UN environment programme

CMS

CONVENTION ON MIGRATORY SPECIES

UNEP/CMS/COP15/Inf.25.1.1
11 December 2025
Original: English

15th MEETING OF THE CONFERENCE OF THE PARTIES
Campo Grande, Brazil, 23 to 29 March 2026
Agenda Item 25.1.1

A REVIEW OF TECHNICAL AND OPERATIONAL MEASURES TO MITIGATE BYCATCH OF MARINE TURTLES IN COMMERCIAL FISHERIES

(Prepared by the Secretariat and the COP-appointed Councillor for Bycatch)

Summary:

This document contains a review of turtle bycatch mitigation measures, developed in accordance with Decision 14.33 (b).

A review of technical and operational measures to mitigate bycatch of marine turtles in commercial fisheries

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Keywords: Turtles, Bycatch, Mitigation, Commercial Fisheries, At-Vessel Mortality, Post-Release Mortality

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Executive Summary

Marine turtles are incidentally killed in a range of fisheries throughout the world and levels of global sea turtle bycatch have been estimated at between 85,000 and 250,000 individuals annually, mainly by pelagic fisheries targeting tuna and billfish. Turtles are killed when they become hooked and drown in longline fisheries, become entangled in netting used in trawl, purse seine or gillnet fisheries, or suffer stress and trauma during retrieval of fishing gear when animals are captured. This bycatch in active fishing gear is one of the biggest threats to marine turtle populations. As these species are long-lived with high adult survival and low breeding productivity, anthropogenic activities that increase mortality levels, such as fisheries bycatch, can have significant, long-term population impacts.

This review assesses technical and operational bycatch mitigation measures across four major gear types – trawl, purse seine, set and gillnet, and longline fisheries – drawing from peer-reviewed literature and grey literature.

Trawl fisheries pose a major threat to sea turtles due to their low selectivity, particularly in tropical shrimp fisheries. Turtle Excluder Devices (TEDs) are among the most effective mitigation tools, reducing turtle bycatch by up to 97% in some regions. TED effectiveness depends on correct design and installation, with critical elements being escape opening size and bar spacing. Hard grids are more effective than flexible grids in excluding turtles, however flexible grids offer advantages for smaller vessels. Long-term success requires industry collaboration and compliance, together with training, monitoring and enforcement.

Purse seine fisheries have relatively low turtle bycatch mortality, with most individuals released alive and unharmed. Risks increase with sets on drifting Fish Aggregating Devices (FADs), which can entangle turtles, and recent mitigation efforts have focused on improving FAD design, promoting the use of biodegradable materials and non-entangling constructions. Avoiding the encirclement of turtles during fishing, and crew training on safe handling techniques, enhance post-capture survival.

Gillnet fisheries, especially in small-scale coastal operations, are among the most significant sources of turtle bycatch, with high mortality rates reported. Net illumination using LEDs (green, violet, UV) is one of the most effective and tested mitigation measures with bycatch reductions of up to 93.3% reported in some studies, without significantly affecting target catch. However, efficacy varies across regions and fisheries, and economic viability may impact adoption. Additional visual strategies (e.g., predator models, high-contrast panels) show potential but require further field validation. Adoption remains low due to limited field testing, economic concerns and lack of regulatory frameworks.

Pelagic longline fisheries are a major source of sea turtle bycatch, particularly for loggerhead and leatherback turtles. The use of large circle hooks and fish rather than squid baits are the most effective known strategies, reducing sea turtle catch rates by 55-90%. Capture probabilities are lowest when both measures are used together. Circle hooks significantly reduce deep hooking and increase post-release survival. Demersal longline fisheries, however, currently lack any effective mitigation measures for sea turtles.

Trailing gear attached to hooks which cannot be safely removed from sea turtles should be cut as close to the hook as possible to decrease post-release mortality.

Sea turtles are also at risk of gas embolisms and decompression sickness, resulting from rapid, forced ascents during gear hauling, especially in trawl and gillnet fisheries. Mortality has been recorded even at relatively shallow depths of 19-37m. However, mortality risk increases with greater depth, haul duration, and faster ascent speeds, with mortality ranging from 20–50% depending on severity and

handling. Mitigation measures include the use of TEDs to limit retention in trawls, reducing haul speeds and gear soak times.

Overall, the review confirms that effective turtle bycatch reduction is fishery-specific, as has been found for mitigation of bycatch of other non-target species including seabirds, marine mammals and sharks. Measures that are highly effective in one region or gear type may be ineffective or impractical elsewhere. Selecting measures to minimize marine turtle bycatch should ensure their implementation does not increase bycatch of other non-target species such as seabirds, marine mammals or sharks. Tailored, evidence-based approaches, combined with stakeholder collaboration, enforcement and training, are essential for successful implementation and long-term conservation outcomes.

This mitigation review forms one of two companion reports prepared under CMS Decision 14.33 and Activity #8 of the Work Programme 2024-2028 of the IOSEA Marine Turtle MOU. The other report summarises findings from the Sea Turtle Bycatch Questionnaire circulated to stakeholders in the Indian Ocean - South-East Asia region, documenting regional patterns of bycatch and current uptake of mitigation measures. The two reports provide complementary technical and contextual information for Parties.

