Commercial Fishery Deterrents for Cetaceans & Pinnipeds

Bibliography

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Background & Scope

This bibliography focuses on deterring cetaceans and pinnipeds from interfering with commercial fishery operations published since 2005. It is intended as a reference resource for Alaska Region staff of the NOAA Fisheries Office of Protected Resource when discussing effective marine mammal deterrents. It covers resources from 2005-2021 and is organized into three sections: Cetacean Deterrents, Pinniped Deterrents, and Multiple Marine Mammal Order Deterrents.

Section I – Cetacean Deterrents

Section one includes resources on cetacean deterrents for commercial fisheries. Information on bycatch, depredation, gear, and acoustic deterrents is covered.

Section II – Pinniped Deterrents

Section two includes resources on pinniped deterrents for commercial fisheries. Information on bycatch, depredation, gear, and acoustic deterrents is covered.

Section III – Multiple Marine Mammal Order Deterrents

Section three includes resources on commercial fishery deterrents for both cetaceans and pinnipeds as well as other marine mammals. Information on gear changes, acoustic deterrents, and legislation is covered.

Sources Reviewed

The following databases were used to identify sources: Clarivate Analytics' Web of Science: Science Citation Index Expanded and Social Science Index; Science.gov; ProQuest's Science and Technology including Aquatic Science Fisheries Abstracts; Elsevier's Science Direct; JSTOR; NOAA's Institutional Repository; the Biodiversity Heritage Library; BioOneComplete; and Google Scholar.

Section I: Cetacean Deterrents

Allen, S. J., Tyne, J. A., Kobryn, H. T., Bejder, L., Pollock, K. H., & Loneragan, N. R. (2014). Patterns of Dolphin Bycatch in a North-Western Australian Trawl Fishery. *Plos One*, 9(4), https://doi.org/10.1371/journal.pone.0093178.

The bycatch of small cetaceans in commercial fisheries is a global wildlife management problem. We used data from skippers' logbooks and independent observers to assess common bottlenose dolphin (Tursiops truncatus) bycatch patterns between 2003 and 2009 in the Pilbara Trawl Fishery, Western Australia. 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 ca. double those reported by skippers (n = 180 dolphins in 27,904 trawls, or 6.5 dolphins/1,000 trawls). Generalised Linear Models based on observer data, which better explained the variation in dolphin bycatch, indicated that the most significant predictors of dolphin catch were: (1) vessel - one trawl vessel caught significantly more dolphins than three others assessed; (2) time of day – the lowest dolphin bycatch rates were between 00:00 and 05:59; and (3) whether nets included bycatch reduction devices (BRDs) - the rate was reduced by ca. 45%, from 18.8 to 10.3 dolphins/1,000 trawls, after their introduction. These results indicated that differences among vessels (or skippers' trawling techniques) and dolphin behavior (a diurnal pattern) influenced the rates of dolphin capture; and that spatial or seasonal adjustments to trawling effort would be unlikely to significantly reduce dolphin bycatch. Recent skipper's logbook data show that dolphin bycatch rates have not declined since those reported in 2006, when BRDs were introduced across the fishery. Modified BRDs, with top-opening escape hatches from which dolphins might escape to the surface, may be a more effective means of further reducing dolphin bycatch. The vulnerability of this dolphin population to trawling-related mortality cannot be assessed in the absence of an ongoing observer program and without information on trawler-associated dolphin community size, broader dolphin population size and connectivity with adjacent populations.

Ayadi, A., Ghorbel, M., & Bradai, M. N. (2013). Do pingers reduce interactions between bottlenose dolphins and trammel nets around the Kerkennah Islands (Central Mediterranean Sea)? *Cahiers De Biologie Marine*, 54(3), 375-383. Retrieved from http://pascal-francis.inist.fr/vibad/index.php?action=getRecordDetail&idt=27600340.

Bottlenose dolphins, Tursiops truncatus, co-exist with artisanal fisheries in Kerkennah Island (Southern part of Tunisia) and are blamed for damage to some fisheries. The resulting catch loss engenders hostility from fishers, and interactions between dolphins and nets can result in bycatch mortality. One potential mitigation measure is the placement of marine mammal acoustic deterrent devices, or pingers, on the nets. With the support of local fishermen, Aquamark 210 pingers were deployed on trammel net set for cuttlefish (Sepia officinalis) during the spring season (March 2010 to May 2010), when there is more interaction with dolphin. Throughout the period of experimentation, we have used trammel nets equipped with pingers (pinger net) and trammel nets that have played the role of control (control net). During the trial, data on fishing operations were recorded by onboard observers. We analysed two response variables, the presence or absence of evidence that dolphins had interacted with the net and catch per unit effort. The pingers attracted the bottlenose dolphins (T truncatus) to trammels nets. Overall, pinger nets were more attacked than control nets. Tested pingers. also appeared to have affected on fishery target species. The catch per unit effort decreased by 22%. Our results suggest that Aquamark 210 pingers in the artisanal fisheries of Kerkennah islands increase the rate of net interaction,

but it was recommended to investigate how bottlenose dolphin (T. truncatus) may interact with other acoustic devices.

Basran, C. J., Woelfing, B., Neumann, C., & Rasmussen, M. H. (2020). Behavioural Responses of Humpback Whales (Megaptera novaeangliae) to Two Acoustic Deterrent Devices in a Northern Feeding Ground off Iceland. *Aquatic Mammals*, 46(6), 584-602 https://doi.org/10.1578/am.46.6.2020.584.

Mitigating cetacean entanglement in fishing gear is of global interest, and strategies include the use of acoustic deterrent devices to warn whales of fishing gear. For baleen whales, responses to these devices are poorly understood. This behavioural response study compared the behaviour of humpback whales (Megaptera novaeangliae) in their feeding grounds off Iceland prior to, during, and after exposure to a whale pinger (Future Oceans: 3 kHz., n = 9 exposures) and a seal scarer (Loft tech AS Ltd.: 10 to 20 kHz, n = 7 exposures) using boatbased focal follows. Linear mixed effects models and binary generalized linear mixed effects models were used to analyze the effect of the devices on breathing rate, dive time, swimming speed, swimming directness, and surface feeding. There was a significant increase in swimming speed and a significant decrease in observed surface feeding during whale pinger exposures. There were no significant behavioural changes that were consistent across individuals during seal scarer exposures. In addition to experimental exposure trials, a field trial of whale pingers on a capelin purse seine was conducted. During this trial, humpback whales were observed entering the net from the bottom while the whale pingers were attached at the top, but the encircled whales were able to locate an opening free of pingers and escape without damaging the net. All in all, the results suggest pingers can be a useful entanglement mitigation tool in humpback whale feeding grounds given that a reduction in feeding around nets likely reduces the risk of whales swimming through them. Furthermore, the use of pingers may also reduce net damage by guiding encircled whales to a pinger-free opening. However, given the observed behavioural changes that may lead to fitness consequences if exposure to pingers is frequent, whale pingers are most advisable for short-term use in conjunction with other entanglement mitigation measures.

Berrow, S., Cosgrove, R., Leeney, R. H., O'Brien, J., McGrath, D., Dalgard, J., & Le Gall, Y. (2008). Effect of acoustic deterrents on the behaviour of common dolphins (Delphinus delphis). *Journal of Cetacean Research and Management*, 10(3), 227-233. Retrieved from https://search.proquest.com/scholarly-journals/effect-acoustic-deterrents-on-behaviour-common/docview/20697648/se-2?accountid=28258.

Not all delphinids are similarly affected by acoustic deterrent devices (pingers). At-sea trials were carried out to assess a range of acoustic signals and deterrents on the behaviour of common dolphins. In initial tests two acoustic deterrent devices, which previously produced an evasive response by bottlenose dolphins, failed to elicit any similar behaviour in common dolphins. A new signal output device, which permitted a range of signals to be tested at various source levels and characteristics was subsequently developed but again no significant effects on the behaviour of common dolphins were observed. Two commercially available acoustic deterrents, which had deterred common dolphins in previous studies, produced an occasional mild evasive response. Significant modification of the signal type or source level may be more effective, but our results suggest that pingers, at their current state of development, may not provide a consistently effective deterrent signal for common dolphins.

Bielli, A., Alfaro-Shigueto, J., Doherty, P. D., Godley, B. J., Ortiz, C., Pasara, A., . . . Mangel, J. C. (2020). An illuminating idea to reduce bycatch in the Peruvian small-scale gillnet fishery. *Biological Conservation*, 241, 8 https://doi.org/10.1016/j.biocon.2019.108277.

Found in the coastal waters of all continents, gillnets are the largest component of small-scale fisheries for many countries. Numerous studies show that these fisheries often have high bycatch rates of threatened marine species such as sea turtles, small cetaceans and seabirds, resulting in possible population declines of these non-target groups. However, few solutions to reduce gillnet bycatch have been developed. Recent bycatch reduction technologies (BRTs) use sensory cues to alert non-target species to the presence of fishing gear. In this study we deployed light emitting diodes (LEDs) - a visual cue - on the floatlines of paired gillnets (control vs illuminated net) during 864 fishing sets on small-scale vessels departing from three Peruvian ports between 2015 and 2018. Bycatch probability per set for sea turtles, cetaceans and seabirds as well as catch per unit effort (CPUE) of target species were analysed for illuminated and control nets using a generalised linear mixed-effects model (GLMM). For illuminated nets, bycatch probability per set was reduced by up to 74.4 % for sea turtles and 70.8 % for small cetaceans in comparison to non-illuminated, control nets. For seabirds, nominal BPUEs decreased by 84.0 % in the presence of LEDs. Target species CPUE was not negatively affected by the presence of LEDs. This study highlights the efficacy of net illumination as a multi-taxa BRT for small-scale gillnet fisheries in Peru. These results are promising given the global ubiquity of small-scale net fisheries, the relatively low cost of LEDs and the current lack of alternate solutions to bycatch.

Bilgin, S., & Kose, O. (2018). Testing two types of acoustic deterrent devices (pingers) to reduce harbour porpoise, Phocoena phocoena (Cetacea: Phocoenidae), by catch in turbot (Psetta maxima) set gillnet fishery in the Black Sea, Turkey. *Cahiers De Biologie Marine*, 59(5), 473-479 https://doi.org/10.21411/cbm.A.D5b58d5b.

Field experiments with Aquamark 100 and Aquamark 200 pingers were conducted in the bottom set gill net fishery for turbot in the Black Sea coast between March and June 2012. The aim of the experiment was to evaluate (i) the effectiveness of two types of pingers to reduce by catch rate of harbour porpoises, and (ii) the effects of pingers on the catches of the target fish species (Psetta maxima) and non-target fish species (Raja clavata, Suqualus acanthias and Trigla lucerna) in the turbot set gillnet fishery. A total of 246 specimens (95 P. maxima, 138 R. clavata, 8 P. phocoena, 4 S. acanthias and 1 T. lucerna) were caught during both Aquamark 100 and Aquamark 200 pingers trials. Catches of Psetta maxima and other fish species (Raja clavata, Suqualus acanthias and Trigla lucerna) were not affected by the sound of the pingers in the active nets. Catch of target P. maxima and non-target fish R. clavata were similar as were also for most caught species. 6 P. phocoena (2 in control and 3 in active nets with Aquamark 100) and 2 P. phocoena (1 in control and 1 in active nets with Aquamark 200) were caught in controls and active nets. There are no statistical differences between active and passive net catch per unit effort among the fish species and also cetaceans. As a conclusion, the acoustic signals clearly showed that these pinger types did not reduce by catch of harbour porpoise from the turbot gill net in the eastern Black Sea coasts, Turkey. The acoustic signals of both pinger types also did not affect the catch of target and non-target fish species.

Bjorge, A., Skern-Mauritzen, M., & Rossrnan, M. C. (2013). Estimated bycatch of harbour porpoise (Phocoena phocoena) in two coastal gillnet fisheries in Norway, 2006-2008. Mitigation and

implications for conservation. *Biological Conservation*, 161, 164-173 https://doi.org/10.1016/j.biocon.2013.03.009.

Using data collected during 2006-2008 from a monitored segment (18 vessels) of the Norwegian coastal fleet (vessels <15 m) of gillnetters targeting monkfish and cod, we used general additive models (GAMs) to derive bycatch rates of harbour porpoise. These bycatch rates were then applied to fishery catch data on the target species to estimate the total number of porpoise taken by the coastal gillnet fisheries. The two best models estimated bycatches of 20,719 and 20,989 porpoises during 2006-2008, with CVs 36% and 27%, respectively. Thus, about 6900 harbour porpoises are taken annually in the coastal monkfish and cod gillnet fisheries. Although no abundance estimate is available for the coastal harbour porpoise population, this annual bycatch is likely not sustainable according to the management objectives defined by ASCOBANS. In the cod gillnet fishery, harbour porpoise bycatch rates decreased rapidly with increasing depth to 50 m and then levelled off. In the monkfish gillnet fishery, bycatch rates decreased linearly with increasing depth throughout the depth range fished. To reduce harbour porpoise bycatches, we recommend that large mesh nets associated with the monkfish fishery to be prohibited at depths less than 50 m. We also recommend to conduct experiments using Acoustic Deterrent Devices (ADDS or 'pingers') on nets set deeper than 50 m. If these devices prove successful in reducing porpoise bycatch, we propose that ADDs should be implemented in the Norwegian coastal gillnet fisheries for cod and monkfish. (C) 2013 Elsevier Ltd. All rights reserved.

Brandt, M. J., Hoschle, C., Diederichs, A., Betke, K., Matuschek, R., & Nehls, G. (2013). Seal scarers as a tool to deter harbour porpoises from offshore construction sites. *Marine Ecology Progress Series*, 475, 291-302 https://doi.org/10.3354/meps10100.

Offshore pile driving, e. g. during wind farm construction, produces substantial noise emissions into the water column, which may harm marine mammals. Therefore, it is common practice to attempt to deter the mammals out of potential danger zones beforehand. Seal scarers are commonly used as a deterrent for harbour porpoises in spite of a lack of clear evidence in support of their effectiveness. We investigated the responses of harbour porpoises to a Lofitech seal scarer by conducting visual observations in conjunction with sound measurements. Porpoise sighting rates within 1 km of the seal scarer significantly decreased to only 1% during seal scarer activity. During 22 trials, when the seal scarer was deployed between 300 m and 3.3 km distance, all observed porpoises always avoided the seal scarer within 1.9 km (translating to sound levels of = 122 dB re 1 mu Pa-rms), avoided the seal scarer half the time within 2.1 to 2.4 km 9119 to 121 dB re 1 mu Pa-rms) and never avoided the seal scarer at distances beyond 2.6 km (<= 118 dB re 1 mu Pa-rms). The closest observed approach distance of a porpoise to the activated seal scarer was 798 m 9132 dB re 1 mu Pa-rms). Thus, the deployment of a Lofitech seal scarer during offshore pile driving activities can greatly reduce the risk of acoustic traumata to harbour porpoises. However, danger zones and thus the necessary deterrence zones have to be calculated specifically for each project based on measurements of sound transmission in the area.

Brandt, M. J., Hoschle, C., Diederichs, A., Betke, K., Matuschek, R., Witte, S., & Nehls, G. (2013). Far-reaching effects of a seal scarer on harbour porpoises, Phocoena phocoena. *Aquatic Conservation: Marine and Freshwater Ecosystems*, 23(2), 222-232 https://doi.org/10.1002/aqc.2311.

Although seal scarers are widely used both to reduce economic losses at fish farms caused by seal predation and to reduce risks posed to marine mammals by offshore pile driving activities, the spatial extent of their deterrent effect on harbour porpoises is still largely unclear. However, this information is crucial to understanding the effects these devices have on the marine environment and to judge their potential as a mitigation measure. A study was conducted in the German North Sea, using passive acoustic monitoring and to some extent simultaneous aerial surveying to specifically study the spatial extent of the deterrence effects of a seal scarer on harbour porpoises. In order to link porpoise detections at various distances to actual sound levels, sound measurements of the seal scarer signal were carried out at several distances from the source. C-POD recordings revealed a significant deterrence effect on harbour porpoises up to 7.5 km away (at about 113 dB re 1 mu Pa sub(rms)), much further than previously reported. During seal scarer operation the number of porpoise detections within 750 m of the C-PODs decreased by between 52 and 95% of the value before the seal scarer was activated. An aerial survey revealed a significant decrease in porpoise density from 2.4 porpoises km-2 before to 0.3 porpoises km-2 during seal scarer operation within the 990 km2 study area, showing that the decrease in porpoise detections by passive acoustic monitoring was probably indeed the result of a decrease in porpoise abundance. These results may raise serious concerns about unwanted disturbance effects on harbour porpoises in the context of seal scarer use at fish farms and also highlight the need for caution when applied as a mitigation measure during offshore construction.

Brown, S. L., Reid, D., & Rogan, E. (2015). Spatial and temporal assessment of potential risk to cetaceans from static fishing gears. *Marine Policy*, 51, 267-280 https://doi.org/10.1016/j.marpol.2014.09.009.

Ecosystem Based Fisheries Management (EBFM) requires the consideration of potential impacts of a commercial fishery on all components of the ecosystem. Assessment of the impact of commercial fishing on marine mammals generally focuses on species at known risk from bycatch. For cetaceans in particular, inclusion under the Threatened, Endangered and Protected (TEP) species component of Ecological Risk Assessment for the Effects of Fishing (ERAEF) can seem redundant if a species is already known to be at risk or is not thought to interact with the fishery with consequences for its conservation. A spatially and temporally explicit Productivity Susceptibility Analysis (PSA) procedure was developed for inclusion under ERAEF to allow cetacean species to be screened for risk. The technique is demonstrated by assessing the potential risk to harbour porpoise and minke whales from a number of static gear fisheries. The results demonstrate that although a fishery might pose high risk to a species, low or moderate risk areas can exist within the range of the fishery, enabling management measures to focus on areas of greatest risk. Designed to complement and support existing methods of bycatch assessment, this approach is a repeatable and standardised assessment, the outputs of which can be used to systematically document the level of risk posed to different species in a transparent way to aid the inclusion of cetaceans in ERAEF and EBFM both now and in the future.

Byrd, B. L., & Hohn, A. A. (2010). Challenges of Documenting Tursiops truncatus Montagu (Bottlenose Dolphin) Bycatch in the Stop Net Fishery along Bogue Banks, North Carolina. *Southeastern Naturalist*, 9(1), 47-62, 16 https://doi.org/10.1656/058.009.0104.

Each fishery presents its own challenges for observers to document bycatch. The North Carolina (NC) stop net fishery is especially challenging because it uses anchored gear (the stop net) that soaks up to 15 days to herd fish, which are then hauled to shore via another gear (a beach seine). Three Tursiops

truncatus (Bottlenose Dolphin) entanglements in stop nets and six Bottlenose Dolphin strandings, each suspected of having been entangled in stop net gear based on injuries noted (lesions) and spatio-temporal overlap with the fishery, were documented by the NC Marine Mammal Network between 1992 and 2007. In 2001–2002, new observational techniques and surveys were used to observe this fishery to estimate bycatch and to document dolphin behavior around the gear. Techniques included observations from the beach during net retrievals and in situ surveys using a vessel with a sonar-video camera system. No entangled dolphins were observed, and, in fact, observations indicated dolphins were not attracted to stop nets and generally changed direction to avoid the gear. Nonetheless, characteristics of the fishery impose severe limitations on the efficacy of bycatch observer methods, rendering those results unreliable. Given low levels of known or suspected entanglements and the challenges of observing this fishery, stranding network data may be the most practical and effective method to monitor dolphin bycatch.

