During the development and implementation of spatial closures it also vital to apply:

- the ecosystem approach to fisheries (EAF)
- the Voluntary Guidelines for Securing Sustainable Small-Scale Fisheries in the Context of Food Security and Poverty Eradication (FAO, 2015),
- the Voluntary Guidelines on the Responsible Governance of Tenure of Land, Fisheries and Forests in the Context of National Food Security (FAO, 2012), and where appropriate,
- the FAO Technical Guidelines for Responsible Fisheries. No. 4. Fisheries management, Suppl. 4. Marine protected areas and fisheries (FAO, 2011a).

3.2 Acoustic alerting or deterrent devices

Acoustic alerting or deterrent devices (primarily pingers), can serve as an effective bycatch reduction measure in certain situations. In some fisheries, data from field research as well as those from fisheries observer monitoring marine mammal bycatch have shown that pingers can exclude certain species of marine mammal within the range of the sound field (Kraus *et al.*, 1997). However, an opposite effect can also occur, whereby some marine mammals become attracted to the devices, while others can suffer serious injury from the use of deterrents with high sound outputs (Dawson *et al.*, 2013).

Acoustic deterrents consist of a range of devices that either emit sounds, using electrical or mechanical means, or acoustically reflect those emitted by echolocating cetaceans. These devices may be deployed on or near fishing gear and include categories referred to as pingers, acoustic harassment devices (including seal-scarer devices), and acoustic alerting devices. Their intended use is to enhance detection of fishing gear by those cetaceans that echolocate for prey detection and other reasons: to do so, they may create an alert or unappealing sound that causes animals to avoid the sound source, or associate it with an obstacle to avoid. The units that actively produce sound span a range of power outputs that are measured in decibels (dB), audio frequency (Hz), sound duration, and the periodicity of sound emission –its duty cycle, which may be regular, random, or triggered by sounds such as those emitted by echolocating cetaceans.

Separating these devices into different categories is somewhat arbitrary, although it helps in understanding of how different units are designed to function.

Pingers tend to be relatively small, cylindrical units roughly the size of a soda can. They produce sound at different frequencies, although generally in the 3–70 kHz range, and lower than 180 dB (re 1 pPa @ 1 m). Some devices operate at random frequencies, such as the Dolphin Deterrence Devices produced by STM Products, which has a range of 5–500 kHz. Pingers are most commonly used to avoid the bycatch of small cetaceans in gillnets, harbour porpoise in particular.

Acoustic Harassment Devices (*AHDs*) are intended to deter animals from approaching fish traps or aquaculture cages and sea pens, using higher sound outputs that typically inflict pain or discomfort. Devices of 180 dB or higher are sometimes classified as AHDs to distinguish them from pingers (Long *et al.*, 2015). Seal-scarers are a type of AHD intended to keep seals and sea lions from preying on fish raised in aquaculture cages and sea pens.

Passive acoustic devices use air-filled or metallic components incorporated into fishing gear to increase their detection by echolocating cetaceans. The logic for using this approach is that marine mammals will avoid gear that they can detect acoustically.

Predator sounds mainly include the playback of killer whale calls, with the aim of prompting marine mammal prey species to flee or avoid the area the sound is being emitted from.

The most critical consideration is whether or not these deterrents elicit a behavioural response in a particular species such that bycatch is prevented or substantially reduced. Evidence shows that acoustic deterrents do not necessarily elicit a behavioural response that reduces bycatch for every marine mammal species. In controlled experiments comparing nets with and without pingers, and multi-year monitoring of bycatch levels, pingers have been shown to be effective in reducing bycatch or causing area avoidance for at least the following 7 species (although possibly as many as 12):

- harbour porpoise
- striped dolphin (*Stenella coeruleoalba*)
- franciscana dolphin (*Pontoporia blainvillei*)
- several beaked whales (Ziphiidae family) – Cuvier's, Hubb's, Stejneger's and Baird's beaked whale (see reviews in Dawson *et al.*, 2013; FAO, 2018).