Recommendations

Parties are encouraged to:

Adopt fishery-specific mitigation strategies that recognize that effective turtle bycatch mitigation measures vary by fishery type and region. Management efforts should tailor approaches accordingly, based on the latest evidence.

Use operational and technical mitigation measures for all fisheries where turtle bycatch is problematic.

Develop and research best practice mitigation options to reduce marine turtle bycatch in fisheries deploying demersal longline gear.

Engage with the fishing industry to ensure design, development and effective implementation of practical solutions, which are essential to creating good outcomes. For mitigation to be considered effective, a significant reduction in bycatch mortality needs to be demonstrated, together with maintenance of target catch quality and quantity, while ensuring no negative effects on bycatch rates of other protected species.

Adopt an adaptive approach to managing turtle bycatch in all fisheries. Operational characteristics of most fisheries are dynamic, and updating and improving knowledge of the biological and behavioural characteristics of target and bycatch species, including temporal and spatial overlap of bycatch species with fishing activities, should be continually evaluated to assess efficacy of bycatch mitigation solutions, and change these as appropriate.

Use systematic monitoring and reporting as crucial tools for assessing and improving mitigation efforts for turtles in all fisheries.

Include species- and fisheries-specific testing with adequate scientific rigour, and a quantitative target to enable efficacy assessment to determine mitigation efficacy.

Introduction

Bycatch, the capture of non-target species in fisheries, represents a principal problem in fisheries management and poses a particular threat for long-lived animals with slow population growth rates, such as sea turtles (Cox et al., 2007). Marine turtles are incidentally killed in a range of fisheries throughout the world and levels of global sea turtle bycatch have been estimated at between 85,000 and 250,000 individuals annually, with most mortality occurring mainly in pelagic fisheries targeting tuna and billfish (Baez et al., 2024). Turtles are killed when they become hooked and drown in longline fisheries, become entangled in trawls and purse seine nets, or suffer stress and trauma during retrieval of fishing gear when animals are captured (Clarke et al., 2014). This bycatch in active fishing gear is one of the biggest threats to marine turtle populations. As these species are long-lived with high adult survival and low breeding productivity, anthropogenic activities that increase mortality levels, such as fisheries bycatch, can have significant, long-term population impacts (Griffiths et al., 2024).

Sea turtles can be accidentally captured in a wide variety of fisheries and fishing gear, ranging from small scale to industrial fleets, and including pelagic longlines, purse seines, driftnets, trawls, gillnets, and pound nets (Coelho et al., 2015, Pilcher et al., 2025). Several mitigation measures have been proposed and implemented, including management measures such as time/area closures (Childerhouse et al., 2013), fishery bans, and limitation of fishing effort; and technical measures such as turtle excluding devices (Brewer et al., 2006), deterrents, and the use of circle hooks (Coelho et al., 2015). For longline fisheries specifically, circle hooks have shown promise as an efficient strategy to reduce sea turtle bycatch, particularly when associated with changes to fish bait (Coelho et al., 2015).

Research on fisheries bycatch and development of solutions has been conducted for over 40 years on a range of organisms, with reviews available for seabirds (Løkkeborg, 2011), marine mammals (Leaper and Calderan, 2018; Hamilton and Baker 2019), and sharks (Drynan et al., 2025; Brewer et al., 2006; Swimmer et al., 2017). For turtles, in 2009 the FAO developed guidelines to reduce sea turtle mortality in a range of fishing operations (Gilman and Bianchi, 2009). Since then, mitigation reviews have focused on particular aspects of mitigation or gear type (Casale, 2011; Echwikhi et al., 2011; Gilman & Huang, 2017; Reinhardt et al., 2017; Gilman et al., 2020; Yan et al., 2024); sensory biology (Lucas & Berggren, 2023); geographical areas (Rodrigues et al., 2024); certain species (Echwikhi et al., 2010, 2012); or particular fisheries (Echwikhi et al., 2010, 2012; Chaboud & Vendeville, 2011; Huang, 2011; Hall and Roman, 2013), but have not comprehensively assessed approaches across a range of gear types, fisheries and species.

Building on the FAO 2009 Guidelines (Gilman and Bianchi, 2009), we aim to provide an overview on the state of development of technical and operational mitigation measures that can reduce the impacts of turtle bycatch in fishing gears in commercial fisheries. While some of the measures reviewed may be effective in artisanal/small-scale fisheries, and indeed may have evolved from such sources, a comprehensive review of mitigation approaches in artisanal gear was outside the scope of this project.

Method and Scope

This review applied a structured approach to gather and analyse literature on technical and operational measures for reducing marine turtle bycatch, and particularly gear-based mitigation measures applied directly in fishing operations. The main fishing gear types considered include trawl, purse seine, gillnet and longline. While the review focussed on technical measures, widely adopted operational bycatch reduction strategies such as spatial and temporal closures were included in the review, particularly when these were instrumental to the use of technical migration measures.