Caslake, R. (2005). *Trial of acoustic deterrents (porpoise pingers) for prevention of porpoise (Phocoena phocoena) by-catch in static net fisheries*: International Council for the Exploration of the Sea, Palaegade 2-4 DK 1261 Copenhagen K Denmark. Retrieved from: http://www.ices.dk/sites/pub/CM%20Doccuments/2005/X/X0905ABS.pdf

This study details the practicalities of attachment, deployment and testing of acoustic deterrents (porpoise pingers) within the Celtic sea gill net fishery. The deployment trial was carried out on commercial fishing trips from Newlyn (Cornwall) over the course of one year using four of the commercially available models of pingers. This study concentrates on the deployment characteristics of the currently available models and includes results of Flume tank testing, deployment data, recommendations for attachment along with feedback given to manufacturers. The feasibility of deployment and cost implications of prolonged use within both gill net and tangle net fisheries are evaluated and consideration is given to how a pinger programme could be accredited to secure its integrity. The results of these studies will be revealed, and the conclusion as to the practicalities of operating, testing and monitoring of pingers within this fishery will be discussed.

Ceurstemont, E., & Rihan, D. (2005). *Design of an interactive acoustic deterrent to prevent by-catch of cetaceans in pelagic trawl fisheries*: International Council for the Exploration of the Sea, Palaegade 2-4 DK 1261 Copenhagen K Denmark. Retrieved from: https://www.ices.dk/sites/pub/CM%20Doccuments/2005/X/X0605.pdf

Incidental catches of cetaceans have been reported in several EU pelagic trawl fisheries and are felt to have a significant impact on cetacean populations. Dolphins have been observed deliberately entering trawls to feed, generally exiting the trawl without being caught. However, entrapment can occur and when it does it can effect many animals at once. Efforts have been made to eradicate the problem by adapting passive acoustic deterrents ("Pingers"), originally developed for use on static gears, but with only limited success due largely to the acoustic noise generated by the vessels and gear used in the fisheries as well as the large size of pelagic trawls. As part of research under an EU funded project, a more intelligent acoustic deterrent system has been designed as a simpler solution to the problem of cetacean by-catch in pelagic fisheries. The interactive unit developed has the benefit of being silent until the detection of echolocation activity from dolphins. When this is detected the unit is triggered and instantaneously outputs a sound based on the wide band signals, which have been shown to be very effective at displacing harbour porpoises in the vicinity of gillnets. This serves two purposes, firstly to

mask the echolocation returns to the animal, thus preventing foraging, and secondly warn off dolphins thus preventing them entering the trawl to begin with. Studies have been carried out into associated trawl noise, and as a consequence of these preliminary experiments, the unit has been developed to cope with the many noise sources present within a trawl net. The interactive unit has to apply advanced recognition algorithms to the signals received to discriminate between background noise / boat sonar activity and true echo-location activity from Dolphins before firing. Initial tests to prove the units ability to distinguish echo location activity from noise have been conducted on captive animals in the dolphinarium, at Kolmarden Wild Animal Park, Sweden. Full interactive experiments with wild dolphins in the Shannon Estuary are planned, followed by extensive trials onboard commercial fishing vessels during the albacore tuna fishing season in late summer.

Chladek, J., Culik, B., Kindt-Larsen, L., Albertsen, C. M., & von Dorrien, C. (2020). Synthetic harbour porpoise (Phocoena phocoena) communication signals emitted by acoustic alerting device (Porpoise ALert, PAL) significantly reduce their bycatch in western Baltic gillnet fisheries. *Fisheries Research*, 232, 10 https://doi.org/10.1016/j.fishres.2020.105732.

Gillnet fisheries are one of the main anthmpogenic causes of harbour porpoise (Phocoena phocoena L., 1758) mortality in the Baltic Sea. A new kind of acoustic alerting device (Porpoise ALert, PAL) was tested in commercial gillnet fisheries in the western Baltic. PAL emits 133 kHz synthetic harbour porpoise communication signals, unlike conventional acoustic deterrent devices (pingers), which emit artificial noise. Trials were undertaken by three commercial gillnet vessels conducting 778 trips during standard fishing operations from 2014 to 2016. In all, 1120 PAL-equipped net strings were tested against 1529 simultaneously set control strings with no devices. We tested two versions of the PAL (v1 and v2) consecutively. These were spaced <=210 m apart on the gillnet floatlines, with all devices pointing in the same direction to ensure complete acoustic coverage of the strings. Two vessels fished in Kiel Bight and around Fehmarn Island in German waters, and the third vessel fished in the Oresund, in inner Danish waters. Overall, 18 harbour porpoises were by caught in control strings (mean 0.01 + 0.1/haul), and five harbour porpoises were taken as bycatch in strings equipped with PALs (0.004 +/- 0.07/haul). The number of net string bycatches was analysed using a generalised linear mixed model (GLMM). The model applied to all observations revealed that the expected bycatch was significantly influenced by PAL deployment ($p < 0.05$), decreasing the expected bycatch by 64.9 % (95 % confidence interval (CI): 8.7-88.7 %). PAL effectiveness was also increased by reducing device spacing to <=200 m (16 bycatches in control, three in PAL strings; mean bycatch reduction 79.7 %). Additional model cases were applied to the data and are discussed. We conclude that, with this specific communication signal, PAL can significantly reduce harbour porpoise bycatch in gillnets deployed in the western Baltic Sea, thus reconciling anthropogenic activities with protection of the marine environment.

Clay, T. A., Alfaro-Shigueto, J., Godley, B. J., Tregenza, N., & Mangel, J. C. (2019). Pingers reduce the activity of Burmeister's porpoise around small-scale gillnet vessels. *Marine Ecology Progress Series*, 626, 197-208 https://doi.org/10.3354/meps13063.

Incidental mortality (bycatch) in gillnet fisheries is a major threat to many cetacean populations. Acoustic alarms or pingers are a widely adopted management tool used to deter dolphins and porpoises from nets; however, their efficacy is largely species- and fishery-dependent. As such, results from experimental trials may have limited transferability to poorly studied species or fisheries. Here, we investigated the effect of pingers on the behaviour of Burmeister's porpoise Phocoena spinipinnis in the

vicinity of the Peruvian small-scale driftnet fleet. Over a 4 yr period (2009-2012), 116 control (without pingers) and 94 experimental (with pingers) fishing sets were observed, and porpoise acoustic activity around nets was recorded using passive acoustic loggers (C-PODs). We modelled variation in detection rates as a function of pinger use and habitat covariates, and found that in regions of preferred habitat associated with cooler (17-18 degrees C), shallow waters (within the 100 m isobath), the use of pingers lead to an 86% reduction in porpoise activity around nets. Our results suggest that pingers are likely to be particularly effective at deterring Burmeister's porpoises from fishing nets, and given the vast capacity of this and other fleets in the region, may substantially reduce mortality. This study also emphasizes the potential of passive acoustic monitoring to determine the effectiveness of bycatch mitigation measures, both for species for which visual observations are scarce, and also in regions where gathering statistically meaningful bycatch rates is logistically challenging.

Cruz, M. J., Jordao, V. L., Pereira, J. G., Santos, R. S., & Silva, M. A. (2014). Risso's dolphin depredation in the Azorean hand-jig squid fishery: assessing the impacts and evaluating effectiveness of acoustic deterrents. *ICES Journal of Marine Science*, 71(9), 2608-2620 https://doi.org/10.1093/icesjms/fsu073.

Depredation by cetaceans is a growing problem that may have serious economic implications for fisheries and for dolphin conservation. We investigated depredation by Risso's dolphin (Grampus griseus) in the hand-jig squid fishery around the Azores to determine the factors that may influence depredation behaviour and impacts on the fishery, and conducted experiments to evaluate the effectiveness of acoustic deterrent devices. Monitoring of the interaction between dolphins and the fishery was carried out through interviews with fishers and observations made from fishing vessels. Depredation was reported in 50% of the 506 interviews conducted from 2009 to 2011 and Risso's dolphins were reportedly responsible for 92% of the depredation events. Risso's dolphin depredation was recorded in 33% of the observed fishing trips (n = 96). Generalized additive models revealed that depth, sea surface temperature, and fishing time were important factors affecting depredation probability. Generalized linear models showed that fishing time also influenced the number of squids depredated, with greater catch losses predicted as duration of the fishing events increased. Depredation rate was calculated at 3% yielding an estimate of 8-12 t of squid lost to dolphins per year and an annual economic loss of (sic)50 000 for the squid fishery of S. Miguel. The use of pingers had no significant effect on the catch per unit effort of squids. Depredation rates were similar for the control (0.20), inactive (0.19), and active (0.19) pinger conditions. Models indicated no significant effect of pinger brand and condition on cetacean depredation. This study is the first attempt to monitor depredation by Risso's dolphins on a hand-jig squid fishery providing a scientific basis for future management of interactions between cetaceans and fisheries.

Dawson, S. M., Northridge, S., Waples, D., & Read, A. J. (2013). To ping or not to ping: the use of active acoustic devices in mitigating interactions between small cetaceans and gillnet fisheries. *Endangered Species Research*, 19(3), 201-221 https://doi.org/10.3354/esr00464.

Active sound emitters ('pingers') are used in several gillnet fisheries to reduce bycatch of small cetaceans, and/or to reduce depredation by dolphins. Here, we review studies conducted to determine how effective these devices may be as management tools. Significant reductions in bycatch of harbour porpoise Phocoena phocoena, franciscana Pontoporia blainvillei, common Delphinus delphis and striped dolphin Stenella coeruleoalba, and beaked whales as a group have been demonstrated. For harbour

porpoise this result has been replicated in 14 controlled experiments in North America and Europe, and appears to be due to porpoises avoiding the area ensonified by pingers. Two gillnet fisheries (California-Oregon driftnet fishery for swordfish; New England groundfish fishery) with mandatory pinger use have been studied for over a decade. Bycatch rates of dolphins/porpoises have fallen by 50 to 60%, and there is no evidence of bycatch increasing over time due to habituation. In both fisheries, bycatch rates were significantly higher in nets sparsely equipped with pingers or in which pingers had failed, than in nets without any pingers at all. Studies of pinger use to reduce depredation by bottlenose dolphins Tursiops truncatus generally show small and inconsistent improvements in fish catches and somewhat reduced net damage. Dolphin bycatch in these fisheries is rare, but still occurs in nets with pingers. Taken together, these studies suggest that the most promising candidates for bycatch reduction via pinger use will be gillnet fisheries in developed countries in which the bycaught cetaceans are generally neophobic species with large home ranges. We offer a set of lessons learned from the last decade of bycatch management.

De Haan, D., Van Marlen, B., Burggraaf, D., & Van Duyn, J. B. (2005). *Field tests of two cetacean barrier designs rigged in a pelagic trawl: effects on trawl-geometry and catch efficiency of target fish*: International Council for the Exploration of the Sea, Palaegade 2-4 DK 1261 Copenhagen K Denmark. Retrieved from: http://www.ices.dk/sites/pub/CM%20Doccuments/2005/X/X-2005.pdf

To reduce cetacean by-catches in pelagic trawls two experimental cetacean barriers were designed for tests on a 4300 meshes circumference pelagic trawl. In the pre-design stage the influence on the geometry of the implementation of a barrier of vertical ropes into a 4300 meshes pelagic trawl was tested in a flumetank on a 1/32 scale. The model tests showed that the vertical trawl opening was reduced with 11% and 22% at the level of the barrier. A second tunnel type of barrier was built of 4 panels of 2 m meshes and tapered backwards to a rectangular opening of 8 x 2 m. Both barriers were rigged at full scale about 50 m behind the headrope of the trawl and tested on board FRV Walther Herwig III in March/April 2005. The influence on the geometry of the trawl and the behaviour of target fish to the barriers was observed using a WESMAR TCS 701 trawl sonar system. The field tests showed that the rope barrier design reduced the vertical trawl opening and catch efficiency. A large amount of fish, probably pilchards, disappeared at the level of the ropes, while the tunnel barrier had less effect on the geometry of the trawl and large mackerel was caught and not observed escaping.

Dolman, S., Baulch, S., Evans, P. G. H., Read, F., & Ritter, F. (2016). Towards an EU Action Plan on Cetacean Bycatch. *Marine Policy*, 72, 67-75 https://doi.org/10.1016/j.marpol.2016.06.020.

For decades, cetacean bycatch has been a major conservation and welfare concern in Europe, with high numbers of harbour porpoises, dolphins and whales continuing to die each year. Despite binding legal requirements to reduce bycatch, there has been limited effective monitoring or mitigation. Bycatch is also an important welfare issue. At this critical juncture, with discussion of incorporating monitoring and mitigation of bycatch of protected species in Europe into the Data Collection Framework and Technical Measures Framework taking place to help deliver the reformed Common Fisheries Policy (CFP), a clear, effective strategy could identify the steps that are required by all EU Member States to reduce bycatch towards zero. Here, implementation of current monitoring and mitigation obligations are reviewed. Recommendations are made for the provision of clear EU guidance in order to improve and unify population surveillance and bycatch monitoring, with enhanced implementation and enforcement from

Member States. A more regionalised evidence-based approach to monitoring and mitigation is in line with the move to more regionalised management under the CFP, with Member States robustly showing that bycatch levels are decreasing over a set period of time (e.g. 5 years) by a specified amount. To this end, an EU Action Plan on Cetacean Bycatch, comparable to the existing 2012 Action Plan for reducing incidental catches of seabirds in fishing gear, might be beneficial and could ultimately form a model for an international Food and Agricultural Organisation (FAO) Cetacean Bycatch Reduction Action Plan.

Fader, J. E., Elliott, B. W., & Read, A. J. (2021). The Challenges of Managing Depredation and Bycatch of Toothed Whales in Pelagic Longline Fisheries: Two U.S. Case Studies. *Frontiers in Marine Science*, https://doi.org/10.3389/fmars.2021.618031.

Direct interactions with fisheries are broadly recognized as the leading conservation threat to small cetaceans. In open-ocean environments, one of the primary gear types implicated in these interactions is the pelagic longline. Unlike accidental entanglement in driftnets or deliberate entrapment by purse-seines, interactions between cetaceans and longlines are often driven by attraction of the animals to feed on bait or fish secured on the gear, a behavior known as depredation. Many small and medium-sized delphinid species have learned to exploit such opportunities, leading to economic costs to fisheries and a risk of mortality to the animals from either retaliation by fishermen or hooking or entanglement in fishing gear. Two pelagic longline fisheries in the United States experience depredation and bycatch by odontocete depredators: the Hawai'i deep-set longline fishery, which is depredated primarily by false killer whales (Pseudorca crassidens), and the Atlantic pelagic longline fishery depredated primarily by short-finned pilot whales (Globicephala macrorhynchus). These fisheries are among the most intensively documented and managed pelagic longline fisheries in the world, with high levels of observer coverage, and bycatch mitigation measures required to reduce the mortality of seabirds, sea turtles and cetaceans. Both fisheries have active, multi-stakeholder 'Take Reduction Teams', enacted under the U.S. Marine Mammal Protection Act (MMPA), that are tasked to develop measures to reduce the bycatch of cetaceans below statutory reference points. Consequently, these two Teams represent model processes within which to address depredation and bycatch, having access to detailed, high-quality data on the nature and frequency of interactions with cetaceans, meaningful stakeholder involvement, resources to test potential solutions, and the institutional will to improve outcomes. We review how mitigation strategies have been considered, developed, and implemented by both Teams and provide a critical analysis of their effectiveness in addressing these problems. Notably, in the absence of straightforward avoidance or deterrence strategies, both Teams have developed gear and handling strategies that depend critically on comprehensive observer coverage. Lessons offered from these Teams, which have implemented consensus-driven management measures under a statutory framework, provide important insights to managers and scientists addressing other depredation problems.

Farmer, N. A. (2016). Evaluation of Alternatives to Winter Closure of Black Sea Bass Pot Gear: Projected Impacts on Catch and Risk of Entanglement with North Atlantic Right Whales Eubalaena glacialis. *Marine and Coastal Fisheries: Dynamics, Management, and Ecosystem Science*, 8(8), 202-221, 220 https://doi.org/10.1080/19425120.2016.1146181

Time-area closures have been widely used in fisheries management to prevent overfishing and reduce the bycatch of protected species. Due to quota overages and concerns about entanglement of federally protected North Atlantic right whales Eubalaena glacialis, the commercial harvest of Black Sea Bass Centropristis striata using pot gear has been prohibited in the southeastern United States in winter since

2009. Following the rebuilding of the Black Sea Bass stock and a change to the start date of the fishing year, the South Atlantic Fishery Management Council (SAFMC) increased the commercial annual catch limit (ACL) and is considering twelve alternatives to the pot gear closure that would revise the timing and/or spatial extent of the closure. Changes to this closure could affect the annual catch of Black Sea Bass and increase the risk of right whale entanglement in pot gear. Using historical fishing effort, landings, and right whale sightings data, we projected Black Sea Bass landings and the relative risk of right whale entanglement for each closure alternative, expressed in relative risk units (RRU). We predict that the ACL would be caught, resulting in an in-season closure for most of the proposed SAFMC closure alternatives. The relative risk of entanglement, estimated from the spatial and temporal overlap of Black Sea Bass pot gear fishing effort and right whale relative abundance, was lower for some alternatives than for others, and the relative differences between alternatives were consistent among uncertainty scenarios. The SAFMC's preferred alternative is projected to result in a relatively low increase in risk to North Atlantic right whales (3–15 RRU off North Carolina and 1–12 RRU off Florida—South Carolina). This framework demonstrates the use of temporally dynamic spatial overlays in assessing the impacts of time—area closures with multiple objectives.

Forney, K. A., Kobayashi, D. R., Johnston, D. W., Marchetti, J. A., & Marsik, M. G. (2011). What's the catch? Patterns of cetacean bycatch and depredation in Hawaii-based pelagic longline fisheries. *Marine Ecology-an Evolutionary Perspective*, 32(3), 380-391 https://doi.org/10.1111/j.1439-0485.2011.00454.x.

