Sea Lion Exclusion Device (SLED)	0.044 sea lions per trawl (average observed capture rate from six seasons prior to use of SLEDs i.e. 1995/96 to 2001/02)	0.008 sea lions per trawl (average observed capture rate from seven seasons following widespread use of SLEDs i.e. 2004/05 to 2010/11) See footnote B5.	Thompson *et al.* 2013

Fishery	Marine mammal bycatch species	Mitigation device	Bycatch rate without mitigation	Bycatch rate with mitigation	Reference
Western Australian Pilbara fish trawl fishery (Case Study 6)	Bottlenose dolphin	Semi-flexible exclusion grid (BRD). Bycatch Reduction Devices (BRD) were designed to address bycatch of all megafauna (dolphins, turtles, sea snakes and sawfish and sharks).	0.015 dolphins per shot in 2005 (Stephenson *et al.* 2008); 0.0188 dolphin bycatch per trawl (independent observer data, Aug 2003-Feb 2006; Allen *et al.* 2014)	0.008 dolphins per shot (9 dolphins in 1,156 shots)(Stephenson *et al.* 2008); 0.0103 dolphin bycatch per trawl with BRD further back in the net (independent observer data, Jan 2005-May 2008; Allen *et al.* 2014); 0.0113 dolphin bycatch per trawl with the BRD moved forward in the net (independent observer data, June 2008-Sept 2009; Allen *et al.* 2014)	Stephenson *et al.* 2008; Allen *et al.* 2014
		"Downward excluding net": semi-rigid downward angled exclusion grid (six stainless steel tubes spaced at 150 mm apart with a side tube length of 795 mm) with escape hatch cut into bottom of the net at the base of and forward to this grid with a mesh cover opening backward.	no data on dolphin bycatch rate (i.e. bycatch animals per trawl) presented	insufficient data on dolphin interactions	Wakefield *et al*. 2014
		"Upward excluding net": semi-rigid upwardly inclined grid (six stainless steel tubes spaced at 200 mm apart with a side tube length of 1030 mm) with an escape hatch cut into the top of the net.	no data on dolphin bycatch rate (i.e. bycatch animals per trawl) presented	insufficient data on dolphin interactions	Wakefield *et al.* 2014

Fishery	Marine mammal bycatch species	Mitigation device	Bycatch rate without mitigation	Bycatch rate with mitigation	Reference
		"Experimental net": semi-rigid downward angled exclusion grid (six stainless steel tubes spaced at 200 mm apart with a side tube length of 1030 mm) with escape hatch cut into bottom of the net. The grid and escape hatch were stitched into 50 mm square mesh which kept this section of the net cylindrical and improved water flow through the net. Longitudinal escape slit (~3 m long, held together with magnets) cut into top of the square mesh net.	no data on dolphin bycatch rate (i.e. bycatch animals per trawl) presented	insufficient data on dolphin interactions	Wakefield *et al.* 2014
UK Bass pair trawl fishery and adjacent, overlapping European fisheries (Case Study 7)	Short-beaked common dolphin, *Delphinus delphis*	Exclusion devices - UK work	UK bass pair trawl fishery mean bycatch rate has been as high as 1 common dolphin per tow. In March 2002, 0.121 dolphin bycatch per tow (i.e. 8 bycatch animals in 66 tows).	No data (due to lower observed bycatch rates than previously observe, any dolphins in the nets were unable to be observed and, therefore, there was no direct evidence of how dolphins behaved in relation to the grid).	Northridge *et al.* 2011
		Exclusion devices - French work - February 2006 trials of dolphin exclusion device	no data	7 out of 22 hauls (0.318) had dolphin bycatch	Larnaud *et al.* 2006
		Dolphin Dissuasive Device (DDD) - UK work	0.767 bycatch dolphins per tow (average for 2001-2006 from Table 32 in Northridge *et al.* 2011); Trials in 2009/10: 0.355 bycatch dolphins per tow (11/31) without DDD deployed	0.114 bycatch dolphins per tow (average for 2007-2010 from Table 32 in Northridge *et al.* 2011); Trials in 2009/10: 0.108 bycatch dolphins per tow (17/157) with DDD deployed	Northridge *et al.* 2011

Fishery	Marine mammal bycatch species	Mitigation device	Bycatch rate without mitigation	Bycatch rate with mitigation	Reference
		Cetasaver (pinger device) - French work	0.180 bycatch dolphins per tow (11/61) without Cetasaver deployed	0.038 bycatch dolphins per tow (2/51) with Cetasaver deployed	Morizur *et al.* 2007

Footnotes (Table 11):

1. Was thought that an overall seal bycatch survival rate of 48% was achieved in nets fitted with SEDs, compared to zero for nets without a SED, largely because the SEDs prevented seals entering the codend where most drownings probably occur. However, SED performance remained largely unquantified because underwater video footage was limited and the numbers of seals interacting with the trawl net and successfully exiting the net via the SED escape hatch during this study were unknown. Obtaining significant results on SED performance by comparing replicate sets of trawl shots with and without a SED was difficult, because of the generally low level of seal bycatch and the complex suite of factors influencing seal interactions with the trawl net.

2. The acoustic SED was deployed in 2011 and 2012 - there were no seal mortalities observed in 2011, though in 2012 twelve seal mortalities were observed with the animals recovered in the codend. A report on the efficacy of the acoustic SED is currently being produced.

3. During 2001-2005, cetaceans made up 8% of the megafauna bycatch with 70–720 dolphins captured (Zeeberg *et al*. 2006). The present LARD prototype achieved a 40–100% reduction of the bycatch of the megafauna species most vulnerable to bycatch. However, while cetaceans made up only 8% of the retained bycatch, zero were released alive (Zeeberg *et al*. 2006).

4. Of 184 seal interactions with mid-water trawl gear during 2001-2010, 175 were incidentally caught during scientific projects aimed to determine the type and frequency of interactions and to assess the performance of various excluder devices as a means to mitigate seal and dolphin interactions (e.g. from Jan 2006-Feb 2007 in the scientific study on seal interactions and SEDs, there were 170 seal interactions in 98 shots with 19-27 of these reported dead or unknown status = mortality rate of 0.19-0.28 dead seals per shot). There have been no reported incidental interactions between fur seal and the mid-water trawl fisheries of the SPF since 2007 (based on observer coverage of <13% mid-water trawl shots per annum since 2007). The lack of reported interactions coincides with a reduction in effort in the fishery, a decline in observer coverage as well as no mid-water trawl fishery catches in 2011.

5. Following the introduction of SLEDs, the mean estimated number of New Zealand sea lions captured in the Auckland Islands Squid Fishery per year declined from 14-142 for 1995/96 to 2001/02 (i.e. pre SLED deployment) to 4-31 for the period 2004/05 to 2010/11 (i.e. post SLED deployment).

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