Searches were conducted across academic databases such as Google Scholar, Research Gate and Scopus. Search terms included *turtle + bycatch + mitigation*, *turtle + bycatch*, *turtle + mitigation + measures*, and similar phrases. In addition to systematic database searches, relevant literature was identified through citation tracking, recommendations from colleagues, and review of grey literature such as reports, presentations, regulatory documents, and unpublished data. All identified sources were screened for relevance. In total, 255 documents were reviewed, of which 68 met the inclusion criteria and were analysed further. Documents were not considered if they did not contain empirical evidence relating to a technical turtle bycatch mitigation measure, or only provided background information on subjects such as species biology, sensory systems, and fishing techniques. However, some of these documents were used as background for the review.

Technical measures are presented on a fishing gear basis (trawl, purse seine, longline, gillnet and pot/trap) with the exception of gears or approaches which are applicable to different fishing gears and are therefore more effectively dealt with in a collated section. Fisheries not considered to be high risk to marine turtle species, such as trolling and jigging, and mitigation of mortalities from lost, discarded or abandoned gear (i.e. ghost fishing) were not included. For each measure, the scientific evidence for mitigation effectiveness, caveats or uncertainties in the methods or results, research requirements and, where possible, recommendations for effective operational implementation were identified. To structure the evaluation of mitigation techniques and assess their effectiveness, we followed Miller et al. (2025) and ranked studies into High, Medium, or Low quality:

- Low, if based on limited anecdotal observations or a theoretical study;
- Medium, if based on either extensive anecdotal observations or limited empirical data; or
- High, if based on extensive empirical data.

We also considered the impact of the mitigation measure on target catch-per-unit-effort (CPUE). To be considered successful and attractive for uptake, any bycatch mitigation measure must demonstrate a reduction or elimination of turtle bycatch; and have little or no impact on target CPUE. We have based these findings on significant results from studies that have tested the mitigation measure in commercial fisheries, noting that some studies are experimentally-based, or did not investigate the impact on target CPUE. We have also provided an indication on the feasibility of applying mitigation measures to commercial fishing gears, following the approach taken by Hamilton and Baker (2019) and Drynan et al. (2025). This has been based on the practicalities of implementation that have been expressed by the authors in the studies reviewed, including logistics, cost, maintenance requirements, safety, and environmental impacts.

This framework accounts for the quality of all studies (‘overall research quality’), how effective mitigation was (regardless of the quality of the study) (‘mitigation effectiveness score’), and any harm caused to either turtles or other species by application of the measure (‘harm score’). An overall assessment is developed on a six-point scale: (1) Beneficial; (2) Likely to be beneficial; (3) Trade-offs between benefits and harms; (4) Unknown effectiveness; (5) Unlikely to be beneficial; or (6) Likely to be ineffective or harmful.

To provide an overall recommendation for each measure assessed, we took into consideration the quality of the studies identified in our literature review, as well as the impact on target catch and feasibility of application in commercial gears, using a simple ‘traffic light’ indicator, modified from the approach taken by Drynan et al. (2025). Table 1 outlines the thresholds applied. This allows the reader to determine whether a bycatch mitigation measure could be suitable for their particular situation. For example, a measure may be supported by good quality research, be effective at reducing turtle bycatch, have no impact on target CPUE, be feasible to implement, but may cause harm to other non-

target species. Depending on the conservation or management priorities within the fishery, this may preclude implementation.

This review focuses exclusively on the seven species of marine turtles (green *Chelonia mydas*, hawksbill *Eretmochelys imbricata*, flatback *Natator depressus*, loggerhead *Caretta caretta*, Kemp's ridley *Lepidochelys kempii*, olive ridley *Lepidochelys olivacea*, and leatherback *Dermochelys coriacea*) and does not consider freshwater turtles and inland fisheries.

A synopsis of the technical mitigation assessment is provided below. A summary of the overall rating approach for each bycatch mitigation measure assessed is provided in Table 1. Where appropriate, a subjective evaluation of the economic viability, practicality, impact on target catch and the ease of compliance monitoring for each technical measure is provided in Tables 2 and 3. However, although this provides a general overview, due to fishery-specific characteristics (e.g., size of target species, operational elements), the evaluation responses are not definitive, and results may differ across fisheries.

Table 1: Overall rating approach for each bycatch mitigation measure assessed in this review.

Overall Rating	Overall research quality	Turtle mitigation Effectiveness	Harm Likelihood of impacting other non-target taxa	Impact on Target Catch	Feasibility
✓	**High** At least 2 studies with extensive empirical data	**Highly effective**	**Low**	**Increase/No Effect**	**Feasible** Already in use, products already available and in use
?	**Medium** Limited empirical data or extensive anecdotal observations	**Medium**	**Unknown**	**Unknown or Inconsistent/ Contrasting**	**Possible, but some issues** (e.g., not fully tested) **or Unknown**
✗	**Low** Limited observations or theoretical study	**Low**	**High**	**Decrease**	**Unfeasible** high cost, impractical, complex deployment

Results of reviewed technical mitigation measures

a. Principles of sensory perception relevant to mitigation in multiple types of fishing gear