U.S. Pacific pelagic longline fisheries operating in the central North Pacific have been subject to a series of regulations to reduce bycatch of protected species, including seabirds and sea turtles. Cetaceans are also occasionally caught, and the bycatch of false killer whales, Pseudorca crassidens, in the Hawaii-based deep-set longline fishery currently exceeds allowable levels under the Marine Mammal Protection Act (MMPA). In this study, we examined longline observer data collected between 1994 and 2009, with emphasis on 2003-2009, to identify patterns of cetacean bycatch and depredation in relation to area, time, vessel, habitat variables, fishing gear, and set characteristics. The objectives of these analyses were to identify relationships amongst fishery interaction rates and variables that could provide opportunities to reduce depredation by cetaceans, reduce the likelihood of incidentally catching a cetacean when present, or reduce the severity of injuries to cetaceans if caught. The results of this study were provided to the False Killer Whale Take Reduction Team, convened under the MMPA, as they developed a plan to reduce serious injury and mortality of false killer whales in these fisheries. No correlates were identified that could markedly reduce depredation rates, but a slight (16%) reduction in repeat depredation within a fishing trip was evident when vessels moved at least 100 km following a depredation event. The most practical option for reducing bycatch of false killer whales was determined to be the use of small (14/0-16/0) circle hooks, which could result in an estimated 6% reduction in bycatch and a greater likelihood of releasing animals with non-serious injuries. Additional research is needed to address unresolved questions relating to processes involved in depredation events and hookings or entanglements of false killer whales.

Gazo, M., Gonzalvo, J., & Aguilar, A. (2008). Pingers as deterrents of bottlenose dolphins interacting with trammel nets. *Fisheries Research* (Amsterdam), 92(1), 70-75 https://doi.org/10.1016/j.fishres.2007.12.016.

In north-eastern Majorca (Balearic Islands), an area where dolphin predations on the nets were repeatedly reported by fishermen, specially during the red mullet fishing season, the effectiveness of pingers in discouraging common bottlenose dolphins from approaching trammel nets was addressed in a field study during September-October 2001. The pingers used emit eight wide-band frequency signals that range between 20kHz and 160kHz, with mean source levels of 145dB (re 1 mu Pa at 1m) at 70kHz. In the same study dolphin damage to the nets and economic losses by the fishermen were also evaluated. Though pingers did not stop dolphins from approaching the fishing nets, the nets equipped with functional pingers received less damage (87% fewer holes) than nets with non-functional devices or without pingers. Tested pingers did not appear to have any effect on fishery target species. Nevertheless, the use of pingers may bear unwanted environmental impacts, which are also reviewed here.

Gilman, E. L., & Lundin, C. G. (2010). *Minimizing bycatch of sensitive species groups in marine capture fisheries: lessons from tuna fisheries*: Oxford University Press, New York (USA). Retrieved from: https://www.iucn.org/sites/dev/files/import/downloads/minimizing_bycatch_of_sensitive_species.pdf

By catch in marine capture fisheries is the retained catch of nontargeted but commercially viable species plus all discards. It is an increasingly prominent international issue, raising ecological concerns, as some bycatch species of cetaceans (whales, dolphins and porpoises), sea birds, sea turtles, elasmobranchs (sharks, skates and rays), and other fish species are particularly vulnerable to overexploitation and slow to recover from large population declines. This chapter employs examples of bycatch in commercial tuna fisheries to describe (1) the range of options to reduce bycatch, (2) principles and approaches to successfully introduce effective bycatch reduction measures, and (3) initiatives taken by intergovernmental organizations, the fishing industry, and retailers to address bycatch. Changes needed to improve the sustainability of tuna production are recommended.

Goetz, S., Laporta, M., Portela, J. M., Santos, M. B., & Pierce, G. J. (2011). Experimental fishing with an "umbrella-and-stones" system to reduce interactions of sperm whales (Physeter macrocephalus) and seabirds with bottom-set longlines for Patagonian toothfish (Dissostichus eleginoides) in the Southwest Atlantic. *ICES Journal of Marine Science*, 68(1), 228-238 https://doi.org/10.1093/icesjms/fsq161.

Depredation, i.e. the damage or removal, of Patagonian toothfish (Dissostichus eleginoides) from longlines by sperm whales (Physeter macrocephalus) can cause considerable economic loss for Spanish fishing vessels in the Southwest Atlantic. The fishery also suffers high bycatch rates of seabirds. The main goal of the study was to assess the extent of depredation and seabird bycatch and to test the potential of the so-called "umbrella" system, coupled with attached stones for faster sinking, for minimizing both. Moreover, we investigated the relationships between sightings of sperm whales, depredation, catches, and environmental variables using generalized additive modelling. Data were collected during 297 hauls on a longliner in 2007/2008 in international waters of the Southwest Atlantic. Sperm whales were sighted during 35% of the hauls, always during gear retrieval, and their presence was positively related to fish damage. The overall depredation rate (0.44% of the total catch) was low, but is assumed to be underestimated because sperm whales were suspected of also taking fish without leaving visual evidence. The "umbrella-and-stones" system was highly effective in preventing bycatch

and appeared to restrict depredation, but significantly reduced the catches. The results demonstrate that there is still some way to go to solve the problem of depredation.

Goetz, S., Read, F. L., Santos, M. B., Pita, C., & Pierce, G. J. (2014). Cetaceanfishery interactions in Galicia (NW Spain): results and management implications of a face-to-face interview survey of local fishers. *ICES Journal of Marine Science*, 71(3), 604-617 https://doi.org/10.1093/icesjms/fst149.

Galicia (NW Spain) is an important fishing region with a high potential for cetaceanfishery interactions. Cetacean depredation on catch and damage to fishing gear can potentially lead to substantial economic loss for fishers, while cetacean bycatch raises conservation concerns. With the aim of gathering information on the types and scale of interactions and of suggesting possible management strategies, we conducted face-to-face interviews with fishers in local fishing harbours, in particular to identify specific problematic interactions and to quantify the level of economic loss and bycatch rates associated with these interactions. We found that cetaceanfishery interactions are frequent, although damage to catch and fishing gear by cetaceans was mostly reported as small. Nevertheless, substantial economic loss can result from common bottlenose dolphins (Tursiops truncatus) damaging coastal gillnets and from short-beaked common dolphins (Delphinus delphis) scattering fish in purse-seine fisheries. Cetacean bycatch mortality was reported to be highest for trawls and set gillnets, and probably exceeds sustainable levels for local common and bottlenose dolphin populations. Although interview data may be biased due to the perceptions of interviewees, and therefore should be interpreted with care, the methodology allowed us to cover multiple sites and fisheries within a reasonable time frame. Minimizing cetaceanfishery interactions requires the implementation of case-specific management strategies with the active participation of fishers. For set gillnet and purse-seine fisheries, the use of acoustic deterrent devices (pingers) may prevent cetaceans from approaching and getting trapped in the nets. For trawl fisheries, where bycatch appears to be particularly high at night in water depths of 100300 m, possible solutions include the implementation of time/area closures and the relocation of some fishing effort to deeper waters.

Gonener, S., & Bilgin, S. (2009). The Effect of Pingers on Harbour Porpoise, Phocoena phocoena Bycatch and Fishing Effort in the Turbot Gill Net Fishery in the Turkish Black Sea Coast. *Turkish Journal of Fisheries and Aquatic Sciences*, 9(2), 151-157 https://doi.org/10.4194/trjfas.2009.0205.

This is the preliminary and the first study for understanding the effect of acoustic deterrent devices (pingers) on catch rates of fish (target turbot fish, Schophthalmus maeoticus and non target thornback ray, Raja clavata) and harbour porpoise (Phocoena phocoena) bycatch directly in the turbo, gill net fishery in the Black Sea conditions. Sea trials carried out using Dukane NetMark (TM) 1000 pingers in an active (with pinger) and in a control (without pingers) turbot gill net between March 5 and April 2, 2006 off the Sinop Peninsula. The results showed that Dukane NetMark (TM) 1000 pingers have been significantly shown to be effective in reducing P. phocoena bycatch in turbot gill net fisheries without significantly affecting target and non-target fish size and catch. The "habituation" problem of the species should also be further investigated in the future.

Gonener, S., & Ozsandikci, U. (2017). Technical measures in order to decrease interactions between dolphins and fishermen: pingers. *Journal of Aquaculture Engineering and Fisheries Research*, 3(3), 151-159 https://doi.org/10.3153/JAEFR17018.

Almost all marine mammal species are in interaction with fishing activities and this interaction frequently results in the death of marine mammals in gillnet fisheries. This situation results in the death of thousands of harbor porpoise (Phocoena phocoena) and bottlenose dolphins (Tursiops truncates) and is defined as by-catch (non-target catch) in gillnet fisheries, and in this way it is at least partially legalized. These interactions between fisheries and dolphins cause ecologic and social concerns, meaning economic loss from the perspective of fishermen. In most of the studies which aim to determine necessary measures to reduce by-catch of dolphins, gillnet fisheries are taken as a basis and dolphin deterrent devices called pingers are used. In this subject many studies have been carried out around the world, while only a few in Black Sea. However, it is still difficult to make an assessment for effectiveness of pingers. In addition to this, many studies including those performed in the Black Sea outline that pingers can keep harbor porpoise (P. phocoena) and bottlenose dolphin (T. truncates) away from gillnets for 1-2 years but it is vital that monitoring the situation after this period.

Guinet, C., Tixier, P., Gasco, N., & Duhamel, G. (2015). Long-term studies of Crozet Island killer whales are fundamental to understanding the economic and demographic consequences of their depredation behaviour on the Patagonian toothfish fishery. *ICES Journal of Marine Science*, 72(5), 1587-1597 https://doi.org/10.1093/icesjms/fsu221.

This paper provides a synthesis of results obtained as part of a long-term collaborative study involving biologists, fishers, and resource managers-centring on the occurrence of killer whales in the Crozet Archipelago before and after the implementation of a demersal longline fishery for Patagonian toothfish. Depredation behaviour was reported as soon as the fishery was initiated, with dramatic effects on both the demographic trajectories of the killer whales and on the amount of fish lost by the fishers. Killer whales interacting with the fishery exhibited very high mortality rates when illegal fishing took place, while killer whales not interacting were unaffected. However, after illegal fishing ended, killer whales interacting with the fishery exhibited both higher fecundity and survival rates compared with killer whales not interacting. Since whales typically removed fish entirely from the hooks, an adapted methodology that did not rely on determining the number of damaged fish was developed to estimate depredation rates. In the Crozet EEZ over a 10-year period, 33.9% of the total amount of Patagonian toothfish caught, representing a total of 28 million (sic), was estimated to be lost due to the combined effects of killer whale and sperm whale depredation. In an effort to reduce depredation losses, modifications to fishing methods, such as changing the fishing season, changing fishing areas when exposed to depredation and changing longline length and hauling speed were successfully tested. Acoustic deterrent devices were ineffective in deterring killer whales from depredating longlines. Alternative fishing gears, such as fish pots, were also tested. However, while providing encouraging results regarding the suppression of depredation and seabird bycatch, fish pots were not efficient enough to sustain an economically viable fishery. In conclusion, we discuss how the findings of this comprehensive study can be used elsewhere in fisheries confronted with depredation.

Hamer, D. J., Childerhouse, S. J., McKinlay, J. P., Double, M. C., & Gales, N. J. (2015). Two devices for mitigating odontocete bycatch and depredation at the hook in tropical pelagic longline fisheries. *ICES Journal of Marine Science*, 72(5), 1691-1705 https://doi.org/10.1093/icesjms/fsv013.

Odontocete bycatch on and depredation from tropical pelagic longlines is globally widespread, having negative impacts on the economic viability of affected fisheries and on the conservation of affected

odontocete populations. Reports by fishers that depredating odontocetes avoid gear tangles has underpinned the development of simulated structures to physically deter depredating odontocetes. This study assessed the efficacy of two such devices developed to mitigate odontocete depredation and associated bycatch. Of particular interest was their impact on (i) soak depth and (ii) sink rate using truncated trials, before determining their impact under full operational conditions on rates of (iii) catch of the five most economically important fish, and (iv) odontocete depredation and bycatch, on changes in (v) fish survival and size, and (vi) setting and hauling speed. The results indicated that the inclusion of devices on longlines had negligible impact on soak depth, thus were unlikely to impact on the suite of fish specifically targeted and caught. The sink rate was slowed, perhaps by drag, trapped air, or propeller wash, although the addition of weight might remedy this if the devices were to be used in areas where seabird bycatch could occur. Most importantly, trials conducted in Australian and in Fijian waters indicated that pooled fish catch rates (i.e. albacore, yellowfin, bigeye, mahi mahi, and wahoo) increased in the presence of the devices, possibly because more fish were attracted by them or because more depredators were deterred. Catch rates on control gear next to gear with devices attached were higher than more distant control gear, suggesting the influences of the devices may have extended to adjacent branchlines. The size of caught fish was mostly unaffected, although the survival of yellowfin and bigeye increased significantly in the presence of the devices. Hauling was slowed by the use of the devices and the need for an extra crewmember during setting and hauling, which could be cost prohibitive in some fisheries, especially if economic benefits from their use are not obvious. Despite the small sample size, odontocete bycatch only occurred on unprotected fishing gear and all individuals were released alive, although their fate was uncertain; there was evidence of injuries sustained from the event. The outcomes are positive and should motivate stakeholders to view such devices as a potentially effective tool for mitigating odontocete bycatch and depredation in this and similar longline fisheries. Future efforts should focus on improving operational integration and reducing implementation costs to encourage voluntary uptake and thus avoid non-compliance and the need for costly monitoring. The use of this technology could bring about marked improvements to the conservation situation for affected odontocete populations and to the economic situation for affected longline fisheries.

Harcourt, R., Pirotta, V., Heller, G., Peddemors, V., & Slip, D. (2014). A whale alarm fails to deter migrating humpback whales: an empirical test. *Endangered Species Research*, 25(1), 35-42 https://doi.org/10.3354/esr00614.

Cetacean entanglements in fishing gear cost governments, fishermen and stakeholders millions of dollars a year, and often result in serious injury or death of the entangled animals. Entanglements have been implicated in preventing the recovery of some large whale populations. Acoustic deterrents on fishing nets are widely used to reduce incidental captures of dolphins and porpoises, but there is little evidence as to whether they effectively deter large whales. We tested whether a low-frequency whale alarm (3 kHz Whale Pinger (R), 135 +/- 5 db, 5 s emission interval and 400 ms emission duration) deterred Southern Hemisphere humpback whales Megaptera novae angliae from approaching a potential source of entanglement. Northerly migrating humpback whale pods were tracked by an observer blind to alarm status (on/off) as they passed an alarm moored in the centre of the peak migration path. Of 137 pods tracked, 82 (60%) passed within the assumed detectable range (500 m) of the alarm, 51/78 (65%) when it was on and 31/59 (52%) when it was off ($p = 0.18$). There was no discernible response to the alarm. Whale pods did not differ in directionality, course heading or dive duration when within detectable range of the alarm, whether it was on or off, and a number of pods passed directly over the alarm while it was operational. This suggests that single alarms as currently

configured and attached to a trap or pot line are unlikely to effectively deter humpback whales from approaching potential hazards, at least during their northerly migration phase.

Hardy, T., Williams, R., Caslake, R., & Tregenza, N. (2012). An investigation of acoustic deterrent devices to reduce cetacean bycatch in an inshore set net fishery. *Journal of Cetacean Research and Management*, 12(1), 85-90. Retrieved from https://search.proquest.com/scholarly-journals/investigation-acoustic-deterrent-devices-reduce/docview/1687686888/se-2?accountid=28258.

In this study, four netting vessels less than 10m long used AQUAmark pingers on part of their nets off the southwest coast of Britain over a 12 month period. During the study, only one harbour porpoise was bycaught, in an unpingered net. In 650 days of acoustic data from pingered and non-pingered nets, matched by location, date and boat, there was a highly significant reduction in the number of porpoise clicks recorded at nets with pingers to 48% of the number predicted from the number recorded at control nets (range 35-51%). This study showed a stronger pinger effect at the quiet site and a much reduced effect at the noisy site. Results suggest that pingers are practical on small vessels, that they reduce harbour porpoise activity around nets and are therefore likely to reduce bycatch. Pingers should be considered as a bycatch mitigation method in small vessel fisheries using bottom set nets.

Janc, A., Richard, G., Guinet, C., Arnould, J. P. Y., Villanueva, M. C., Duhamel, G., . . . Tixier, P. (2018). How do fishing practices influence sperm whale (Physeter macrocephalus) depredation on demersal longline fisheries? *Fisheries Research*, 206, 14-26 https://doi.org/10.1016/j.fishres.2018.04.019.

Marine mammal depredation on fisheries (animals removing fish caught on fishing gear) is a worldwide issue involving socio-economic and ecological consequences. Longline fisheries are the most impacted by odontocete (toothed whales) depredation. While technological means have provided limited efficacy in reducing depredation, this study examined the fishing practices influencing both the proportion of depredated longline sets and the amount of fish removed by whales. We used an 8-year dataset from the Patagonian toothfish (Dissostichus eleginoides) longline fisheries operating in Crozet and Kerguelen Economic Exclusive Zones (EEZs) (South Indian Ocean) and GLMMs to investigate sperm whale (Physeter macrocephalus) depredation. Sperm whale depredation occurred on 61% of 5260 sets in Crozet and 41% of 16,902 sets in Kerguelen, and resulted in minimum estimated toothfish losses of 702 tons and 2649 tons, respectively, in the two areas. The probability of depredation decreased in winter months, increased with depth fished and decreased when vessels travelled over distances of > 60 km from fishing grounds with encountering depredation. These findings suggest the natural spatiotemporal distribution of sperm whales and their ability to follow vessels over limited ranges influence the number of captured fish removals. The amount of depredated toothfish decreased with the speed at which longline sets were hauled and increased with the soaking time of sets suggesting that whales may depredate sets during both hauling and soaking operations. Together, these observations indicate that rates of depredation may be influenced by the conditions of fishing operations and could therefore be employed to implement strategies of avoidance in all fisheries facing similar depredation impacts.

Kastelein, R. A., Huybrechts, J., Covi, J., & Helder-Hoek, L. (2017). Behavioral Responses of a Harbor Porpoise (Phocoena phocoena) to Sounds from an Acoustic Porpoise Deterrent. *Aquatic Mammals*, 43(3), 233-244 https://doi.org/10.1578/AM.43.3.2017.233.

To determine whether sounds from the FaunaGuard Porpoise Module or Acoustic Porpoise Deterrent-01 (APD-01) can deter harbor porpoises (Phocoena phocoena) far enough away from an offshore pile driving site to prevent hearing damage in the form of permanent hearing threshold shift (PTS) due to the first and following strikes, a harbor porpoise in a pool was exposed to the sounds at seven mean received sound pressure levels (SPLs; range: 74 to 110 dB re 1 µPa). The mean received behavioral response threshold SPL of a harbor porpoise responding to the sounds and an acoustic dose-behavioral response relationship were established. Two behavioral parameters were recorded during test and control sessions: (1) the harbor porpoise's respiration rate and (2) its distance from the transducer. Compared to in the control periods, the harbor porpoise's respiration rate increased significantly in test sessions at mean received SPLs of 104 dB re 1 µPa and above. The harbor porpoise's distance from the transducer was significantly greater during test sessions than during control sessions when mean received SPLs in test sessions were 86 dB re 1 µPa and above, indicating that it responded to the APD-01 primarily by swimming away from it. Because of the high frequency of the APD-01 sounds, harbor porpoises can determine the location of the sound source relatively easily. To calculate the effective deterring range of the APD-01 for harbor porpoises at sea, information on the behavioral threshold SPL for distance (established in the present study), the source level, and modeled information on the local propagation conditions and ambient noise need to be combined. The distance at which the APD-01 sounds are effective as deterrents is sufficient for their use to prevent PTS in wild harbor porpoises due to sound from the first strike of offshore pile driving.