A pinger trial involving Burmeister's porpoise (*Phocoena spinipinnis*) suggested that pingers might also help reduce bycatch of this species (Clay *et al.*, 2019), yet acoustic deterrents appear ineffective with dugong (*Dugong dugon*) (Hodgson *et al.*, 2007). Similarly, while some North Atlantic right whales (Nowacek, 2004) showed a behavioural response to high frequency sound exposure – just as humpback whales (*Megaptera novaeangliae*) did to pinger sounds (Lien, 1992; Harcourt *et al.*, 2014; Pirotta *et al.*, 2016) – there is no evidence that the type of response will help prevent entanglements in fishing gear. Some species, such as bottlenose dolphin (*Tursiops truncatus*), are attracted to the sound of pingers, presumably because they associate the sound with easy-to-catch fish caught in gillnets (Cox *et al.*, 2004; Leeney *et al.*, 2007). As such, there is no indication that pingers deter bottlenose dolphins from entering trawl nets (Allen *et al.*, 2014). The interactions of both California (*Zalophus californianus*) and South American (*Otaria flavescens*) sea lions with gillnets appear to increase when acoustic deterrents are used; this has been termed the "dinner bell effect" (Barlow and Cameron, 2003; Bordino *et al.*, 2002; Carretta and Barlow, 2011). Increasing the frequency to make pingers less audible to pinnipeds may eliminate this undesirable outcome. A trial in Argentina using a pinger with a higher frequency of 70 kHz, instead of 10 kHz, showed a similar reduction in franciscana dolphin bycatch without increasing the attraction of sea lions (Bordino *et al*., 2004).

Playbacks of predator calls have shown some potential for deterring particular marine mammal species (Werner *et al.*, 2015), but they can also affect the behaviour of target fish, leading to a reduced target catch (Doksæter *et al.*, 2009).

Passive acoustic devices with enhanced reflecting materials have shown to be effective in some studies but not others (Trippel *et al.*, 2003; Bordino *et al.*, 2013), and would be limited to echolocating marine mammals.

Given the insufficient evidence of a bycatch prevention effect with louder devices (AHDs), predator playbacks or passive acoustic deterrents, it can be concluded that of all the devices available pingers are the most appropriate ones to use where they are effective.

In addition to species-specific differences, the effectiveness of acoustic deterrents is also dependent upon their experimental design, the fishery in which they are tested, the sound they create, the ambient noise level, gear type and fishing practices. Tests of the devices should therefore be carried out in local fisheries before widespread implementation. Monitoring the use of pingers is also critical to ensure that bycatch reduction targets are being met, even when they have been shown to reduce bycatch experimentally, as results reported from experiments often show greater reductions than when implemented in a fishery (Dawson *et al.*, 2013).

Introducing unnatural sounds into the environment is far from straightforward. Many variables influence how they are propagated, as well as how the sounds are received by animals, which in turn affects the degree of bycatch deterrence. A partial list of physical factors that influence sound propagation includes depth, bathymetry, temperature, turbulence, density of particulate matter, and refraction (Erbe *et al.*, 2018). Furthermore, acoustic deterrents vary in the strength of their signal and the directionality of sound waves. Pingers also have a range of duty cycles (i.e. the periodicity and duration of signal output, including how it is activated). The spacing of multiple units and whether or not they are all in working condition can also affect how effective they may act as a deterrent, with different sound frequencies attenuating at different distances from the source. Some guidelines for deploying pingers are provided in Box 2.

The costs of purchasing pingers and maintaining them can be a significant barrier to their use. Gillnets require several pingers along a net string at varying intervals, meaning that fishers must acquire and maintain numerous units. Based on anecdotal reports of injury when hauling solid objects, some models may also have safety issues, while some units can rupture when the battery becomes exposed to water after deployment in deep waters.

Table 2. Pros and cons of using acoustic deterrents in gillnet fisheries

Pros	Cons	Marine mammal species
Have demonstrated reduction in marine mammal bycatch for some species, and in some cases over many fishing seasons Do not tend to affect target catch Supported by a range of studies involving field trials, behavioural responses, and fisheries monitoring	Do not work for all species Effect may be nullified or reduced depending on where they are deployed In a few cases, species or populations may habituate, in which case the deterrent effect no longer works without adjustments (e.g. change in sound frequency)	Pinger trials report bycatch reduction or increased area avoidance for at least 7 (but possibly up to 12) species: harbour porpoise, striped dolphin, franciscana dolphin, and several beaked whales (Ziphiidae) – Cuvier's, Hubb's, Stejneger's, and Baird's beaked whale