Visual Cues

Recent bycatch reduction technologies use sensory cues to alert non-target species to the presence of fishing gear. A review and further analysis of the sensory ecology of turtle-gillnet interactions to understand the factors which predispose animals to become entangled nets, particularly vision, shows that turtles probably have a trichromatic colour vision system mediated by cones and a standard rod system (Martin & Crawford, 2015). Turtles have coloured oil droplets which act as spectral filters within individual cone receptors and serve to sharpen the spectral sensitivity of individual receptors, strongly suggesting the presence of colour vision which correlates with the tendency of most hard-shelled species to spend their time in the brightly lit surface layers of the water column (Martin & Crawford, 2015). However, leatherbacks turtles have a narrower spectral range and probably reduced colour vision (Martin & Crawford, 2015). Anatomical and optical results of laboratory testing indicate that sea turtles can see in the red spectrum and UV waveband, while pelagic fishes cannot (Fritsches et al., 2000), suggesting red and UV light as possible 'communication channels' to reduce fisheries interaction with sea turtles. However, Martin and Crawford (2015) note that UV sensitive retinal photopigments have not been identified in turtles and they conclude that the visible spectrum of green sea turtles does not extend into the UV.

Sea turtles are visual predators and the potential for interactions should increase when the bait becomes more visible either through brighter ambient light, attachment of attractive light sticks, ambient colour contrasts or turtle colour preferences (Clarke et al., 2014, and references therein). Contemporary studies have seen knowledge of turtle vision used to alert them to the presence of fishing gear. These have included deploying light emitting diodes (LEDs) on gillnets (Wang et al., 2010, 2013; Ortiz et al., 2016; Lucchetti et al., 2019; Bielli et al., 2020; Darquea et al., 2020; Jančič et al., 2020; Gautama et al., 2022; Snape et al. 2024), the use of chemical or electrical light sticks on gillnets and longline gear (Wang et al., 2010; Gilman & Huang, 2017), the addition of visual models such as shark shapes to gillnets to deter turtles (Wang et al., 2010; Bostwick et al., 2014), and suggested integration of high contrast visual panels into gillnets (Martin & Crawford, 2015). Review and evaluation of these techniques, where applied, will be discussed in detail under gillnet and longline gear types.

Auditory and Chemical Cues

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✗	✗	?	?	?

Overall assessment:	Unknown mitigation effectiveness
Gear types tested:	None tested, concept evaluation only of deterrent potential
Applicability for commercial use:	Requires further assessment but increased vigilance and escape behaviour observed in response to playback
Regions/countries where tested:	Not tested
Impact on target catch:	Not assessed
Number of studies assessed:	8 (6 tested in commercial gears, 2 modelling/meta-analysis studies)

Pingers, acoustic deterrent devices with relatively low acoustic outputs (<160 dB), were developed to reduce high levels of small cetacean bycatch in gillnets (Hamilton and Baker, 2019) to deter marine mammals from trawl nets or to reduce pinniped or odontocete interactions and depredation around aquaculture, longline or pot/trap operations, and have received mixed responses following extensive testing. However, with marine turtles, only a few studies have investigated the effect of auditory sensory approaches in fisheries, and the use of this technology has not proven effective for the mitigation of turtle bycatch.

A review of the sensory biology of sea turtles, indicates that auditory deterrents are unlikely to be effective in reducing bycatch of these animals. Both sea turtles and pelagic fishes are generalists in low-frequency hearing (200–700 Hz), and past attempts to use intense underwater acoustic signals have resulted in only temporary avoidance behaviours, followed by rapid habituation. Moreover, such sound levels risk disturbing non-target species and potentially causing temporary or even permanent threshold shifts in their hearing, undermining their selectivity and practicality (Southwood et al., 2008). Recent research has shown that green turtles produce underwater vocalizations and behaviourally respond to them. In field playback experiments, natural conspecific sounds, classified as “Rumble” and “Squeak”, elicited strong behavioural reactions in wild foraging turtles, including increased vigilance and escape. Rumble sounds triggered responses in 94% of tested individuals, while squeak sounds led to reactions in 61%. In response to playback of the ‘rumble call’ animals reacted strongly when within 200 metres of the sound source. Habituation to repeated exposures was observed, with responses diminishing after the third playback (Chevallier et al., 2024). The response of sea turtles to vocalizations opens new perspectives to reduce their bycatch but requires further research.

Similarly, chemical cues were found to be of limited use as deterrents. Although both sea turtles and pelagic fishes use chemical signals in prey detection and foraging initiation, experimental treatments of bait with aversive compounds did not deter consumption in either group (Southwood et al., 2008).

Increasing Setting Depth – Hooks and Nets

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✓	✓	?	?

Overall assessment:	Likely to be beneficial
Gear types tested:	Longline (most studies), gillnet, trawl
Applicability for commercial use:	Suitable when targeting tunas, reduced applicability with swordfish
Regions/countries where tested:	Canada, Costa Rica, USA, northern Pacific Ocean, Atlantic Ocean
Impact on target catch:	Variable, no impact but limited studies, reduced CPUE in swordfish fisheries
Number of studies assessed:	19 (15 tested in commercial gears; 3 meta-analyses, 1 physiological)

Sea turtles have to organise their underwater activities around the necessity to return to the surface to breathe and have developed extraordinary diving capacities that allow them to exploit oceanic and neritic habitats (Hochscheid, 2014). While depths exceeding 1200m have been recorded for leatherback turtles, usual dive depths are much shallower, with preferences varying by species: loggerheads in the Pacific were found to spend 40% of their time at the surface and only rarely (10%) were found below 40m (Parker et al., 2005); olive ridley turtles prefer deeper habitats than loggerheads but are still usually found above 40m; and the average depth of a leatherback dive is 62m although they have also been found to spend the majority of their time near the surface (Eckert et al., 1989). Depth preferences appear to vary by season as well as behavioural phase (Clarke et al., 2014 and references therein) and water temperature (Hochscheid, 2014).