Lesgae, V., Keays, J., Turgeon, S., & Hurtubise, S. (2006). Bycatch of harbour porpoises (Phocoena phocoena) in gillnet fisheries of the Estuary and Gulf of St Lawrence, Canada, 2000-02. *Journal of Cetacean Research and Management*, 8(1), 67-78. Retrieved from https://search.proquest.com/scholarly-journals/bycatch-harbour-porpoises-phocoena-gillnet/docview/19546454/se-2?accountid=28258.

The incidental catch of harbour porpoises (Phocoena phocoena) in the gillnet fishery of the Estuary and Gulf of St. Lawrence, Canada, was examined using: (1) questionnaires mailed to fishermen inquiring about bycatches in 2000 and 2001 (n=2,277 or 44% of the fishermen with valid licenses); and (2) using data from an at-sea observer programme and sentinel fishery programme in 2001 and 2002. The questionnaire survey had a low response rate (22%) and provided bycatch estimates of 2,215 (95% CI 1,151-3.662) and 2,394 (95% CI 1,440-3,348) porpoises in 2000 and 2001, respectively. The low number of hauls monitored by at-sea observers prevented the estimation of bycatch levels for several zones and the study area as a whole, and provided only imprecise estimates for all other zones. The results from questionnaires indicated a 24-63% reduction in harbour porpoise bycatches since the late 1980s, whereas the at-sea observer programme provided bycatch levels for 2001 and 2002 that were unreliable and underestimated, approaching one quarter of those documented in the late 1980s. Although both indices indicated a decrease in bycatches since the late 1980s, the magnitude of this change remains uncertain given the weaknesses associated with the two approaches. Considering the maximum population rate of increase (R sub(max)) for harbour porpoises as 4% and the lower and upper 95% confidence limits (1,440-3,348) of our most reliable estimate of bycatches (i.e. the 2001 questionnaire survey results), the harbour porpoise population in the Gulf of St. Lawrence would need to be at least 36,000-83,700 individuals for current incidental catches to be sustainable. If the rate of increase is less

than maximal, e.g. 0.5R sub(max) or 2%, then 72,000-167,400 harbour porpoises would be needed to attain sustainability. Kingsley and Reeves (1998) estimated that an average 36,000 to 125,000 porpoises occupied the Gulf of St. Lawrence during the summers of 1995 and 1996. Although the trajectory of the population since it was last surveyed in 1996 is uncertain, these findings suggest that bycatch levels might remain a cause for concern for the harbour porpoise population in the Gulf of St. Lawrence. The results from the comparison between the sentinel fishery and the commercial fishery subjected and not subjected to at-sea observations suggest that fine-scale temporal and spatial changes in fishing activities may greatly affect harbour porpoise bycatch levels.

Mangel, J. C., Alfaro-Shigueto, J., Witt, M. J., Hodgson, D. J., & Godley, B. J. (2013). Using pingers to reduce bycatch of small cetaceans in Peru's small-scale driftnet fishery. *Oryx*, 47(4), 595-606 https://doi.org/10.1017/S0030605312000658.

There is growing awareness that small-scale fisheries may have large impacts on threatened marine fauna. Bycatch of small cetaceans by the Peruvian small-scale driftnet fleet results in the deaths of thousands of animals annually. We sought to assess the effectiveness of acoustic alarms (pingers) for reducing the incidental capture of dolphins and porpoises by this fleet. Forty-three experimental trips (156 fishing sets) and 47 control trips (195 fishing sets) out of Salaverry Port, northern Peru, were observed from April 2009 to August 2011. Twenty-two percent of control sets captured small cetaceans (67 individuals) and 16% of experimental sets had captures of small cetaceans (33 individuals). The bycatch rate of experimental sets was 0.50 individuals km super(-2)h super(-1), whereas for control sets the rate was 0.80 individuals km super(-2)h super(-1). This 37% reduction in bycatch rate suggests that pingers may be effective in reducing the bycatch of small cetaceans in this fishery. Catch rates of the fishery's target shark and ray species were unchanged. Given the vast size of this fishery and its current levels of bycatch of small cetaceans (> 10,000 individuals annually), even the modest declines in bycatch we observed could result in reductions in mortality of hundreds or thousands of small cetaceans per annum. Challenges, including increased costs, to large-scale utilization of pingers have yet to be overcome. The harpooning of dolphins for use as bait will also need to be addressed for further reductions in dolphin and porpoise bycatch and mortality to be achievable.

Milani, C. B., Vella, A., Vidoris, P., Christidis, A., Kamidis, N., & Leykaditou, E. (2019). Interactions between fisheries and cetaceans in the Thracian sea (Greece) and management proposals. *Fisheries Management and Ecology*, 26(4), 374-388 https://doi.org/10.1111/fme.12370.

Greek fisheries (purse seine, trawling and small-scale coastal, by order of importance) mostly operate in the Thracian Sea, which despite its relatively small size relative to the Aegean Sea (approximate to 4.4%) is the most productive region in Greek waters due to its elevated nutrient concentration. The Thracian Sea is also vital to several species of cetaceans, mainly bottlenose dolphin, Tursiops truncatus (Montagu), and common dolphin, Delphinus delphis L. The area has been proposed as a potential cetacean conservation hotspot. For this reason, the interactions between fishing activities and local cetacean populations have been investigated through reports of stranded dolphins, interviews with fishers, surveys and detailed dolphin stomach content analysis. Reports of stranded cetaceans and interviews with fishers revealed cases of cetacean entanglement in fishing nets, as well as frequent dolphin damage to fishing nets. Necropsy stomach analysis of stranded dolphins revealed a preference for fish and cephalopods of low commercial value, indicating a low trophic overlap between cetaceans

and commercial fisheries. Recommendations for the management of fisheries-cetacean interactions in the Thracian Sea are provided.

Morizur, Y., Le Gall, Y., Van Canneyt, O., & Gamblin, C. (2008). *Experiments with the acoustic deterrent CETASAVER for mitigation of bycatch of common dolphins in trawl fisheries: results issued from trials with French commercial vessels in 2007 and 2008*. Retrieved from http://www.ifremer.fr/docelec/doc/2008/rapport-4506.pdf

An acoustic repellent was developed by Ixtrawl and Ifremer to mitigate incidental catches of common dolphins in trawl fisheries. The system developed-which bears the name of CETASAVER-was developed after behavioural tests performed on groups of common dolphins. These tests conducted at sea for the European project Necessity showed that the trajectories of animals could be changed by this pinger. The CETASAVER emits a beam directing conical with an opening between 75 and 15 degrees. This allows directional less disturbing environmental noise and must 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. Numerous trials were conducted with a pelagic trawl in commercial conditions, most often in the presence of scientific observers. 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 capture were respectively found in 5 and 10 hauls with comparative numbers of dolphins of 6 and 20. The results show a reduction in common dolphin bycatch of around 70% during the two years. The bootstraps shows the need to double the number of observations to reach a significant difference through the confidence intervals in numbers of dolphins.

Northridge, S., Sanderson, D., & Mackay, A. (2005). *The net effect: understanding how porpoise by-catches occur when you cannot see them*: International Council for the Exploration of the Sea, Palaegade 2-4 DK 1261 Copenhagen K Denmark. Retrieved from https://www.ices.dk/sites/pub/CM%20Doccuments/2005/X/X-2005.pdf

By-catches of cetaceans are rare events, and understanding how and why they happen should be a major goal in trying to minimise them. For most fisheries, few if any by-catch events have been adequately observed or described, so that one is forced to make inferences about how and why such events occur. Analysis of uncontrolled observations of fishing operations can be misleading. We describe two assumptions regarding porpoise by-catch in gillnets that we have tested through controlled experimental work. The first is that monofilament twines have a higher by-catch rate than multi-monofilament twines, and the second is that increasing the acoustic reflectivity of monofilament may reduce porpoise by-catch rates. In the first, case a controlled experiment in which an existing tangle net fishery was modified so that half of the nets being used were mono-filament and half were multi-monofilament, showed no difference in porpoise by-catch rates. In the second we found that increasing the acoustic reflectivity of tangle nets by using a monofilament twine impregnated with barium sulphate actually increased the by-catch rate rather than decreasing it. A similar experimental approach showed that smaller meshed and thinner twined nets have a significantly lower by-catch rate than larger meshed thicker twined nets. Previous work, summarised here, showed that porpoises are often found around the vicinity of nets, and we conclude that they are likely aware of the presence of gillnets, are rarely snared by the nets, and even more rarely actually get caught.

Nowacek, D. P., Thorne, L. H., Johnston, D. W., & Tyack, P. L. (2007). Responses of cetaceans to anthropogenic noise. *Mammal Review*, 37(2), 81-115 https://doi.org/10.1111/j.1365-2907.2007.00104.x.

1. Since the last thorough review of the effects of anthropogenic noise on cetaceans in 1995, a substantial number of research reports has been published and our ability to document response(s), or the lack thereof, has improved. While rigorous measurement of responses remains important, there is an increased need to interpret observed actions in the context of population-level consequences and acceptable exposure levels. There has been little change in the sources of noise, with the notable addition of noise from wind farms and novel acoustic deterrent and harassment devices (ADDs/AHDs). Overall, the noise sources of primary concern are ships, seismic exploration, sonars of all types and some AHDs. 2. Responses to noise fall into three main categories: behavioural, acoustic and physiological. We reviewed reports of the first two exhaustively, reviewing all peer-reviewed literature since 1995 with exceptions only for emerging subjects. Furthermore, we fully review only those studies for which received sound characteristics (amplitude and frequency) are reported, because interpreting what elicits responses or lack of responses is impossible without this exposure information. Behavioural responses include changes in surfacing, diving and heading patterns. Acoustic responses include changes in type or timing of vocalizations relative to the noise source. For physiological responses we address the issues of auditory threshold shifts and 'stress', albeit in a more limited capacity; a thorough review of physiological consequences is beyond the scope of this paper. 3. Overall, we found significant progress in the documentation of responses of cetaceans to various noise sources. However, we are concerned about the lack of investigation into the potential effects of prevalent noise sources such as commercial sonars, depth finders and fisheries acoustics gear. Furthermore, we were surprised at the number of experiments that failed to report any information about the sound exposure experienced by their experimental subjects. Conducting experiments with cetaceans is challenging and opportunities are limited, so use of the latter should be maximized and include rigorous measurements and or modelling of exposure.

O'Connell, V., Straley, J., Liddle, J., Wild, L., Behnken, L., Falvey, D., & Thode, A. (2015). Testing a passive deterrent on longlines to reduce sperm whale depredation in the Gulf of Alaska. *ICES Journal of Marine Science*, 72(5), 1667-1672 https://doi.org/10.1093/icesjms/fsv014.

In Alaska, sperm whale (Physeter macrocephalus) depredation on longline sets has increased since implementation of the Individual Fishing Quota programme in 1995. A collaborative effort (SEASWAP) between longliners, scientists, and managers has undertaken research to evaluate this depredation with a primary objective to develop and test a passive deterrent that would reduce depredation without reducing catch rate of sablefish (Anoplopoma fimbria). Commercial longliners, fishing for their own sablefish quotas during the regular season, deployed beaded gear (25 mm lucite beads attached to gangions) with control gear and set recorders to collect acoustic data. Beaded and control gear were randomly assigned by skate quad (672 hooks) with 5 quads in each longline set. Acoustic recorders were used to document sperm whale creak-pause events, representative of depredation of the longline gear. Although there were more sablefish per skate quad on the beaded gear and there was a decrease in depredation events on the beaded gear compared with the control, neither effect was significant ($p = 0.205$ and 0.364, respectively). The SEASWAP project is testing other deterrent strategies including gear modifications and the establishment of a sighting network to improve avoidance.

Omeyer, L. C. M., Doherty, P. D., Dolman, S., Enever, R., Reeses, A., Tregenza, N., . . . Godley, B. J. (2020). Assessing the Effects of Banana Pingers as a Bycatch Mitigation Device for Harbour Porpoises (Phocoena phocoena). *Frontiers in Marine Science*, 7, 10 https://doi.org/10.3389/fmars.2020.00285.

Bycatch is a significant cause of population declines of marine megafauna globally. While numerous bycatch mitigation strategies exist, acoustic alarms, or pingers, are the most widely adopted strategy for small cetaceans. Although pingers have been shown to be an effective measure for numerous species, there are some concerns about their long-term use. Bycatch is recognized as a persistent problem in waters around Cornwall, United Kingdom, where several cetacean species are resident, with harbour porpoises (Phocoena phocoena) being the most-commonly sighted. In this study, we assessed the effects of a Banana Pinger (Fishtek Marine Limited) on harbour porpoises in Cornwall between August 2012 and March 2013. Two passive acoustic loggers (C-PODs; Chelonia Limited) were deployed 100 m apart to record cetacean activity during cycles of active and inactive pinger periods. Harbour porpoises were 37% less likely to be detected at the C-POD near the pinger when the pinger was active, while they were only 9% less likely to be detected 100 m further away. The effect of the pinger was constant over the study period at both C-PODs despite the temporal variation in harbour porpoise detections. In addition, we found no evidence of reduced pinger effect with changing environmental conditions. Furthermore, harbour porpoise detections at the C-POD near the pinger did not depend on the time elapsed since the pinger turned off, with harbour porpoises returning to the ensonified area with no delay. Together these results suggest that (1) harbour porpoises did not habituate to the pinger over an 8-month period, (2) the pinger effect is very localized, and (3) pinger use did not lead to harbour porpoise displacement over the study period, suggesting an absence of long-term behavioral effects. We suggest that the deployment of pingers on fishing nets would likely reduce net-porpoise interactions, thereby mitigating bycatch of harbour porpoises and potentially other cetacean species. As the small-scale fishery dominates in United Kingdom waters, there is an acute need for cost-effective mitigation strategies with concurrent monitoring to be implemented rapidly in order to address the problem of harbour porpoise, and more generally, cetacean bycatch.

Palka, D. L., Rossman, M. C., Vanatten, A., & Orphanides, C. D. (2008). Effect of pingers on harbour porpoise (Phocoena phocoena) bycatch in the US Northeast gillnet fishery. *Journal of Cetacean Research Management*, 10(3), 217-226. Retrieved from https://porpoise.org/library/effect-pingers-harbour-porpoise-phocoena-phocoena-bycatch-us-northeast-gillnet-fishery/.

Harbour porpoise (Phocoena phocoena) bycatch in the US Northeast gillnet fishery is managed under the Harbour Porpoise Take Reduction Plan (HPTRP), which was implemented on 1 January 1999. The HPTRP divides this fishery into management areas that are either completely closed to all gillnets or closed only to gillnets that do not use pingers. Questions about pingers that have arisen include: (1) would pingers be as effective in an operational fishery as in controlled scientific experiments; (2) would the fishery comply with these regulations; and (3) would harbour porpoises habituate to pingers? To investigate these questions, data from over 25,000 gillnet hauls observed by the Northeast Fisheries Observer Program after the implementation of the HPTRP, 1999-2007, were examined. In a 1994 controlled scientific experiment conducted in part of this fishery that used 15cm mesh gillnets, the bycatch rate in pingered nets was 92% less than that in nets without pingers. In contrast, in the operational fishery, the bycatch reduction in pingered nets was 50-70%, depending on the time, area

and mesh size. In particular, there was no observed bycatch in pingered nets that used the same mesh size as used in the experiment. Thus, it seem that the apparent decrease in pinger effectiveness in the operational fishery was partially due to the type of gillnet used and lack of compliance. Pinger usage started out high in 1999 (the first year required), dropped substantially during 2003-05 and perhaps due to outreach activities increased beginning in 2006. During years of high pinger usage, 87% of the tested pingers were functional, while only 36% of the tested pingers were functional during years of low pinger usage. In general, as expected, observed bycatch rates in hauls without pingers were greater than bycatch rates in hauls with the required number of pingers. Unexpectedly, bycatch rates of observed hauls with an incomplete set of pingers were higher that in observed hauls without pingers. Confounding factors that could partially explain this apparently contrary result are discussed. There was no evidence for temporal trends in the bycatch rates, suggesting that harbour porpoises had not habituated to the pingers. In conclusion, in the US Northeast gillnet fishery, harbour porpoises do not appear to have habituated to pingers, and pingers appear to have reduced the bycatch rate, particularly when the required number of pingers were used and in nets using mesh sizes of 15cm or less.

Peterson, M. J., & Carothers, C. (2013). Whale interactions with Alaskan sablefish and Pacific halibut fisheries: Surveying fishermen perception, changing fishing practices and mitigation. *Marine Policy*, 42, 315-324 https://doi.org/10.1016/j.marpol.2013.04.001.

Whale depredation occurs when whales steal fish, damage fish or damage fishing gear. In Alaska, killer whales (Orcinus orca) and sperm whales (Physeter macrocephalus) primarily depredate on demersal sablefish (Anoplopoma fimbria) and Pacific halibut (Hippoglossus stenolepis) longline fisheries. Quantitative data on whale depredation in Alaska is limited due to low fishery observer coverage and minimal depredation evidence left on longline fishing gear. This study utilized semidirected interviews (n=70) and written questionnaires (n=95) with longline fishermen to examine: (I) perceptions and experiences of whale-fishery interactions in Alaska, (2) effects of depredation on fishing practices, and (3) potential depredation mitigation measures. Eighty-seven percent of fishermen surveyed agreed that whale depredation became worse between 1990 and 2010. Respondents reported changing their fishing practices in response to depredating whales in several ways, including: traveling up to 50 nautical miles and ceasing hauling operations up to 24 h until the whales left the fishing grounds. Respondents fishing in western Alaska, primarily encountering killer whales, were forced to wait longer and travel greater distances than fishermen operating in central and southeast Alaska, regions more affected by sperm whales. Deterrent research, gear modifications and real-time tracking of depredating whales were solutions favored by study participants. Survey respondent answers varied based on areas fished, quota owned, years involved in the fishery and vessel size. This study presents the first statewide evaluation of fishermen's perception and knowledge of whale interactions with the Alaskan longline fleet and is a critical step toward developing baseline data and feasible depredation mitigation strategies.