Pros	Cons	Marine mammal species
Produced by a number of manufacturers with different models, some of which continue to receive upgrades to battery life, LED indicators that confirm proper function, modified duty cycles, and other features Help reduce depredation by pinnipeds with increased sound frequency	May overly ensonify an environment and exclude some marine mammals from critical habitats when used at a large scale Requires units that are functioning properly and spaced correctly to avoid the risk of increased bycatch Some units emit high power outputs that can cause hearing impairment and other adverse health effects to marine mammals When implemented, the level of bycatch reduction generally tends to be lower than that recorded in scientific trials; the use of acoustic deterrents is therefore a less suitable option for highly endangered species When implemented, the level of bycatch reduction generally tends to be lower than that recorded in scientific trials; the use of acoustic deterrents is therefore a less suitable option for highly endangered species There are reports that pingers can pose risks to fishermen, as devices have been known to explode during hauling, owing to increased gear weight At certain frequencies, pingers may lead to increased depredation and bycatch through the “dinner bell effect”	Possibly effective for Burmeister’s porpoise They do not appear effective for dugong, North Atlantic right whales, humpback whales and, in many instances, for bottlenose dolphins In both California and South America, sea lion interactions with fishing nets appear to increase when acoustic deterrents are used; however, this can be managed by increasing pinger frequency

Box 2
Guidelines for deploying pingers

1. Pingers should be used only when there is evidence for an area displacement effect, or the population is large enough and has adequate observer coverage for evaluating the long-term effects of using pingers.
2. The type of gear should be considered and fully assessed.
3. A minimum number of pingers is required to ensure adequate coverage of the sound field for producing the bycatch deterrence effect, which can be informed by guidelines from other fisheries but especially from local field trials.
4. Review the range of acoustic deterrents and select the one with sound characteristics and duty cycle that best meets the focal species, fishery and environment.
5. Engage fishers, gear engineers, marine mammologists, fisheries managers and other stakeholders in evaluating and deploying pingers.
6. Calculate an acceptable bycatch level or reduction effect and ensure adequate monitoring and enforcement of pingers in the fishery.
7. Identify any unintended consequences on other species and the environment exposed to the sound source.
8. Maintain the operating condition of pingers (e.g. sufficient battery charge, no leakage).

The use of acoustic deterrents without a carefully considered plan of deployment and appropriate monitoring can cause more harm than good. The improper or unmanaged uses of acoustic deterrents can create an assumption that the marine mammal bycatch problem has been solved when this is not the case, with potentially negative consequences for fishers, marine mammals and the environment. These may include habitat exclusion (if the units are deployed in a dense fishery that is also a major critical habitat for marine mammals), excessive sonification (saturating an area with an introduced source of sound), habituation, physical harm (such as long-term hearing impairment when using AHDs), and operational safety concerns. Encouragingly, habituation has not been reported from fisheries on the east- (multi-species gillnet) and west-coast (driftnet) fisheries of the United States of America, which have long-term monitoring data (FAO, 2018). Nevertheless, all of the concerns mentioned above need to be considered prior to implementing acoustic deterrents in a fishery. The pros and cons of using acoustic deterrents in gillnet (and possible trawl) fisheries are presented in Table 2.

In summary, there is much evidence to support the contention that pingers are one of the best technical measures available to mitigate bycatch of some species, predominantly in gillnet fisheries. However, many factors can influence their effectiveness, suitability and/or practicality as a deterrent. They therefore require scientific evaluation within a fishery prior to their widespread implementation, and their use should be subject to ongoing monitoring.

3.3 Modifications to fishing gear

Fishing gear may be modified to reduce interactions with marine mammals or to facilitate animals to self-release when they become hooked or entrapped. There are many physical modifications, some of which have been tested and others are used but not adequately studied.

Excluder devices

Trawl fisheries that are prone to marine mammal bycatch should consider using excluder devices with escape openings (holes) through which these animals can exit the net after becoming entrapped.

Marine mammal excluder devices follow the same principle as turtle excluder devices (TEDs). An excluder device usually consists of a grid that allows the target catch to pass through to the codend but blocks the marine mammal from doing so because of its size. The grid is placed inside the net, before the codend, at an angle, so the mammal is directed towards an escape opening (Dotson *et al.*, 2010; Baker *et al.*, 2014). The escape opening is placed on the top or bottom of the net, but the top placement has proven the most effective for pinnipeds, perhaps because of their need to swim upwards for air (CCAMLR, 2017; Hamilton and Baker, 2015a; Tilzey *et al.*, 2006). However, in order for such devices to be effective, the escape responses and other behaviours of marine mammal species must be known, as well as the size and shape differences between target and bycatch animals. Similarly, towing speed, depth, gear characteristics, vessel size and the space available for hauling and stowing gear must be taken into account for each fishery when designing or implementing a marine mammal excluder device (Baker *et al.*, 2014; Hamilton and Baker, 2019).