Sea turtle bycatch is closely associated with setting depth of gear, with multiple studies indicating that shallower gear poses a higher risk (Ito and Machado, 2001; Watson & Bigelow, 2014; Swimmer et al., 2017). A general consensus is that the majority of turtle interactions occur within lines set shallower than 40 metres (Kiyota et al., 2004; Brazner & McMillan, 2008; Sales et al., 2010), and certainly in the upper 100m of the water column (Polovina et al., 2003, 2004; Swimmer et al., 2006). Furthermore, very shallow hook placements (<25 m) and high hook-to-float ratios were linked to increased turtle interaction risk (Swimmer et al., 2017). To address this, mid-water float systems have been proposed to standardize deeper hook deployment (Kiyota et al., 2004).

In general, deep-set hooks catch fewer sea turtles but those that are hooked are more likely to drown because they cannot reach the surface to breathe (Clarke et al., 2014). Therefore, while it may be possible to reduce interactions through hook depth, depending on the species of concern some sources recommend fishing all hooks below 40m whereas others recommend 100m as a minimum depth (Beverly et al., 2009; FAO, 2010; Gilman, 2011; all cited in Clarke et al., 2014). This would have minimal impact on target catch in tuna fisheries (Watson & Bigelow, 2014) but see reductions in catch of other commercial species (Beverly et al., 2009). We would encourage setting below 100m where possible, acknowledging that setting depth is fishery-specific and potential economic loss needs to be balanced against conservation gains (Beverly et al., 2009; Watson and Bigelow, 2014).

Deeper setting to avoid the upper water column where turtles are most abundant is an intuitive and effective measure of minimising capture of turtles in trawl and gillnet fisheries too (Gilman & Bianchi, 2009) although little research has been done in these gear types.

b. Technical Measures

Trawl

Due to their low selectivity, trawl fisheries are responsible for large numbers of sea turtle mortalities worldwide (Wakefield et al., 2017). Trawl gear poses a significant threat, as turtles become trapped in nets and drown, raising concerns about its impact on marine wildlife (Epperly, 2003). Industrial shrimp trawling in tropical waters is particularly problematic, contributing to 27% of global discards, including not only turtles but other species such as sharks, dugongs, sea snakes, sea horses and corals (Eayrs, 2005). Commonly employed turtle bycatch mitigation measures involve physical modifications to the nets, releasing non-target species. These measures are referred to as bycatch reduction devices (BRDs) (Eayrs, 2005; Wakefield et al., 2017) or more specifically turtle excluder devices (TEDs) (Robins et al., 2002; Epperly, 2003; Cox et al., 2007; Haas, 2011; Lucchetti et al., 2016, 2019).

Turtle Excluder Devices – TEDs or BRDs

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✓	✓	✓	✓

Overall assessment:	Beneficial
Gear types tested:	Trawl
Applicability for commercial use:	Modification to existing gears, many designs/configurations already in use
Regions/countries where tested:	Australia, Gulf of Mexico, Mauritania, Mediterranean Sea, USA, Western Indian Ocean
Impact on target catch:	None (with reduced damage to target catch in prawn/shrimp fisheries) when efficiently configured
Number of studies assessed:	8 (all tested in commercial gears)

TEDs are grids sewn into trawl nets that selectively direct large organisms such as turtles to an opening in the net while allowing the target species to pass through into the cod end (Robins et al., 2002; Epperly, 2003; Cox et al., 2007; Haas, 2011). The escape opening is usually placed in the top of the net. TEDs can be made in "hard" designs, utilizing rigid materials like aluminium or steel, or "flexible" using softer or flexible materials like high-strength plastic or mesh materials (Eayrs, 2005; Lucchetti et al., 2019).

Most experimental research has shown that use of TEDs significantly reduces turtle bycatch. In Australia's Northern Prawn Fishery, TEDs reduced annual turtle bycatch from approximately 5,000 to under 200 individuals, a ~97% reduction (Robins et al., 2002) and in another Australian fishery reductions of up to 95% were observed (Cox et al., 2007). In two Mediterranean trials, TED-equipped

trawls caught no turtles, while control nets caught 10 (Lucchetti et al., 2019) and 16 (Baldi et al., 2025), respectively. Comparative studies have also reported reductions of up to 97% in U.S.A. trials, though real-world effectiveness varied with compliance and gear design.

Studies in the United States, Australia and the Mediterranean have shown that the effectiveness of TEDs depends on multiple factors (Cox et al., 2007; Haas, 2011; Lucchetti et al., 2019). Proper design and compliance, including the spacing of the bars and the escape opening size are important considerations. A wider spacing of the bars improves target species retention but potentially allows smaller turtles to pass through. Adult turtles may not be able to exit the net through a TED if the escape opening is too small, reducing overall effectiveness (Epperly, 2003; Cox et al., 2007; Haas et al., 2011). Increasing the escape opening size allows larger turtles to escape while allowing the smaller target species to be caught, however, widening bar space of the grid has minimal impact on reducing bycatch (Haas et al., 2011).