Pilcher, N. J., Nickson, A., McClellan, L., & Cartwright, I. (2006). *Hook, line and bycatch workshop setting the agenda for mitigation of bycatch in longline fisheries*. Retrieved from https://search.proquest.com/books/hook-line-bycatch-workshop-setting-agenda/docview/19813892/se-2?accountid=28258

During the IUCN World Conservation Congress in 2004, we identified the need for a forum where bycatch issues could be considered at an ecological, multi-species level rather than on a case-by-case basis. We recognized that several bycatch reduction measures are already in place, but noted that there

was insufficient communication and collaboration among the various species groups impacted by longline fisheries, and that opportunities might exist for cross-group information sharing and collaboration. The workshop was intended as a forum to: 1. Exchange knowledge on bycatch problems and mitigation techniques among four key species groups (turtles, seabirds, cetaceans, sharks); 2. Identify conflicts/mutual benefits of mitigation gears and fishing strategies; 3. Share knowledge on the spatial-temporal overlap of distributions of these species; 4. Identify needs, priorities and opportunities for collaborative mitigation research; and, 5. Define a priority global agenda to create a significant and measurable reduction in longline bycatch. The workshop brought together marine resource specialists composed of managers and policy makers, scientists, NGOs, IGOs, industry representatives and fishers, from 14 countries and sharing a wealth of global experience, who worked to identify, develop, and recommend applicable and integrated solutions to reduce interactions of birds, mammals, turtles and sharks with pelagic longline fisheries. The technical report includes commonalities, synergies and conflicts between species groups and mitigation measures for target (and non-target) species, through the use of a comparative matrix, and identifies criteria for evaluating trade-offs in the application of bycatch mitigation methods. It highlights the potential for the use of risk-based methods for assessing i) bycatch reduction priorities and ii) multi-species effects of bycatch reduction methods and strategies, and suggests means of monitoring and evaluating mitigation efforts with respect to performance indicators and adaptive management approaches, including timing considerations. The outcomes highlight research priorities including filling data gaps, and promising new mitigation methods and strategies aimed at raising awareness of multi-species data needs, to encourage governments and industry to collect standardized multi-species data in all observer programs. The Technical Report is envisioned to form the basis of a 'roadmap' or plan of action with regard to multi-species bycatch mitigation. A second key outcome was a preliminary mathematical model based on existing mitigation measures and intended to assist fisheries managers in decision making. The model is a process through which decision-makers can determine the top priorities for mitigation, both in terms of the bycatch species and the mitigation options, and combinations thereof at a multi-species (ecological) level. The model requires an up front determination of the species being impacted by a given fishery, which are then assigned 'conservation values' or some form of risk assessment weighting based on existing criteria. Based on the groups of species being impacted, a list of all potential bycatch mitigation measures is then assembled, and a matrix drawn up of the potential positive or negative impact of any given measure on each species or species group. A mathematical modeling process then assigns weights to species value, factors these against mitigation measures, and prioritizes the top mitigation measures.

Pirotta, V., Slip, D., Jonsen, I. D., Peddemors, V. M., Cato, D. H., Ross, G., & Harcourt, R. (2016). Migrating humpback whales show no detectable response to whale alarms off Sydney, Australia. *Endangered Species Research*, 29(3), 201-209 https://doi.org/10.3354/esr00712.

Migratory Group V (Stock E1) humpback whales Megaptera novaeangliae are at risk of entanglement with fishing gear as they migrate north and south along the east coast of Australia. This study investigated the effectiveness of 2 distinct tones for use as an alarm to acoustically alert whales to fishing gear presence and therefore reduce the chance of entanglement. We compared how whales responded in terms of changes of surface behaviour and changes in direction of travel in response to 2 acoustic tones and when there was no alarm. These 2 acoustic tones were a 5 kHz tone (5 s emission interval and 400 ms emission duration, similar to but higher frequency than the signal from a Future Oceans F3 (TM) 3 kHz Whale Pinger (R)) and a 2-2.1 kHz swept tone (8 s emission interval and 1.5 s emission duration). A total of 108 tracks (focal follows) were collected using a theodolite at Cape Solander, Sydney, Australia, during the whales' 2013 northern migration. Linear mixed effects models

were used to determine the effect of the different acoustic tones on whale direction (heading), and behaviour (dive duration and speed). Whales showed no detectable response to either alarm. Whale direction and surfacing behaviour did not differ whether the alarm was 'on' or 'off'. Although the response may have been different if the alarms were attached to fishing gear, the lack of measurable response suggests that the types of tones used are not likely to be effective in alarms intended to reduce entanglement of northward migrating Australian humpback whales.

Popov, D. V., Meshkova, G. D., Hristova, P. D., Gradev, G. Z., Rusev, D. Z., Panayotova, M. D., & Dimitrov, H. A. (2020). Pingers as Cetacean Bycatch Mitigation Measure in Bulgarian Turbot Fishery. *Acta Zoologica Bulgarica*, 235-242. Retrieved from https://www.bmis-bycatch.org/system/files/zotero_attachments/library_1/XKQN9BRR%20-%20Popov%20et%20al.%20-%20Pingers%20as%20Cetacean%20Bycatch%20Mitigation%20Measure%20in%20.pdf.

Bycatch (incidental catch) of small cetaceans is a major problem in a number of gillnet fisheries around the World and harbour porpoise (Phocoena phocoena) is one of the most heavily affected species. Pingers (acoustic deterrent devices) are recommended as mitigation measure to decrease bycatch rate. First large-scale use of pingers (Future Oceans 10 kHz and 70 kHz models) was made during standard turbot fishing operations in Bulgarian waters of Black Sea in 2019 during spring and summer - respectively before and after turbot fishing ban (15 April - 15 June). Four vessels have been involved with part of the nets being without pingers - control and other parts fitted with pingers - active. A total of 105 cetaceans (Phocoena phocoena relicta - 104 and Tursiops truncatus ponticus - 1) were recorded as bycatch in both control and active nets in spring and summer. Bycatch rates in active and control nets have not shown significant difference in both seasons. Significant increase in bycatch was registered in both active and control nets from spring to summer: 3.25 to 38.76 and 1.55 to 58.58 ind.km(-2).day(-1), respectively.

Rabearisoa, N., Bach, P., & Marsac, F. (2015). Assessing interactions between dolphins and small pelagic fish on branchline to design a depredation mitigation device in pelagic longline fisheries. *ICES Journal of Marine Science*, 72(5), 1682-1690 https://doi.org/10.1093/icesjms/fsu252.

Depredation by false killer whales (Pseudorca crassidens) and short-finned pilot whales (Globicephala macrorhynchus) in pelagic longlining is an issue leading to negative impacts on the economics of the fishery and on odontocetes themselves. We investigated the efficacy of a new depredation mitigation device called "DEPRED" in the interaction between bottlenose dolphins (Tursiops aduncus), spinner dolphins (Stenella longirostris), and small pelagic fish (SPF) attached to branchlines to simulate caught fish. We suggest implications for DEPRED efficacy with larger toothed whales interacting with pelagic longline capture in the open ocean. The design of the device uses streamers to both deter cetaceans and protect fish from predation. In controlled experiments, we tested its efficacy by observing changes in the dolphin's behaviour brought on by the presence or absence of the device on branchlines. First, dolphin-SPF interactions were observed at the small scale using video footage recorded with an underwater camcorder. Second, the efficacy of the device was quantified from interactions between dolphins and 80 branchlines deployed on a longline 500 m long baited with SPF. One half of the SPF on successive branchlines was protected by DEPRED and the other half was not. A total of 707 branchlines were set when dolphins interacted with SPF, and among them, 355 were equipped with DEPRED. Encouraging results were obtained: over the short term, the number of damaged unprotected SPF was

on average more than twice the number of protected ones. Nevertheless, habituation behaviour was observed for a resident group of T. aduncus in the experimental area. The relation between the deterrent effect of the device and constraints related to the design of such a device to be used at a commercial operational level are discussed.

Read, A. J. (2013). Development of conservation strategies to mitigate the bycatch of harbor porpoises in the Gulf of Maine. *Endangered Species Research*, 20(3), 235-250 https://doi.org/10.3354/esr00488.

In this paper I review the development of conservation strategies to address the bycatch of harbor porpoises Phocoena phocoena in Gulf of Maine gillnet fisheries from 1982, when bycatches were first detected, until a Take Reduction Plan was implemented in 1999. After consideration of several mitigation options, the plan included a combination of time-area closures and the use of acoustic alarms. Implementation of these measures reduced the annual bycatch of porpoises from a high of 2900 in 1990 to 323 in 1999, the first year in which bycatches fell below the potential biological removal (PBR) level. The success of these measures can be attributed to several factors, including a clear conservation goal, the PBR level, mandated by the US Marine Mammal Protection Act. The importance of PBR is underscored by contrasting experiences in the USA, where the goal was achieved, and those in Canada, where no comparable goal existed and no conservation measures were implemented. The availability of detailed scientific information on bycatch levels and abundance was critical to persuading all stakeholders of the need to act. Successful negotiation within the Take Reduction Team was facilitated by a long prior history of informal collaboration and dialogue. Finally, the monitoring program provided important feedback on the efficacy of measures in reducing bycatch, effectively closing the loop on the management process. This case study is instructive in several regards with respect to the elements necessary to address bycatch issues involving small cetaceans and gillnet fisheries.

Richard, G., Guinet, C., Bonnel, J., Gasco, N., & Tixier, P. (2018). Do commercial fisheries display optimal foraging? The case of longline fishers in competition with odontocetes. *Canadian Journal of Fisheries and Aquatic Sciences*, 75(6), 964-976 https://doi.org/10.1139/cjfas-2016-0498.

Depredation in longline fisheries by odontocete whales is a worldwide growing issue, having substantial socioeconomic consequences for fishers as well as conservation implications for both fish resources and the depredating odontocete populations. An example of this is the demersal longline fishery operating around the Crozet Archipelago and Kerguelen Island, southern Indian Ocean, where killer whales (Orcinus orca) and sperm whales (Physeter macrocephalus) depredate hooked Patagonian toothfish (Dissostichus eleginoides). It is of great interest to better understand relationships of this modern fishery with its environment. Thus, we examined the factors influencing the decision-making process of fishers facing such competition while operating on a patch. Using optimal foraging theory as the underlying hypothesis, we determined that the probability captains left an area decreases with increasing fishing success, whereas in presence of competition from odontocete whales, it increases. Our study provides strong support that fishers behave as optimal foragers in this specific fishery. Considering that captains are optimal foragers and thus aim at maximizing the exploitation of the resources, we highlight possible risks for the long-term sustainability of the local ecosystems.

Simonis, A. E., Forney, K. A., Rankin, S., Ryan, J., Zhang, Y. W., DeVogelaere, A., . . . Baumann-Pickering, S. (2020). Seal Bomb Noise as a Potential Threat to Monterey Bay Harbor Porpoise. *Frontiers in Marine Science*, 7, 9 https://doi.org/10.3389/fmars.2020.00142.

Anthropogenic noise is a known threat to marine mammals. Decades of research have shown that harbor porpoises are particularly sensitive to anthropogenic noise, and geographic displacement is a common impact from noise exposure. Small, localized populations may be particularly vulnerable to impacts associated with displacement, as animals that are excluded from their primary habitat may have reduced foraging success and survival, or be exposed to increased threats of predation or bycatch. Seal bombs are underwater explosives used in purse seine fisheries to deter marine mammals during fishery operations. Pinnipeds are believed to be the primary target for seal bomb use, however there may be indirect impacts on harbor porpoises. Active purse seine fishing using seal bombs in the greater Monterey Bay area may, at times, span the entire range of the Monterey Bay harbor porpoise stock, which may lead to negative impacts for this population. In this contribution, we review anthropogenic noise as a threat to harbor porpoises, with a focus on the potential for impacts from seal bomb noise exposure in the Monterey Bay region.

Snape, R. T. E., Broderick, A. C., Cicek, B. A., Fuller, W. J., Tregenza, N., Witt, M. J., & Godley, B. J. (2018). Conflict between Dolphins and a Data-Scarce Fishery of the European Union. *Human Ecology*, 46(3), 423-433 https://doi.org/10.1007/s10745-018-9989-7.

Fisheries depredation by marine mammals is an economic concern worldwide. We combined questionnaires, acoustic monitoring, and participatory experiments to investigate the occurrence of bottlenose dolphins in the fisheries of Northern Cyprus, and the extent of their conflict with set-nets, an economically important metier of Mediterranean fisheries. Dolphins were present in fishing grounds throughout the year and were detected at 28% of sets. Net damage was on average six times greater where dolphins were present, was correlated with dolphin presence, and the associated costs were considerable. An acoustic deterrent pinger was tested, but had no significant effect although more powerful pingers could have greater impact. However, our findings indicate that effective management of fish stocks is urgently required to address the overexploitation that is likely driving depredation behaviour in dolphins, that in turn leads to net damage and the associated costs to the fisheries.

Soto, A. B., Cagnazzi, D., Everingham, Y., Parra, G. J., Noad, M., & Marsh, H. (2013). Acoustic alarms elicit only subtle responses in the behaviour of tropical coastal dolphins in Queensland, Australia. *Endangered Species Research*, 20(3), 271-282 https://doi.org/10.3354/esr00495.

Incidental bycatch in gill nets is the most serious of the global threats to marine mammals. Consequently, many management agencies wish to implement practical and efficient bycatch mitigation systems that both protect species of conservation concern and are readily adopted by fishermen. Australian snubfin Orcaella heinsohni and humpback dolphins Sousa chinensis occur in small fragmented populations along most of the remote coast of subtropical and tropical Australia, where they are caught in gillnet fisheries operated from small vessels. We experimentally investigated whether a commercially available acoustic alarm modified the behaviour of each of these species in the absence of a net. The movements and behaviour of both species changed subtly when the pingers were active, but the likelihood of the animals leaving an area was not significantly different from the controls. Our results suggest that this technological approach may not be effective in reducing the bycatch of these species.

We suggest that further experimentation is unlikely to be cost effective and that government agencies should work with fishers and scientists to explore alternative mitigation measures.

Thorne, L. H., Baird, R. W., Webster, D. L., Stepanuk, J. E., & Read, A. J. (2019). Predicting fisheries bycatch: A case study and field test for pilot whales in a pelagic longline fishery. *Diversity and Distributions*, 25(6), 909-923. Retrieved from https://www.jstor.org/stable/26635139.

Aim: Fisheries bycatch is a major threat to populations of protected species such as marine mammals, seabirds and sea turtles, and static management approaches are often unsuccessful in mitigating bycatch of these highly mobile species. Combining species distribution models (SDMs) with oceanographic data has been proposed as a means of predicting when and where bycatch is likely to occur. However, studies assessing whether SDMs can accurately predict fisheries bycatch using independent data are lacking. Assessing model performance using independent data is necessary to test whether a model is generalizable, and this is particularly important for models with management applications. Here, we use short-finned pilot whale (Globicephala macrorhynchus) bycatch in a pelagic longline fishery as a case study to inform efforts to mitigate fisheries bycatch. Location: Offshore waters, north-east United States. Methods: We integrated telemetry and oceanographic data using mixed-effects generalized additive models to predict pilot whale occurrence and assessed model performance using k-folds cross-validation. We then evaluated the model's ability to predict pilot whale bycatch using data from independent on-board observers. Results: The model performed well, and predictions were strongly and significantly correlated with observed rates of bycatch in space and time. Temperature and proximity to mesoscale oceanographic features (thermal fronts and sea level anomalies) were important predictors of pilot whale occurrence, and as a result, spatial predictions of the risk of bycatch varied through time. Main conclusions: Our findings demonstrate that SDMs can be used to accurately predict times and places with a high risk of bycatch, and illustrate that models using dynamic oceanographic variables can identify smaller, more specific focal management regions than static management approaches. Combining SDMs with near realtime or forecasted environmental conditions could provide a promising tool for decreasing bycatch and will be valuable in developing adaptive management strategies to mitigate fisheries bycatch of protected species.

Tixier, P., Gasco, N., Duhamel, G., Viviant, M., Authier, M., & Guinet, C. (2010). Interactions of Patagonian toothfish fisheries with killer and sperm whales in the Crozet islands Exclusive Economic Zone: an assessment of depredation levels and insights on possible mitigation strategies. *Ccamlr Science*, 17, 179-195. Retrieved from https://www.ccamlr.org/en/system/files/science_journal_papers/10tixier-et-al.pdf

Within the Crozet Islands Exclusive Economic Zone (EEZ), the Patagonian toothfish (Dissostichus eleginoides) longline fishery is exposed to high levels of depredation by killer (Orcinus orca) and sperm whales (Physeter macrocephalus). From 2003 to 2008, sperm whales alone, killer whales alone, and the two species co-occurring were observed on 32.6%, 18.6% and 23.4% respectively of the 4 289 hauled lines. It was estimated that a total of 571 tonnes ((sic)4.8 million) of Patagonian toothfish were lost due to depredation by killer whales and both killer and sperm whales. Killer whales were found to be responsible for the largest part of this loss (>75%), while sperm whales had a lower impact (>25%). Photo-identification data revealed 35 killer whales belonging to four different pods were involved in 81.3% of the interactions. Significant variations of interaction rates with killer whales were detected between vessels suggesting the influence of operational factors on depredation. When killer whales were absent at the beginning of the line hauling process, short lines (<5 000 m) provided higher yield

and were significantly less impacted by depredation than longer lines. Also, when facing depredation, it is recommended that vessels leave their fishing area and travel distances >40 n miles to prevent killer whales from finding them within a few hours. Although more data are still needed to better understand the way killer whales search and detect vessels, this study gives preliminary insights into possible mitigation solutions to the widespread depredation issue.

Tulloch, V., Grech, A., Jonsen, I., Pirotta, V., & Harcourt, R. (2020). Cost-effective mitigation strategies to reduce bycatch threats to cetaceans identified using return-on-investment analysis. *Conservation Biology*, 34(1), 168-179 https://doi.org/10.1111/cobi.13418.

Globally, fisheries bycatch threatens the survival of many whale and dolphin species. Strategies for reducing bycatch can be expensive. Management is inclined to prioritize investment in actions that are inexpensive, but these may not be the most effective. We used an economic tool, return-on-investment, to identify cost-effective measures to reduce cetacean bycatch in the trawl, net, and line fisheries of Australia. We examined 3 management actions: spatial closures, acoustic deterrents, and gear modifications. We compared an approach for which the primary goal was to reduce the cost of bycatch reduction to fisheries with an approach that aims solely to protect whale and dolphin species. Based on cost-effectiveness and at a fine spatial resolution, we identified the management strategies across Australia that most effectively abated dolphin and whale bycatch. Although trawl-net modifications were the cheapest strategy overall, there were many locations where spatial closures were the most cost-effective solution, despite their high costs to fisheries, due to their effectiveness in reducing all fisheries interactions. Our method can be used to delineate strategies to reduce bycatch threats to mobile marine species across diverse fisheries at relevant spatial scales to improve conservation outcomes.

van Beest, F. M., Kindt-Larsen, L., Bastardie, F., Bartolino, V., & Nabe-Nielsen, J. (2017). Predicting the population-level impact of mitigating harbor porpoise bycatch with pingers and time-area fishing closures. *Ecosphere*, 8(4), 17 https://doi.org/10.1002/ecs2.1785.