Comparing materials, hard and flexible grids both reduce sea turtle bycatch without effecting commercial catch (Lucchetti et al., 2016, 2019; Wakefield et al., 2017). Well-designed TEDs do not affect trawl technical performances (horizontal and vertical net opening and door spread) or increase required towing force and hence fuel consumption (Lucchetti et al., 2016). Overall, hard grids are more effective than soft grids due to their superior exclusion efficiency, durability, and regulatory compliance, as they provide a more reliable barrier against turtle entanglement (Eayrs, 2005). However, flexible grids allow easier net retrieval and storage, improving fishing efficiency, particularly on smaller vessels (Lucchetti et al., 2019).

In one study the use of a soft grid TED reduced turtle bycatch in a coastal Mediterranean demersal multispecies fisheries (Lucchetti et al., 2019) while commercial catch and size of major target species was unaffected. Underwater video camera recordings documented that fish caught in the net swam through the grid and easily reached the cod-end, missing the TED escape opening. However, in another multispecies study in the Adriatic some vessels experienced important reductions in commercial catch when using TEDs with mean catch loss of 19.7% directly observed in TEDs (Baldi et al., 2025). Consistent with previous studies in the Adriatic Sea, results showed high variability among hauls, likely influenced by environmental factors and vessel characteristics.

For TEDs to achieve their full potential, long-standing collaboration between the fishing industry, scientists, and resource managers is essential, together with education and outreach, pre- and postimplementation monitoring, enforcement, and incentives for adoption. Compliance issues and inadequate monitoring also need to be considered for TEDs to be considered as successful mitigation measures (Cox et al., 2007). In addition, TEDs need proper installation and maintenance, as issues such as clogging, incorrect fitting, or intentional disabling can reduce effectiveness (Robins et al. 2002, Eayrs 2005) and thus reduce industry confidence in adoption of the technology.

Purse Seine

Fish Aggregating Devices – Construction and Deployment of Non-entangling FADs

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✓	✓	✓	✓

Overall assessment:	Beneficial
Gear types tested:	Purse Seine
Applicability for commercial use:	Non-entangling FADs use already required by some Tuna RFMOs
Regions/countries where tested:	Western Indian Ocean, Pacific Ocean
Impact on target catch:	None (Moreno et al., 2018, Restrepo et al., 2023)
Number of studies assessed:	5 (4 tested in commercial gears; 1 meta-analyses)

Purse seine fishing involves encircling fish schools with a large net, often using drifting fish aggregating devices (FADs) to attract tuna and increase catch efficiency. FADs provide structure in an open ocean environment, creating habitat for fish and other marine wildlife including turtles. Fish are attracted to FADs for various reasons, including to feed on prey species or as reference points for schooling. These are categorized into anchored FADs, mainly used in small-scale coastal fisheries, and drifting FADs (or dFADs), which are used by industrial purse seine fleets in the open ocean (Dagorn et al., 2012).

Sea turtles are infrequently caught by purse seine fisheries, and the majority are released alive with minimal handling. Across ocean regions, an estimated 5 to 200 turtles are caught annually, with over 90% successfully released alive (Gilman, 2011; Dagorn et al., 2012; Pons et al., 2023). However, unobserved mortality due to entanglement in the submerged netting of FADs remains a significant concern, as such events are rarely included in bycatch estimates (Dagorn et al., 2012).

Drifting FADs are associated with higher bycatch of juvenile bigeye tuna and overfished shark species, but lower sea turtle bycatch, particularly for leatherback turtles. In contrast, free school sets, which target unassociated tuna schools, result in significantly higher leatherback bycatch, approximately 90% greater than in FAD sets, as well as increased catches of billfishes and threatened manta and devil rays. Log sets, targeting natural floating debris, exhibit the highest turtle bycatch rates overall (Gilman et al., 2016). However, dFADs pose a risk of ghost fishing and entanglement, especially in large-mesh designs. Traditional FADs with large mesh panels have been known to entangle turtles, but monitoring is difficult since these events often go unobserved (Pons et al., 2023).

To reduce sea turtle bycatch in tropical tuna purse seine fisheries, a combination of technical modifications and monitoring strategies is recommended. Technical measures include the use of non-entangling FADs, which eliminate mesh components or restrict mesh size to below 2.5 cm to prevent entanglement. FADs using biodegradable components in the submerged structure are as effective as non-biodegradable FADs aggregating tuna and non-tuna species (Moreno et al., 2018). Only FADs constructed without netting can completely eliminate the unintentional entanglement of turtles,

sharks and finfish species and be considered totally non-entangling FADs (Restrepo et al., 2023). These FADs are constructed with soft or solid materials such as canvas, ropes, or other non-netting structures, reducing the risk of turtle entrapment (Dagorn et al., 2012; Pons et al., 2023). Biodegradable materials, including bamboo and cotton, are also encouraged to reduce ghost fishing and long-term marine debris (Pons et al., 2023). In addition, limiting purse seine sets on floating objects, especially logs and FADs with high entanglement risk, and avoiding encirclement of visibly present turtles during fishing operations can reduce turtle encounters (Gilman, 2011, 2016).