Unintentional mortality of higher trophic-level species in commercial fisheries (bycatch) represents a major conservation concern as it may influence the long-term persistence of populations. An increasingly common strategy to mitigate bycatch of harbor porpoises (Phocoena phocoena), a small and protected marine top predator, involves the use of pingers (acoustic alarms that emit underwater noise) and time-area fishing closures. Although these mitigation measures can reduce harbor porpoise bycatch in gillnet fisheries considerably, inference about the long-term population-level consequences is currently lacking. We developed a spatially explicit individual-based simulation model (IBM) with the aim to evaluate the effectiveness of these two bycatch mitigation measures. We quantified both the direct positive effects (i.e., reduced bycatch) and any indirect negative effects (i.e., reduced foraging efficiency) on the population size using the inner Danish waters as a biological system. The model incorporated empirical data on gillnet fishing effort and noise avoidance behavior by free-ranging harbor porpoises exposed to randomized high-frequency (20- to 160-kHz) pinger signals. The IBM simulations revealed a synergistic relationship between the implementation of time-area fishing closures and pinger deployment. Time-area fishing closures reduced bycatch rates substantially but not completely. In contrast, widespread pinger deployment resulted in total mitigation of bycatch but frequent and recurrent noise avoidance behavior in high-quality foraging habitat negatively affected individual survival and the total population size. When both bycatch mitigation measures were implemented

simultaneously, the negative impact of pinger noise-induced sub-lethal behavioral effects on the population was largely eliminated with a positive effect on the population size that was larger than when the mitigation measures were used independently. Our study highlights that conservationists and policy makers need to consider and balance both the direct and indirect effects of harbor porpoise bycatch mitigation measures before enforcing their widespread implementation. Individual-based simulation models, such as the one presented here, offer an efficient and dynamic framework to evaluate the impact of human activities on the long-term survival of marine populations and can serve as a basis to design adaptive management strategies that satisfy both ecological and socioeconomic demands on marine ecosystems.

Wild, L., Straley, J., Thode, A., Falvey, D., Liddle, J., & O'Connell, V. (2014). Can We Be as Clever as a Sperm Whale? Efficacy of Countermeasures to Reduce Sperm Whale Depredation on Demersal Longlines in the Gulf of Alaska. Lowell Wakefield Fisheries Symposium Series, (29), 63. Retrieved from https://seagrant.uaf.edu/events/2014/wakefield-bycatch/wakefield-2014-program.pdf

Since 2003, fishermen and scientists have been working collaboratively under the Southeast Alaska Sperm Whale Avoidance Project (SEASWAP) to reduce sperm whale depredation upon demersal longlines in the Gulf of Alaska. One research result has identified the acoustic cue alerting whales to fishing activity as engine cycling. The North Pacific Research Board has enabled testing of a countermeasure that broadcasts engine cycling sounds from a decoy playback device. The goal is to prevent or delay whales from approaching true fishing activity. In summer 2013, 26 trial deployments were conducted on 10 longline sets with whales present. Five of these data sets meet criteria for analysis and bulk processing has started. The remaining five out of 10 were problematic due to an internal clock reset issue. These data were salvageable by matching the fisherman's notes with the acoustics from the recorders. Preliminary power analysis showed 7-10 sets required for statistical power, which have been achieved. Statistical analysis will be conducted to analyze the proportion of time the fishing hauls were whale-free, with regard to the distance from the set to the decoy device, the time of decoy activation, time of haul, and time whales were first observed at the haul. Whales showed up at the true fishing haul 7 out of the 10 times they were acoustically present in the area or at the decoy device. The number of whales observed at each set ranged from 0 to 3 (mean = 1.1+ or -0.94 SD). Continued analysis will dictate efficacy of this potential deterrent.

Wild, L., Thode, A., Straley, J., Rhoads, S., Falvey, D., & Liddle, J. (2017). Field trials of an acoustic decoy to attract sperm whales away from commercial longline fishing vessels in western Gulf of Alaska. *Fisheries Research*, 196, 141-150 https://doi.org/10.1016/j.fishres.2017.08.017.

In the Gulf of Alaska, sperm whales (Physeter macrocephalus) are known to remove sablefish (Anoplopoma fimbria) from commercial longline fishing gear. This removal, called depredation, is economically costly to fishermen, presents risk of injury or mortality to whales, and could lead to unknown removals during the federal sablefish longline survey that contributes to estimation of the annual fishing quota. In 2013 the Southeast Alaska Sperm Whale Avoidance Project (SEASWAP) evaluated the efficacy of an acoustic decoy in reducing encounters between sperm whales and longline fishing gear. The aim of the acoustic decoy was to use fishing vessel sounds to attract whales to an area away from the true fishing haul in order to reduce interactions between commercial fishing vessels and whales. A custom playback device that could be remotely activated via a radio modem was incorporated into an anchored buoy system that could be deployed by the vessel during a two-month trip between

June and July 2013. Once activated, the decoy broadcasted vessel-hauling noises known to attract whales, while the vessel performed several true hauls at various ranges from the device. Passive acoustic recorders at both the decoy and true set locations were also deployed to evaluate whale presence. Twenty-six hauls were conducted while a decoy was deployed, yielding fourteen sets with whales present while the decoy was functional. A significant relationship was found between the number of whales present at the true fishing haul and the distance of the haul from the decoy (1–14km range), with the decoy being most effective at ranges greater than 9km ($t=-2.06$, $df=12$, $p=0.04$). The results suggest that acoustic decoys may be a cost-effective means for reducing longlining depredation from sperm and possibly killer whales under certain circumstances.

Zeeberg, J., Corten, A., & De Graaf, E. (2006). Bycatch and release of pelagic megafauna in industrial trawler fisheries off Northwest Africa. *Fisheries Research* (Amsterdam), 78(2-3), 186-195 https://doi.org/10.1016/j.fishres.2006.01.012.

The accidental capture of large animals such as sharks, manta rays, sea turtles, and dolphins in pelagic trawler fisheries remains controversial because it threatens biological diversity in many biogeographical regions, including the subtropical eastern North Atlantic. Bycatch rates observed during more than 1400 trawl sets off Mauritania, Northwest Africa, are shown to have been considerable during the past 4 years, with high animal abundance in Summer when the Northwest African shelf is occupied by subtropical water. We demonstrate the urgency for bycatch reduction and evaluate the use of species-selective gear, a conservation method immediately available and immediately effective in waters fished through international access agreements. A modification tested in commercial trawls during the observer program guides pelagic megafauna deflected by a filter to an escape tunnel along the bottom of the trawl. This "excluder" reduces bycatch mortality of the most vulnerable megafauna species by at least 40-100%.

Zollett, E. A. (2008). *Conserving dolphins and fishermen: Combining science and local knowledge to reduce cetacean bycatch.* (Ph.D.). University of New Hampshire, Durham. Retrieved from https://scholars.unh.edu/dissertation/465/

Bycatch is the portion of catch that is neither targeted nor retained by fishermen. It threatens the survival of many marine mammal populations globally, and it occurs in nearly every fishing gear type. Despite its widespread occurrence, observations of bycatch are rare, and scientific data on marine mammal bycatch are limited. Difficulties result in developing models that accurately depict the interactions. This study focuses on developing methodology to combine disparate data sources, specifically data from fishery observer programs and interviews of fishermen, to better understand these interactions and to identify effective mitigation measures. As a case study, this research investigates the spatial and temporal patterns associated with Atlantic white-sided dolphin (Lagenorhynchus acutus) bycatch in the New England bottom trawl fishery for groundfish to aid in the development of an effective bycatch reduction plan. A quasi-binomial model of the fishery observer data was developed using environmental and fishing-related covariates to describe the probability of dolphin bycatch in this fishery. Significant variables in describing dolphin bycatch included sea surface temperature ($p<0.001$), depth ($p<0.001$), and an interaction between bottom slope and depth ($p<0.05$). The model was mapped using geographic information systems and incorporated into interviews with bottom trawl fishermen to facilitate discussion on patterns of bycatch. Thirty-one bottom trawl fishermen were interviewed, and results were consistent with the probability model that bycatch was rare and was more likely to occur in offshore fishing areas. Interviewed fishermen did not relate bycatch

to environmental variables and did not provide consistent responses regarding spatial or temporal patterns associated with these events. As a result, this study was unable to develop methodology to spatially combine these data sources. However, fishermen did provide useful information to scientists and fishermen. For instance, interview results suggested that area-based management would not be effective in this fishery, contrary to the results of the probability model, due to the occurrence of bycatch throughout the fishing area. Instead broad-scale measures, coupled with incentives, would be a more effective mitigation measure in this fishery. Collaborative research between fishermen and scientists or gear technologists is recommended to better understand operational patterns associated with bycatch.

Section II: Pinniped Deterrents

Cook, T. C., James, K., & Bearzi, M. (2015). Angler perceptions of California sea lion (Zalophus californianus) depredation and marine policy in Southern California. *Marine Policy*, 51, 573-583 https://doi.org/10.1016/j.marpol.2014.09.020.

California sea lions (Zalophus californianus) off the coast of Southern California are known to damage both commercial and recreational fishing activities, causing decreases to fish catch and damage to gear. Their increasing population has intensified the potential for conflict between sea lions and anglers, likely requiring changes to current legislation. The recreational fishing community in Southern California is a valuable and largely underutilized source for information and potential solutions to management and legislative problems. This recreational fishing survey-based study conducted in 2013 utilized personal interviews, conducted in the field with recreational anglers and commercial passenger fishing vessel (CPFV) crews in Southern California, to gather data on: (a) the occurrence and impact of sea lion depredation on the local fishing, (b) angler awareness and opinions on current legislation, and (c) the conflict between fishing activities and conservation efforts. Results show that surveyed CPFV operators and private boaters had the most conflict with sea lions and perceive them as more of a problem than anglers on piers, jetties or kayaks. The conflict was also reportedly more prevalent in San Diego County compared to the other counties surveyed (Orange, Los Angeles and Ventura). Participating CPFV operators were overwhelmingly in support of a government culling program for sea lions, while recreational angler respondents did not feel that a control program was necessary. These CPFV operators reported more money lost, and were willing to pay more for an effective deterrent device. There was also a consensus among respondents that fish catch is declining, yet anglers were unsatisfied with the effectiveness of current legislation designed to increase fish stocks. These data will provide a better understanding of California sea lion depredation in Southern California and its effect on recreational anglers in order to aid future mitigation efforts. Additionally, these results provide stakeholder feedback on local marine protected areas and other fisheries management legislation, and build a foundation for future conservation and education programs. (C) 2014 Elsevier Ltd. All rights reserved.

Forrest, K. W., Cave, J. D., Michielsens, C. G. J., Haulena, M., & Smith, D. V. (2009). Evaluation of an Electric Gradient to Deter Seal Predation on Salmon Caught in Gill-Net Test Fisheries. *North American Journal of Fisheries Management*, 29(4), 885-894 https://doi.org/10.1577/m08-083.1.

An electric deterrent system was tested as an effective and safe method of deterring predation by Pacific harbor seals Phoca vitulina richardsi on sockeye salmon Oncorhynchus nerka and pink salmon Oncorhynchus gorbuscha caught in a Fraser River gill-net test fishery. Seals were deterred from foraging in a test fishing gill net in the Fraser River by using a pulsed, low-voltage DC electric gradient. Salmon catch per unit effort (CPUE) was significantly greater for the treated (electric) section of the gill net than for the nontreated section (marginal mean CPUE = 4.0/1,000 m . min versus 1.0/1,000 m . min), and there was no overlap in the 95% confidence intervals for the two treatments. There were no apparent injuries to any animals during the study. This previously Undocumented nonlethal technology demonstrates the potential to reduce pinniped predation on salmon, with meaningful implications for fisheries management agencies that rely on gill-net test fisheries in freshwater rivers frequented by pinnipeds.

Gordon, J., Blight, C., Bryant, E., & Thompson, D. (2019). Measuring responses of harbour seals to potential aversive acoustic mitigation signals using controlled exposure behavioural response studies. A*quatic Conservation (Online)*, 29(S1), 157-177 https://doi.org/10.1002/aqc.3150.

Some anthropogenic activities pose acute risks for marine species. For example, pile driving could damage the hearing of marine mammals while underwater explosions can also result in physical damage or death. Effective mitigation is required to reduce these risks, but the exclusion zones specified in regulations can extend over hundreds or thousands of metres and seals pose particular problems because they are difficult to detect at sea.Aversive sound mitigation aims to exclude animals from high-risk areas before dangerous activities take place by broadcasting specific acoustic signals. Field research is needed to identify signals that might be effective in eliciting short-term avoidance by marine species such as harbour seals (Phoca vitulina). A series of controlled-exposure experiments (CEEs) were undertaken to measure seal movements in response to acoustic deterrent devices (ADD) and predator calls, and to assess the effectiveness of candidate signals for aversive sound mitigation.Seals were fitted with UHF/GPS transmitters providing continuous high-resolution tracks and real-time transmissions of their locations. A tracking/playback vessel located seals at sea and transmitted either ADD signals or orca (Orcinus orca) calls over a range of distances while seals were foraging or moving between sites. Behaviour before, during and after exposure was analysed to assess responses.One-hundred and ten CEEs were assessed as being of at least 'adequate' quality. Of the 71 adequate trials with the Lofitech ADD, all 38 at ranges of <1 km (predicted received level 134.6 dB RMS re 1 µPa) elicited a response. The maximum response range was 3123 m (predicted RL: 111 dB RMS re 1 µPa). However, the responses observed did not always result in substantial movements away from the source, especially for seals that were travelling at the time of the exposures. More work is needed to better understand how exposure risks would be reduced in different scenarios.The mean net speed of horizontal movements for seals responding to aversive sounds (1.15 m s−1) was only 7% higher than their mean travel speed.Responses to broadcasts of orca calls were highly variable.The results suggest that signals similar to those generated by a Lofitech ADD could be used to reduce risks to harbour seals from pile driving and underwater explosions in coastal waters. More work will be needed to develop systems that match the requirements of industry and regulators and to explore whether these results can be generalized to offshore waters and to other phocids.

Gotz, T., & Janik, V. M. (2013). Acoustic deterrent devices to prevent pinniped depredation: efficiency, conservation concerns and possible solutions. *Marine Ecology Progress Series*, 492, 285-+ https://doi.org/10.3354/meps10482.

Acoustic deterrent devices (ADDs) to prevent pinniped predation on fish farms and fisheries are widely used, but show highly varying success. Recently, ADDs have also been highlighted as a conservation concern due to their adverse impact on toothed whales. We review the available literature on the efficiency of commercial ADDs, evaluate the unintended impact on behaviour, communication and hearing of marine life, and suggest solutions based on psychophysiological predictions. The main problems associated with ADDs are a lack of long-term efficiency, introduction of substantial noise pollution to the marine environment and long-term effects on target and non-target species. Odontocetes have more sensitive hearing than pinnipeds at the frequencies where most ADDs operate, which may explain the reported large-scale habitat exclusion of odontocetes when ADDs are used. Furthermore, long-term exposure to ADDs may damage the hearing of marine mammals. Fish and invertebrates have less sensitive hearing than marine mammals and fewer efforts have been made to quantify the effects of noise on these taxa. Solutions can be found by decreasing sound exposure,

exploiting neuronal reflex arcs associated with flight behaviour and making use of differences in species' hearing abilities to increase target specificity. To minimise adverse effects, environmental impact assessments should be carried out before deploying ADDs and only effective and target-specific devices should be used.

Graham, I. M., Harris, R. N., Denny, B., Fowden, D., & Pullan, D. (2009). Testing the effectiveness of an acoustic deterrent device for excluding seals from Atlantic salmon rivers in Scotland. *ICES Journal of Marine Science*, 66(5), 860-864 https://doi.org/10.1093/icesjms/fsp111.

In Scotland, there is frequent conflict between salmon rod fisheries and seals, which is often managed by the shooting of seals in rivers, with potential negative impacts on protected populations of seals. Non-lethal devices have not been tested extensively in rivers as an alternative to shooting. Trials were carried out between January and May 2006 on the River North Esk and between October 2007 and February 2008 on the River Conon in northeast Scotland to examine the effectiveness of an acoustic deterrent device (ADD) at deterring seals from a specific area of river and as a barrier to the upstream movement of seals. The ADD was switched on and off alternately for periods of several days, and surveys were carried out to estimate the number of seals present within each river. The ADD had no significant effect on the absolute abundance of seals in the survey area in either river, but it did reduce seal movement upstream significantly, by similar to 50% in both rivers. This reduction was constant over the 4-month period of both trials. The results suggest that ADDs might be a useful conservation tool in the management of seal-salmon conflicts, particularly in estuaries and rivers where the potential for adversely impacting cetaceans is limited.

Hamer, D. J., Ward, T. M., Shaughnessy, P. D., & Clark. (2011). Assessing the effectiveness of the Great Australian Bight Marine Park in protecting the endangered Australian sea lion Neophoca cinerea from bycatch mortality in shark gillnets. *Endangered Species Research*, 14(3), 203-216 https://doi.org/10.3354/esr00353.

The Endangered Australian sea lion Neophoca cinerea occurs in low numbers, exhibits low fecundity, extreme philopatry and substantial population genetic structure at the breeding colony level. These traits may increase susceptibility to population decline, with additional mortality as bycatch in shark gillnets being a possible threat. The Great Australian Bight Marine Park (GABMP) was established, in part, to protect the small and remote Bunda Cliffs population from anthropogenic impacts such as commercial fishing. This study investigated the effectiveness of the GABMP in reducing spatial overlap between Australian sea lions and gillnets and in preventing bycatch. An independent fishery observer program reported a mortality rate of 0.0206 individuals (ind.) km-1 of gillnet set within the GABMP, amounting to between 4 and 15 (confidence bounds of standard error of the estimate) ind. killed there during the most recent breeding cycle. A mortality rate of 0.0093 ind. km-1 of gillnet set was recorded across the broader GAB region, amounting to between 14 and 33 ind. killed each breeding cycle during recent times, and between 128 and 177 over the 10 yr since the GABMP was established in the mid-1990s. These reported bycatch levels are unlikely to be sustainable and may represent minimum estimates, because drowned individuals may drop out of the gillnet and go unobserved. A tracking program involving 9 females (5.6% of the estimated female population) demonstrated that they spent only 27.7% of their time inside the GABMP. Four of them regularly travelled more than 180 km from home, or 9 times further than the southern boundary of the GABMP. These results indicate that the level of protection afforded by the GABMP to Australian sea lions residing at Bunda Cliffs is unlikely to

reduce -bycatch to below the levels that would reduce the risk of decline in this small population. Suggested -improvements to the GABMP include a year-round closure to gillnetting, low bycatch limits and extension of the southern boundary further south. Additional regulatory mechanisms may be needed in the gillnet fishery to minimise its impact on this and other small Australian sea lion populations.

Harris, R. N., & Northridge, S. (2015). *Seals and wild salmon fisheries*. Retrieved from http://www.smru.st-andrews.ac.uk/files/2015/10/SSI_seals_and_salmon_VF1.pdf

This document reports on the progress made during 2014 with regard to marine mammal research at wild salmon fisheries. The objectives were: to continue studies into the effectiveness of Acoustic Deterrent Devices (ADDs) and the modification of salmon nets to mitigate the effects of seals on these fisheries; collect shot seals for dietary analysis and provide support to district salmon fishery boards (DSFBs). Activities primarily focused on two sites in the Moray Firth, Portmahomack and Crovie. During 2013 the salmon net fishery at Portmahomack reported that seals were regularly seen at the net and that salmon landings were damaged by seals despite the use of an ADD. During 2014 seal sightings and salmon landings data were collected and photo-identification of seals from land-based photography was used to identify individual seals. Images were collected and all seal sightings at the net while the ADD was 'on' were attributed to adult male grey seals. Photo-identification revealed only two adult male grey seals were prepared to visit the salmon net while the ADD was 'on'. During 2013 tests began on the effectiveness of an ADD at Crovie. This work continued in 2014 through the collection and processing of underwater video footage to study the rate at which seals entered the net. The deployment of a C-POD was trialled to provide information on the presence of cetaceans during ADD 'on' and 'off' treatments; however, the elevated noise levels during ADD 'on' periods compromised the C-PODs ability to detect cetaceans. Dolphins and porpoises were regularly detected on the C-POD during ADD 'off' periods. Land-based observations recorded dolphins during both ADD 'off' and 'on' periods. Seal sightings were between five and six times higher during ADD 'off' periods compared to ADD 'on'. At Crovie in 2014 the evaluation of net modifications continued by examining the effectiveness of a different size of net entrance. Results from the 2014 study suggested that the new design increased salmon landings and reduced fish hesitation in the outer part of the net, an important aspect of reducing depredation from this area. In April 2014 a report on the diet of seals shot at salmon nets from 2005 to 20131 was produced. The most frequently encountered prey was whitefish, sandeels and flatfish. However, an increase in the proportion of seals testing positive for salmonid DNA since the introduction of ADDs and net modifications may suggested that fewer 'transient' seals are now being shot with lethal control becoming more targeted to those consuming salmon.

Kastelein, R. A., Horvers, M., Helder-Hoek, L., Van de Voorde, S., ter Horstede, R., & van der Meij, H. (2017). Behavioral Responses of Harbor Seals (Phoca vitulina) to FaunaGuard Seal Module Sounds at Two Background Noise Levels. *Aquatic Mammals*, 43(4), 347-363 https://doi.org/10.1578/am.43.4.2017.347.

To prevent permanent hearing impairment in seals, SEAMARCO and Van Oord Dredging and Marine Contractors have developed the FaunaGuard Seal Module (PG-SM), which is intended to deter seals to safe distances from high-amplitude impulsive sound sources such as offshore pile driving operations. As a first step towards testing and validating the FG-SM, a study with captive harbor seals is presented. The effects of 16 sounds (200 Hz to 20 kHz, with random inter-sound intervals of 3 to 10 s, mean interval 6.5

s, and duty cycle similar to 60%) produced by the FG-SM on the behavior of two harbor seals were quantified in a pool. The overall behavioral response threshold for these sounds was determined by transmitting the sounds at four sound pressure levels (SPLs) at two background noise levels resembling those occurring during Beaufort Sea States 0 and 4. Behavioral responses ranged from no reaction to increased time spent with the head above the water surface, more frequent hauling, out, and increased numbers of jumps. The seals differed in their responses to the sounds: whereas seal 01 increased the time she spent with her head above the water surface as the SPL increased, seal 02 hauled out more often. Based on "jump" behaviors specifically, the mean received behavioral threshold SPL of the two seals in both background noise conditions appeared to be between 136 and 148 dB re 1 mu Pa (for the effect calculation, 142 dB re 1 mu Pa was used). No effect of the ambient noise level was observed; the level of the ambient noise at both Sea States was too low to mask the sounds of the FG-SM at the average levels the animals were exposed to in the pool. Based on the source level of the FG-SM, the mean behavioral response threshold SPL found in the present study for jumps, and two generic propagation models, the deterring effect range of the PU-SM is estimated to vary between 100 m (propagation model: 20log R) and 500 m (propagation model: 15log R). In most cases in the shallow North Sea, permanent hearing threshold shift (PTS) in harbor seals would be prevented if they moved 100 to 200 in away from the source of pile driving sounds, and, thus, the FG-SM is considered a good mitigation device.

Kastelein, R. A., van der Heul, S., Terhune, J. M., Verboom, W. C., & Triesscheijn, R. J. V. (2006). Deterring effects of 8-45 kHz tone pulses on harbour seals (Phoca vitulina) in a large pool. *Marine Environmental Research*, 62(5), 356-373 https://doi.org/10.1016/j.marenvres.2006.05.004.

The marine aquaculture industry suffers losses due to pinniped attacks which damage net enclosures and fish stocks. Acoustic harassment devices (AHDs) emit loud sounds which are intended to deter pinuipeds from approaching aquaculture enclosures. At present, many AHDs emit sounds in the 8-20 kHz frequency range. It is not known whether sounds of higher frequencies have a deterrent effect on seals. Therefore five captive harbour seals (Phoca vitulina) were subjected to four series of tone pulses together spanning a broad frequency range (8, 16, 32 and 45 kHz). Pulse duration was 250 ms and pulse interval was 5 s. Each of the four sounds was made deterrent by increasing the amplitude. The seals reacted by swimming away from the sounds. The displacement effect of each sound was judged by comparing the animals' surface positions, and number of surfacings, during ten 45 min baseline periods with ten 45 min test periods per frequency (one frequency per day in rotation, 40 sessions in total). The seals were displaced by all four frequencies throughout the 40 trial days. The seals came to the surface more often when the test tones were produced than in the baseline periods. The initial displacement distances did not change over the 40 test days. This suggests that operating AHDs for only short periods will be more effective and less likely to result in habituation by the seals than operating them continuously. The discomfort threshold sound pressure level (SPL) was established for each of the four pulse frequencies. The acoustic discomfort threshold SPL is defined as the boundary SPL between the area that the animals generally occupied during the transmission of the sounds and the area that they generally did not enter during sound transmission. The discomfort threshold SPL may depend on the context.

Schakner, Z. A., Gotz, T., Janik, V. M., & Blumstein, D. T. (2017). Can fear conditioning repel California sea lions from fishing activities? *Animal Conservation*, 20(5), 425-432 https://doi.org/10.1111/acv.12329.

Marine mammal interactions with fisheries create conflicts that can threaten human safety, economic interests and marine mammal survival. A deterrent that capitalizes on learning mechanisms, like fear conditioning, may enhance success while simultaneously balancing welfare concerns and reduce noise pollution. During fear conditioning, individuals learn the cues that precede the dangerous stimuli, and respond by avoiding the painful situations. We tested the efficacy of fear conditioning using acoustic stimuli for reducing California sea lion Zalophus californianus interactions from two fishing contexts in California, USA; bait barges and recreational fishing vessels. We performed conditioning trials on 24 individual sea lions interacting with bait barges. We tested for acquisition of conditioned fear by pairing a neutral tone with a startle stimulus. Avoidance was strongest in response to the startle stimulus alone, but low when paired with a neutral tone. From actively fishing vessels, we tested for fear conditioning by exposing sea lions to a neutral tone followed by a startle pulse, a startle pulse alone or a no sound control. We conducted playbacks from 146 (including 48 no sound control) stops over two summer fishing seasons (2013, 2014). The startle stimulus decreased surfacing frequency, reduced bait foraging and increased surfacing distance from the vessel while the conditioned stimulus only caused a mild reduction in surfacing frequency with no other behavioral change. Exposing animals to a pair of a conditioned stimulus with a startle pulse did not achieve the intended management outcome. Rather, it generated evidence (in two study contexts) of immediate learning that led to the reduction of the unconditioned response. Taken together, our results suggest that for fear conditioning to be applied as a non-lethal deterrent, careful consideration has to be given to individual behavior, the unconditioned/conditioned responses and the overall management goals.

Harris, R. N., Northridge, S. (2016). *Seal Salmon Interactions SSI Annual Report. Seals and Wild Salmon Fisheries.*University of St. Andrews. Retrieved from: http://www.smru.st-andrews.ac.uk/files/2016/10/SSI-annual-report-year-1.pdf

This document reports on progress made on marine mammal research at wild salmon fisheries during 2015. The objectives of the research were: 1) to continue studies into the effectiveness and practical application of Acoustic Deterrent Devices (ADDs) and the modification of salmon nets to mitigate the effects of seals on these fisheries; 2) to collect shot seals for dietary analysis; and 3) to provide support to District Salmon Fishery Boards (DSFBs). Activities related to the first two objectives were primarily focused on two sites in the Moray Firth; Gamrie Bay and Portmahomack. During 2015, trials on the efficacy of an Airmar ADD continued near Crovie, Gamrie Bay, as did the evaluation of net modifications at this fishery by assessing the effectiveness of two different sizes of fish court entrance. Both ADD trials and net modification trials were conducted at the same netting site, with a balanced design of ADD on and off periods across the deployment of the two types of net. Underwater video equipment collected footage from inside the nets for over 1200 hours. The fishery provided salmonid catch and fish damage statistics for each haul of the net for the entire season, and environmental data were collected from a weather station deployed close to the netting site. Analysis of the collated data showed there was a significantly lower probability of detecting a seal during ADD on treatments compared with ADD off treatments. Furthermore, undamaged catch per unit effort was significantly greater when the ADD was on compared with off, but also significantly greater when the wind direction was onshore compared with offshore. Net modification trials enabled the identification of a compromise that excluded seals from the fish court whilst allowing swift passage of fish through the net, reducing depredation opportunities for seals in both chambers of the net. At Gamrie Bay (More Head) and Portmahomack, support was provided for fishery-led ADD deployments. In both instances the deployments were run entirely by the fisheries who also collected and provided catch statistics and anecdotal observations. The

overall perception of the fishers towards the ADD was positive, and was supported by the data which indicated that landings were higher when the ADDs were on and that levels of damage were lower. There was still some evidence however that seals can depredate and damage fish in the nets while ADDs were on. During 2015, a further twelve shot seal carcasses were recovered from bag-net sites. Diet information from these seals shows that lethal control is becoming increasingly selective, with a greater proportion of the recovered seals having consumed salmonids. This may be the result of the increasing use of ADDs and net modifications which are helping to reduce the shooting of transient seals. Presentations have been provided on these studies, along with further support to river fisheries when requested, particularly from the Dee Fishery Board. This project is continuing to produce encouraging results from the use of ADDs and net modifications at mitigating the effects of seals on these fisheries, and is maintaining positive and open relations with both net and river fisheries.

Sepulveda, M., Martinez, T., Oliva, D., Couve, P., Pavez, G., Navarro, C., . . . Luna-Jorquera, G. (2018). Factors affecting the operational interaction between the South American sea lions and the artisan gillnet fishery in Chile. *Fisheries Research*, 201, 147-152 https://doi.org/10.1016/j.fishres.2018.01.014.

The South American sea lion (SASL, Otaria byronia) is one of the species of pinnipeds that display the strongest level of conflict with fishing activities throughout its distribution range. However, little is known about potential temporal and/or spatial variations in the magnitude and effects of SASL and fishing interactions over an entire year and at different sites simultaneously. This study examines the factors that affect the intensity of the operational interaction between SASL and the artisan gillnet fishery in central Chile. Between 2014 and 2016, a total of 145 hauls at three artisan fishing coves were analyzed. South American sea lion interactions were observed in 82 of the 145 (56.6%) hauls analyzed, most frequently at the coves of San Antonio and El Membrillo. From the examined factors, Predation per Unit Effort increased with the number of SASL, however it decreased both during the summer and with greater distance from the nearest SASL colony. Artisan deterrent systems used by fishermen were found to be inefficient in avoiding the interactions with sea lions. Although the intensity of the interaction has increased in recent years (compared with previous studies in the area), the observed Catch per Unit Effort did not differ significantly during fishing trips with or without interaction, indicating that SASL is not a determining factor in the variation of artisan fishery catches. These results demonstrate that the intensity of interactions is not produced at random but rather it is related to factors that obey biological and ecological aspects of the SASL. These factors should be considered for the development of effective actions to prevent, or at least to reduce the interaction between SASL and artisan fisheries.

van den Hoff, J., Kilpatrick, R., & Welsford, D. (2017). Southern elephant seals (Mirounga leonina Linn.) depredate toothfish longlines in the midnight zone. *Plos One*, 12(2), 13 https://doi.org/10.1371/journal.pone.0172396.

Humans have devised fishing technologies that compete with marine predators for fish resources world-wide. One such fishery for the Patagonian toothfish (Dissostichus eleginoides) has developed interactions with a range of predators, some of which are marine mammals capable of diving to extreme depths for extended periods. A deep-sea camera system deployed within a toothfish fishery operating in the Southern Ocean acquired the first-ever video footage of an extreme-diver, the southern elephant seal (Mirounga leonina), depredating catch from longlines set at depths in excess of 1000m. The

interactions recorded were non-lethal, however independent fisheries observer reports confirm elephant seal-longline interactions can be lethal. The seals behaviour of depredating catch at depth during the line soak-period differs to other surface-breathing species and thus presents a unique challenge to mitigate their by-catch. Deployments of deep-sea cameras on exploratory fishing gear prior to licencing and permit approvals would gather valuable information regarding the nature of interactions between deep diving/dwelling marine species and long-line fisheries operating at bathypelagic depths. Furthermore, the positive identification by sex and age class of species interacting with commercial fisheries would assist in formulating management plans and mitigation strategies founded on species-specific life-history strategies.

Section III: Multiple Marine Mammal Order Deterrents

Bisack, K., & Clay, P. M. (2020). Compliance with marine mammal protection: Focus groups reveal factors in commercial fishermen's decisions. *Marine Policy*, 115, 9 https://doi.org/10.1016/j.marpol.2019.103789.

In researching non-compliance with use of an acoustical device (a pinger), required under the Marine Mammal Protection Act (MMPA) to protect harbor porpoise (Phocoena phocoena) in the Northeast U.S., focus group research provided insight on facets of non-compliance not previously considered. This method of group interview can reveal individuals' knowledge and perceptions of the legitimacy of a problem, process and solution along with social (including legitimacy) and economic factors, and cultural norms that can influence compliance or other decisions. In addition, each participant filled out a short survey on topics we already expected to be of interest. We investigate how these factors from the focus group discussion and the survey influence a fisherman's decision to comply with marine mammal regulations. Prior to the focus groups we expected participants to either fully comply or not comply at all with pinger requirements. By using multi-method research, we found that there was a third group that included fishermen that mostly complied but eliminated one mandatory pinger for safety reasons. Using harbor porpoise as a case study, we provide insight on approaches to improve compliance, a key component of a successful management plan designed to reduce marine mammal bycatch in commercial fisheries.

Carretta, J. V., & Barlow, J. (2011). Long-Term Effectiveness, Failure Rates, and "Dinner Bell" Properties of Acoustic Pingers in a Gillnet Fishery. Marine Technology Society Journal, 45(5), 7-19. Retrieved from https://www.ingentaconnect.com/content/mts/mtsj/2011/00000045/00000005/art00002?crawler=true&mimetype=application/pdf.

The long-term effectiveness of acoustic pingers in reducing marine mammal bycatch was assessed for the swordfish and thresher shark drift gillnet fishery in California. Between 1990 and 2009, data on fishing gear, environmental variables, and bycatch were recorded for over 8,000 fishing sets by at-sea fishery observers, including over 4,000 sets outfitted with acoustic pingers between 1996 and 2009. Bycatch rates of cetaceans in sets with >= 30 pingers were nearly 50% lower compared to sets without pingers (p = 1.2 x 10(-6)), though this result is driven largely by common dolphin (Delphinus delphis) bycatch. Beaked whales have not been observed entangled in this fishery since 1995, the last full year of fishing without acoustic pingers. Pinger failure (>= 1 nonfunctioning pingers in a net) was noted in 3.7% of observed sets. In sets where the number of failed pingers was recorded, approximately 18% of deployed pingers had failed. Cetacean bycatch rates were 10 times higher in sets where >= 1 pingers failed versus sets without pinger failure (p = 0.002), though sample sizes for sets with pinger failure were small. No evidence of habituation to pingers by cetaceans was apparent over a 14-year period of use. Bycatch rates of California sea lions in sets with >= 30 gingers were nearly double that of sets without pingers, which prompted us to examine the potential "dinner bell" effects of pingers. Depredation of swordfish catch by California sea lions was not linked to pinger use-the best predictors of depredation were total swordfish catch, month fished, area fished, and nighttime use of deck lights on vessels.

Findlay, C. R., Ripple, H. D., Coomber, F., Froud, K., Harries, O., van Geel, N. C. F., . . . Wilson, B. (2018). Mapping widespread and increasing underwater noise pollution from acoustic deterrent devices. *Marine Pollution Bulletin*, 135, 1042 https://doi.org/10.1016/j.marpolbul.2018.08.042

Acoustic deterrent devices (ADDs) are used in attempts to mitigate pinniped depredation on aquaculture sites through the emission of loud and pervasive noise. This study quantified spatio-temporal changes in underwater ADD noise detections along western Scotland over 11 years. Acoustic point data ('listening events') collected during cetacean line-transect surveys were used to map ADD presence between 2006 and 2016. A total of 19,601 listening events occurred along the Scottish west coast, and ADD presence was recorded during 1371 listening events. Results indicated a steady increase in ADD detections from 2006 (0.05%) to 2016 (6.8%), with the highest number of detections in 2013 (12.6%), as well as substantial geographic expansion. This study demonstrates that ADDs are a significant and chronic source of underwater noise on the Scottish west coast with potential adverse impacts on target (pinniped) and non-target (e.g. cetaceans) species, which requires further study and improved monitoring and regulatory strategies.

Gotz, T., & Janik, V. M. (2015). Target-specific acoustic predator deterrence in the marine environment. *Animal Conservation*, 18(1), 102-111 https://doi.org/10.1111/acv.12141.

Acoustic deterrent devices (ADDs) have often been considered a benign solution to managing pinniped predation. However, ADDs have also been highlighted as a conservation concern since they can inflict large-scale habitat exclusion in toothed whales (odontocetes). We tested a new method that selectively inflicted startle responses in harbour seals (Phoca vitulina) at close ranges to the loudspeaker but not in a non-target species, the harbour porpoise (Phocoena phocoena), by using a frequency range where porpoise hearing was less sensitive than that of phocid seals. The sound exposure consisted of isolated 200ms long, 2-3 octave-band noise pulses with a peak frequency of 1kHz, which were presented at a source level of approximate to 180dB re 1Pa. Field tests were carried out within a 2-month period on a fish farm on the west coast of Scotland where marine mammal behaviour was observed within three distance categories. Seal numbers dropped sharply during sound exposure compared with control observation periods within 250m of the sound source but were unaffected at distances further away from the farm. A Poisson regression model revealed that the number of seal tracks within 250m of the device decreased by approximate to 91% during sound exposure and was primarily influenced by sound exposure with no evidence for a change in the effect of treatment such as habituation, throughout the experiment. In contrast to seals, there was no shift in the number of porpoise groups in each distance category as a result of sound exposure and porpoises were regularly seen close to the device. We also sighted six common minke whales during sound exposure while only one was seen during control periods. Our data demonstrate that the startle method can be used to selectively deter seals without affecting porpoises.

Gotz, T., & Janik, V. M. (2016). Non-lethal management of carnivore predation: long-term tests with a startle reflex-based deterrence system on a fish farm. *Animal Conservation*, 19(3), 212-221 https://doi.org/10.1111/acv.12248.