Longline

Pelagic longline fishing is a globally widespread method used primarily to target high value pelagic species such as swordfish (*Xiphias gladius*), bigeye (*Thunnus obesus*), yellowfin (*Thunnus albacares*), and albacore tuna (*Thunnus alalunga*) (Yan et al., 2024). The fishing technique involves deploying long mainlines from which numerous baited hooks are suspended via shorter gangions or branchlines at regular intervals (Piovano et al., 2009; Fernandez-Carvalho et al., 2015). These branchlines hang vertically from the mainline, which floats in the water column, often drifting with ocean currents (Santos et al., 2023). Depending on the target species, the gear is set at different depths: deep-set gear is used mainly for tuna, while shallow-set gear is used to target swordfish (Beverly et al., 2009; Swimmer et al., 2017).

Compared to trawling or gillnetting, pelagic longlining is considered relatively selective in terms of species and size of targeted catch (Sales et al., 2010). Nonetheless, its extensive use across tropical and temperate oceans raises considerable ecological concerns, particularly due to high bycatch rates of non-target species, including sharks, seabirds, and especially sea turtles (Fernandez-Carvalho et al., 2015; Yan et al., 2024).

Sea turtles are among the most vulnerable non-target species affected by pelagic longline fisheries. Several species, including the loggerhead, leatherback, olive ridley, and green turtle, frequently interact with longline gear due to overlapping depth ranges with hook deployment zones (Yan et al., 2024). Shallow-set longlines (typically set at <60 m) used for swordfish are particularly problematic, exhibiting significantly higher turtle bycatch rates than deep-set tuna targeting lines (Swimmer et al., 2017).

Turtles are usually hooked while attempting to consume the bait, often resulting in hooks embedded in the mouth, throat, or digestive tract (Kiyota et al., 2004; Echwikhi et al., 2010, 2011). In some cases, turtles may become foul hooked or entangled, not necessarily due to feeding but perhaps from curiosity (Echwikhi et al., 2011). While some turtles escape or are released alive, the stress and injuries sustained during capture frequently result in delayed mortality (Swimmer et al., 2013; Santos et al., 2023).

Post release survival is highly variable and largely uncertain. Mortality risk increases with the severity of injuries, particularly deep hooking, entanglement, and the presence of retained gear (Ngyuen et al., 2022). Turtles that appear viable at the time of release may die within weeks due to internal injuries, starvation, or drowning (Ngyuen et al., 2022). This is especially critical for shallow-set fisheries, where most loggerhead turtles are initially alive upon capture but may not survive long after release (Swimmer et al., 2013).

Most of the efforts to reduce turtle bycatch in longline fisheries have involved use of alternative hook types to facilitate hook removal and haul mortality and use of alternatives to squid baits, including the use of artificial bait.

Circle Hooks

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✓	✗	✓	✓

Overall assessment:	Trade-off between benefit to turtles and negative impact on sharks.
Gear types tested:	Pelagic longline
Applicability for commercial use:	Circle hooks are commercially available and widely used
Regions/countries where tested:	Australia, Canada, Mediterranean Sea, USA, Western Indian Ocean, Pacific Ocean, Atlantic Ocean
Impact on target catch:	Variable, but generally no effect or increase. Decrease reported in two studies (Drynan et al., 2025)
Number of studies assessed:	>10 tested in commercial gears; 2 meta-analyses;

A circle hook is a fishing hook manufactured so that the point is turned perpendicularly back to the hook shank to form a generally circular, or oval, shape, and provide an alternative to J or tuna hooks. In comparison, a J-hook is less rounded and its point is oriented parallel to the shank. Circle hooks tend to cause less injury to captured animals because they typically lodge in the lower jaw or jaw hinge as opposed to hooking in more damaging areas, such as the oesophagus, respiratory organs, or roof of the mouth (Serafy et al., 2012). These shape and point-to-shank orientation differences, combined with other aspects of hook size, configuration, and mode of deployment, can change catch rates of both target and bycatch species, while also affecting the condition of hooked animals on haulback. In many, but not all cases, circle hook use has been associated with improved condition of captured target and non-target individuals (Cooke & Suski, 2004; Watson et al., 2005; Kerstetter & Graves, 2006; Diaz, 2008; Epperley et al., 2012; all cited in Serafy et al., 2012).

Most of the evidence suggests that circle hooks, particularly those which have large minimum widths and are large relative to mouth size of susceptible sea turtles (e.g., size 18/0), can reduce hooking interactions and the probability of deep hook ingestion (Serafy et al., 2012; Clarke et al., 2014; WCPFC-SPC, 2016). Multiple studies have reported that J-hooks are more likely than circle hooks to cause internal or gut hooking as well as jaw hooking when compared to circle hooks (Drynan et al., 2025). Use of circle hooks is now mandatory in many jurisdictions managing pelagic longline fisheries.

Most studies report minimal impact on target catch when circle hooks are used, and in many cases an increase in target CPUE. While the change from J-hooks to circle hooks appears to be effective in reducing at-vessel mortality of both turtles and target species, there is a trade-off against conservation benefits for turtles and apparent higher CPUE for multiple species of sharks on circle hooks, although this increase is not universal. Regardless of the variety of responses to hook type reported, there is general agreement that circle hooks appear to increase CPUE for sharks, be they a target species or bycatch (Drynan et al., 2025).