Carnivore depredation on human livestock is a worldwide problem with few viable solutions. Non-lethal management tools such as acoustic devices show highly varying success and often pose a conservation risk due to noise pollution and habitat degradation. We tested the long-term effectiveness of a

deterrence system which harnesses an autonomous reflex (startle) to selectively inflict avoidance responses in a target species (phocid seals) by emitting band-limited noise pulses with sharp onset times. Seal predation was monitored at a marine salmon farm (test site) over a full production cycle (19 month) with a multitransducer deterrent system deployed for the final year. Predation was also monitored for several months at two control sites and additional short-term tests were carried out at sites which suffered higher predation rates. Generalized linear (mixed) models revealed that sound exposure caused a 91% reduction in lost fish when comparing predation levels within the test site and 97% when comparing the test site against both control sites. Similarly, sound exposure led to a 93% reduction in the number of fish lost due to seal damage at a short-term test site. Visual monitoring of marine mammals around the long-term test site showed that the number of seal surfacings within 100 m from the loudspeakers was only slightly lower during sound exposure. Harbour porpoise and otter distribution around the farm was not affected by sound exposure. By adjusting the frequency composition of startle stimuli, our method has the potential to provide solutions for managing human-wildlife conflicts in terrestrial and marine habitats by selectively deterring target species.

Hamilton, S., & Baker, G. B. (2019). Technical mitigation to reduce marine mammal bycatch and entanglement in commercial fishing gear: lessons learnt and future directions. *Reviews in Fish Biology and Fisheries*, 29(2), 223-247 https://doi.org/10.1007/s11160-019-09550-6.

Fisheries bycatch is one of the biggest threats to marine mammal populations. A literature review was undertaken to provide a comprehensive assessment and synopsis of gear modifications and technical devices to reduce marine mammal bycatch in commercial trawl, purseseine, longline, gillnet and pot/trap fisheries. Successfully implemented mitigation measures include acoustic deterrent devices (pingers) which reduced the bycatch of some small cetacean species in gillnets, appropriately designed exclusion devices which reduced pinniped bycatch in some trawl fisheries, and various pot/trap guard designs that reduced marine mammal entrapment. However, substantial development and research of mitigation options is required to address the bycatch of a range of species in many fisheries. No reliably effective technical solutions to reduce small cetacean bycatch in trawl nets are available, although loud pingers have shown potential. There are currently no technical options that effectively reduce marine mammal interactions in longline fisheries, although development of catch and hook protection devices is promising. Solutions are also needed for species, particularly pinnipeds and small cetaceans, that are not deterred by pingers and continue to be caught in static gillnets. Large whale entanglements in static gear, particularly buoy lines for pots/traps, needs urgent attention although there is encouraging research on rope-less pot/trap systems and identification of rope colours that are more detectable to whale species. Future mitigation development and deployment requires rigorous scientific testing to determine if significant bycatch reduction has been achieved, as well as consideration of potentially conflicting mitigation outcomes if multiple species are impacted by a fishery.

Lepper, P. A., Gordon, J., Booth, C., Theobald, P., Robinson, S. P., Northridge, S., & Wang, L. (2014). *Establishing the sensitivity of cetaceans and seals to acoustic deterrent devices in Scotland*. Retrieved from http://www.snh.org.uk/pdfs/publications/commissioned_reports/517.pdf

The aim of the project is to provide the capability to establish potential risks to cetaceans and seals from the use of acoustic deterrent devices in Scottish waters. Acoustic Deterrent Devices (ADDs) are often used on aquaculture sites to reduce predation of seals on fish stocks using acoustic emissions. These acoustic emissions may also have secondary effects on marine mammals (including non-target species)

ranging from physical injury, behavioural response and reduced sensory capability. The main findings were: - Modelling of propagation losses show dependence on water depth, sediment type and seabed slope. - In relation to determining the sensitivity of cetaceans and seals to noise, the use of dual impact criteria based on zero-peak Sound Pressure Level (SPL) and broadband Sound Exposure Level (SEL) metrics have grown. - The dominant frequency components of ADD systems range from 2-40 kHz. - A generalised sensitivity model has been developed to allow the prediction of received level and ranges to exceed given SEL thresholds for various ADD models. Variant parameters include number of devices, duty cycle and the influencing factors of local environments, sediment types, the functional hearing capabilities of seals and cetaceans and simplistic assumptions about animal movements. - Broadband noise was broken into third octave bands. Propagation losses for a range of environments were then calculated for each frequency band. - Seabed slope was found to impact the propagation of noise. An upslope was found to generally have lower propagation loss when compared to a flat seabed and so additional functions were added to the model to accommodate this. Down slopes were generally found to have higher propagation loss. - Poor understanding of the extent to which behavioural change and avoidance are dependent on received levels of sound means that the propagation modelling completed in this project can contribute little (at present) to understanding the extent of habitat exclusion around fish farms with operating ADDs. - Modelling of the exposure time to exceed injury criteria for seals and porpoises at given ranges from active ADDs suggest that there is a credible risk of exceeding injury criteria for both seals and porpoises. Thus the risk that ADDs at Scottish aquaculture site is causing permanent hearing damage to marine mammals cannot be discounted.

Martin, G. R., & Crawford, R. (2015). Reducing bycatch in gillnets: A sensory ecology perspective. *Global Ecology and Conservation*, 3, 28-50 https://doi.org/10.1016/j.gecco.2014.11.004.

Sensory capacities and perceptual challenges faced by gillnet bycatch taxa result from fundamental physiological limits on vision and constraints arising within underwater environments. To reduce bycatch in birds, sea turtles, pinnipeds and blue-water fishes, individuals must be alerted to the presence of nets using visual cues. Cetaceans will benefit but they also require warning with cues detected through echolocation. Characteristics of a visual warning stimulus must accommodate the restricted visual capacities of bycatch species and the need to maintain vision in a dark adapted state when foraging. These requirements can be provided by a single type of visual warning stimulus: panels containing a pattern of low spatial frequency and high internal contrast. These are likely to be detectable across a range of underwater light environments by all bycatch prone taxa, but are unlikely to reduce the catch of target fish species. Such panels should also be readily detectable by cetaceans using echolocation. Use of sound signals to warn about the presence of gillnets is not recommended because of the poor sound localisation abilities of bycatch taxa, cetaceans excepted. These warning panels should be effective as a mitigation measure for all bycatch species, relatively easy to deploy and of low cost.

Moore, J. E., Wallace, B. R., Lewison, R. L., Zydelis, R., Cox, T. M., & Crowder, L. B. (2009). A review of marine mammal, sea turtle and seabird bycatch in USA fisheries and the role of policy in shaping management. *Marine Policy*, 33(3), 435-451 https://doi.org/10.1016/j.marpol.2008.09.003.

This paper reviews the available information (observer programs, estimates, statutes, regulations) for bycatch of marine mammals, sea turtles, and seabirds in fisheries of the United States, Goals of the review were to evaluate the state of knowledge of bycatch and the role of existing protective legislation in shaping bycatch management for different taxa. Pressing issues are identified, as well as knowledge

gaps and policy limitations that hinder multi-species bycatch reduction. The USA has made important progress toward reducing bycatch in its fisheries, but the efficacy of its management has been limited somewhat by a focus on taxon- and fishery-specific regulation and the lack of consistent mandate across taxa for taking a cumulative perspective on bycatch. Applying consistent criteria across taxa for setting bycatch limits (e.g., extending the approach used for marine mammals to sea turtles and seabirds) would be the first step in a multi-species approach to bycatch reduction. A population-based multi-species multi-gear approach to bycatch would help identify priority areas where resources are needed most and can be used most effectively.

Morizur, Y., Hassani, S., Le Niliot, P., Gamblin, C., & Pezeril, S. (2010). *Note on the recent French studies on by catch and pingers in the English Channel (AC17/Doc.4-16 (P))*: Ifremer, Plouzane (France). Retrieved from https://archimer.ifremer.fr/doc/00020/13132/

The English Channel comprised the ICES areras VIIe and VIId which are more or less a part of the North Sea area as delimitated by Ascobans. Two studies (Pingiroise and FilManCet) were conduced in that area. Filmancet study comprises two different areas: North Brittany and Nord Pas de Calais. The main objectives are to quantify accidental catches of marine mammals in set nets and identify solutions to limit them. Pingiroise is a study dedicated to the set net fishery in the Iroise area at the west of Brittany. The three objectives of that study in a marine protected area was to make comparative trials with pingers, to determine the bycatch in set net fishery operating inside and around the Marine protected area and to estimate the abundance and the distribution of cetaceans. Harbour porpoises, pilot whales and common dolphin are sometimes incidentally caught in set nets; The by-catch rate for harbour porpoise is very low compared to other areas (Celtic Seas or North sea). The low bycatch rate calculated in the fisheries in Brittany is probably due to a lower abundance of the harbour porpoise in the sampled area: 0.132 ind/km super(2) in Iroise Sea (Pingiroise study) compared to 0.408 ind/km2 in the Celtic Sea (SCANSII). An other explanation could be linked to the fishing process, especially for spider crab netting. The pinger systems as mandated by the EC 812/2004 regulation are very expensive, not always reliable and their utilization involved fishermen security concerns. The less expensive system seems the DDD02 placed at each end of the net but the system has the greatest exclusion area. These experiments raise the problems of practicability and certification of acoustic deterrent systems as some trades have a poor technical reliability. Furthermore, first results of the FilManCet study show that it is necessary to assess the impacts of fishing gear with an area and seasonal approach in order to find the more adapted solution to limit them.

Read, A. J. (2008). The looming crisis: Interactions between marine mammals and fisheries. *Journal of Mammalogy*, 89(3), 541-548 https://doi.org/10.1644/07-mamm-s-315r1.1

Direct fisheries interactions pose a serious threat to the conservation of many populations and some species of marine mammals. The most acute problem is bycatch, unintended mortality in fishing gear, although this can transition into unregulated harvest under some circumstances. A growing issue in some fisheries is depredation, in which marine mammals remove captured fish from nets or lines. Depredation reduces the value of catch and may lead to a greater risk of entanglement and the potential for retaliatory measures taken by fishermen. The conservation threat caused by direct fisheries interactions is most dire for small populations of cetaceans and dugongs. Immediate action is needed to assess the magnitude of bycatch, particularly in many areas of Africa and Asia where little work has been conducted. New and innovative solutions to this problem are required that take account of the

socioeconomic conditions experienced by fishermen and allow for efficient transfer of mitigation technology to fisheries of the developing world.

Read, A. J., Drinker, P., & Northridge, S. (2006). Bycatch of Marine Mammals in U.S. and Global Fisheries. *Conservation Biology*, 20(1), 163-169 https://doi.org/10.1111/j.1523-1739.2006.00338.x

Fisheries bycatch poses a significant threat to many populations of marine mammals, but there are few published estimates of the magnitude of these catches. We estimated marine mammal bycatch in U.S. fisheries front 1990 to 1999 with data taken from the stock assessment reports required by the U.S. Marine Mammal Protection Act. The mean annual bycatch of marine mammals during this period was 6215 ± 448 (SE). Bycatch of cetaceans and pinnipeds occurred in similar numbers. Most cetacean (84%) and pinniped (98%) bycatch occurred in gill-net fisheries. Marine mammal bycatch declined significantly over the decade, primarily because of a reduction in the bycatch of cetaceans. Total marine mammal bycatch was significantly lower after the implementation of take reduction measures in the latter half of the decade. We derived a crude first estimate of marine mammal bycatch in the world's fisheries by expanding U.S. bycatch with data on fleet composition from the Food and Agriculture Organization. The global bycatch of marine mammals is in the hundreds of thousands. Bycatch is likely to have significant demographic effects on many populations of marine mammals. Better data are urgently needed to fully understand the impact of these interactions.

Rios, N., Drakulic, M., Paradinas, I., Milliou, A., & Cox, R. (2017). Occurrence and impact of interactions between small-scale fisheries and predators, with focus on Mediterranean monk seals (Monachus monachus Hermann 1779), around Lipsi Island complex, Aegean Sea, Greece. *Fisheries Research*, 187, 1-10 https://doi.org/10.1016/j.fishres.2016.10.013.

Antagonistic interaction between Mediterranean marine mammals, including the endangered monk seal (Monachus monachus), and small-scale fisheries is a growing problem in the Aegean Sea. Effective management measures are needed to ensure both the survival of the monk seal population, and its coexistence with the small-scale fisheries. In this study, data from 371 fishing journeys by 8 different boats was collected between March and November 2014. Evidence of depredation by monk seals was recorded in 19.1% of fishing journeys, by cetaceans in 5%, and by other predators in 16.5%. Analysis of landings data showed that gear and depth were the variables mOst likely to influence the occurrence of depredation. There was a significant decrease in the catch per unit effort (CPUE) of fotir of the nine targeted fish species when depredation by monk seals occurred. The total cost of monk seal depredation was estimated to be 21.33% of the mean annual income of fishermen in the Aegean Sea. We discuss how the implementation of marine protected areas and the use of specific fishing gear could reduce the frequency of interactions, and thus mitigate the loss experienced by the fisheries as well as contribute to the conservation of an endangered species.

Scales, K. L., Hazen, E. L., Jacox, M. G., Castruccio, F., Maxwell, S. M., Lewison, R. L., & Bograd, S. J. (2018). Fisheries bycatch risk to marine megafauna is intensified in Lagrangian coherent structures. *Proceedings of the National Academy of Sciences of the United States of America*, 115(28), 7362-7367 https://doi.org/10.1073/pnas.1801270115

Incidental catch of nontarget species (bycatch) is a major barrier to ecological and economic sustainability in marine capture fisheries. Key to mitigating bycatch is an understanding of the habitat requirements of target and nontarget species and the influence of heterogeneity and variability in the dynamic marine environment. While patterns of overlap among marine capture fisheries and habitats of a taxonomically diverse range of marine vertebrates have been reported, a mechanistic understanding of the real-time physical drivers of bycatch events is lacking. Moving from describing patterns toward understanding processes, we apply a Lagrangian analysis to a high-resolution ocean model output to elucidate the fundamental mechanisms that drive fisheries interactions. We find that the likelihood of marine megafauna bycatch is intensified in attracting Lagrangian coherent structures associated with submesoscale and mesoscale filaments, fronts, and eddies. These results highlight how the real-time tracking of dynamic structures in the oceans can support fisheries sustainability and advance ecosystem-based management.

Schakner, Z. A., & Blumstein, D. T. (2013). Behavioral biology of marine mammal deterrents: A review and prospectus. *Biological Conservation*, 167, 380-389 https://doi.org/10.1016/j.biocon.2013.08.024.

Marine mammal depredation of fisheries is a concern from a scientific, management, and conservation perspective. This conflict has prompted the development of non-lethal deterrents, a management technique that uses aversive stimuli to elicit avoidance. Animals are expected to be sensitive to cues of danger to avoid sources of mortality. Deterrents capitalize on behavioral mechanisms such as threat detection, assessment and learning. A deterrent must create enough risk, or cost, that it overcomes the heightened foraging benefits of depredation. Theoretically, effective deterrence relies on altering the relative costs and benefits to the individual depredator by creating a perceived risk associated with human resources. Here we discuss the underlying behavioral basis of how deterrents generate avoidance. We review deterrents applied to marine mammals to mitigate conflict with fisheries and suggest that fear conditioning could be useful in this context. This is discussed in the context of some potential management concerns of application of non-lethal deterrents in the wild.

Tixier, P., Lea, M. A., Hindell, M. A., Welsford, D., Maze, C., Gourguet, S., & Arnould, J. P. Y. (2021). When large marine predators feed on fisheries catches: Global patterns of the depredation conflict and directions for coexistence. *Fish and Fisheries*, 22(1), 31-53 https://doi.org/10.1111/faf.12504.

The sustainable mitigation of human-wildlife conflicts has become a major societal and environmental challenge globally. Among these conflicts, large marine predators feeding on fisheries catches, a behaviour termed "depredation," has emerged concomitantly with the expansion of the world's fisheries. Depredation poses threats to both the socio-economic viability of fisheries and species conservation, stressing the need for mitigation. This review synthesizes the extent and socio-ecological impacts of depredation by sharks and marine mammals across the world, and the various approaches used to minimize it. Depredation was reported in 214 fisheries between 1979 and 2019 (70% post-2000) and affected fleets from 44 countries, in all sectors (commercial, artisanal and recreational), and in all major fishing techniques (nets, traps and hook-and-lines). A total of 68 predator species were involved in depredation (20 odontocetes, 21 pinnipeds and 27 sharks), and most (73%) were subject to either by-catch and/or retaliatory killing from fishers when interacting with gear. Impacts on fishers were primarily associated with catch losses and gear damage but often lacked assessments. Deterrence was a major mitigation approach but also the least effective. Gear modifications or behavioural adaptation by

fishers were more promising. This review highlights the need for improved monitoring, and interdisciplinary and integrated research to quantify the determinants and impacts of depredation in the socio-ecological dimension. More importantly, as the conflict is likely to escalate, efforts directed towards changing perceptions and integrating knowledge through adaptive co-management are raised as key directions towards coexistence between fisheries and large marine predators.

Žydelis, R., Wallace, B. P., Gilman, E. L., & Werner, T. B. (2009). Conservation of Marine Megafauna through Minimization of Fisheries Bycatch. *Conservation Biology*, 23(3), 608-616 https://doi.org/10.1111/j.1523-1739.2009.01172.x

Many populations of marine megafauna, including seabirds, sea turtles, marine mammals, and elasmobranchs, have declined in recent decades due largely to anthropogenic mortality. To successfully conserve these long-lived animals, efforts must be prioritized according to feasibility and the degree to which they address threats with the highest relative impacts on population dynamics. Recently, Wilcox and Donlan (2007, Frontiers in Ecology and the Environment) and Donlan and Wilcox (2008, Biological Invasions) proposed a conservation strategy of "compensatory mitigation" in which fishing industries offset bycatch of seabirds and sea turtles by funding eradication of invasive mammalian predators from the terrestrial reproductive sites of these marine animals. Although this is a creative and conceptually compelling approach, we find it flawed as a conservation tool because it has narrow applicability among marine megafauna, it does not address the most pervasive threats to marine megafauna, and it is logistically and financially infeasible. Invasive predator eradication does not adequately offset the most pressing threat to most marine megafauna populations—fisheries bycatch. For seabird populations, fisheries bycatch and invasive predators infrequently are overlapping threats. Invasive predators have limited population-level impacts on sea turtles and marine mammals and no impacts on elasmobranchs, all of which are threatened by bycatch. Implementing compensatory mitigation in marine fisheries is unrealistic due to inadequate monitoring, control, and surveillance in the majority of fleets. Therefore, offsetting fisheries bycatch with eradication of invasive predators would be less likely to reverse population declines than reducing bycatch. We recommend that efforts to mitigate bycatch in marine capture fisheries should address multiple threats to sensitive bycatch species groups, but these efforts should first institute proven bycatch avoidance and reduction methods before considering compensatory mitigation.