Depending on target species, some fisheries opt to use smaller circle hooks. Due to their shape, circle hooks of any size tend to shift the number of hookings to the mouth, as opposed to being swallowed.

This has been deemed a better option for improving post-release mortality. However, it is unclear if the anatomy and physiology of marine turtles is fully considered (Parga, 2012; M. Parga in ICES, 2025). The oesophagus of turtles has a strong, thick muscular wall covered with queratinous papillae, making it rather resistant to injuries and infections: unless the hook lodges close to the heart or large blood vessels, and as long as handling practices are correct, a marine turtle can survive with several hooks lodged here, something commonly seen in the Mediterranean (M. Parga in ICES, 2025). In contrast, the mouth has several rather sensitive and fragile structures which should be carefully considered, such as the glottis (entrance to the respiratory system), the tongue (easily broken and infected) and the mandibular joint. A hook lodged in the mouth, therefore, is only beneficial if fishers remove it safely, including all trailing line: lines left trailing are by far the most dangerous part of the gear (Parga, 2012). Due to their shape, circle hooks are much more difficult to remove than J-hooks, causing further damage due to their large barb. If smaller hooks (<size 16/0) are desirable for target specificity, use of small J-hooks may be more beneficial than similar sized circle hooks because of ease of safe removal. Removal of hooks is expected to benefit sea turtles mainly if there is proper training and equipment available for the safe removal of hooks.

Information is lacking about the post-release mortality of captured turtles in relation to hook location and associated lesions, which is essential information to adequately determine gear impacts (Parga, 2012) and hence selection of appropriate management options to minimise bycatch. Circle hooks are best considered in the context of an integrated bycatch reduction or fisheries management strategy that includes and/or considers a variety of voluntary and regulatory tools and options. Factors such as hook size, fishing style, fish feeding mode, and mouth morphology all appear to affect the effectiveness of circle hooks. For these reasons, it is difficult to promote the adoption of the use of circle hooks as a panacea for all fish and fisheries. Instead, Cooke & Suski (2004) recommended that management agencies focus on recommending circle hooks only for instances for which appropriate scientific data exist.

Change Bait Type from Squid to Fish

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✓	✗	?	✓

Overall assessment:	Trade-offs between benefits to turtles and negative impact on sharks in some fisheries (Drynan et al., 2025 and references therein)
Gear types tested:	Pelagic longline
Applicability for commercial use:	Both squid and fish baits already in use
Regions/countries where tested:	Northeast, Northwest, & South Atlantic Ocean, Northwest Pacific Ocean, Gulf of Mexico, Hawaii
Impact on target catch:	Variable, but generally no effect (Echwikhi et al., 2011) or increase (Drynan et al., 2025)
Number of studies assessed:	8 (6 tested in commercial gears; 1 meta-analysis; 1 captive trial)

The type of bait used in pelagic longline fisheries has a significant influence on sea turtle bycatch rates, hooking location, and associated post-capture outcomes. Across studies, fish bait, particularly mackerel, has consistently been associated with reduced sea turtle bycatch compared to squid bait (Kiyota et al., 2004; Brazner & McMillan, 2008; Echwikhi et al., 2010; Echwikhi et al., 2011; Gilman, 2011; Swimmer et al. 2017; Gilman et al., 2020).

Fish bait appears to reduce bycatch primarily by altering feeding mechanics. Turtles often nibble or tear fish bait rather than swallow it whole, leading to superficial or mouth hooking instead of deep ingestion. This behaviour reduces the likelihood of severe internal injury and improves post-release survival (Kiyota et al., 2004; Gilman, 2011; Gilman et al., 2020). In contrast, squid bait tends to be swallowed whole, increasing the probability of gut hooking and retained gear (Kiyota et al., 2004; Gilman et al., 2020). Meta-analytical evidence supports these findings. A comprehensive analysis across 21 study-specific effect sizes showed that fish bait reduced turtle catch risk by approximately 60%. This pattern was particularly evident for loggerhead and leatherback turtles. Additionally, blue shark bycatch risk was reduced by 34% with fish bait, although this bait type may simultaneously reduce catch rates of economically important target species like tunas and billfishes (Gilman et al., 2020).

In individual studies, mackerel bait consistently outperformed squid in reducing turtle captures. For example, mackerel bait led to fewer turtle captures in North Atlantic longline operations (Brazner & McMillan, 2008). In captive trials, loggerhead turtles swallowed squid whole but tore or bit fish bait, confirming behavioural differences that explain field outcomes (Kiyota et al., 2004). A field study in the Gulf of Gabès, Tunisia, compared mackerel and stingray bait and found that stingray bait showed the lowest turtle bycatch (0.217 turtles/1000 hooks vs. 1.173 with mackerel), while also increasing catch rates of target species. However, direct mortality remained high (20.7%), and delayed mortality from internal hooking was not assessed (Echwikhi et al., 2010). A subsequent review confirmed the general effectiveness of fish bait over squid across multiple regions, without reducing target catch (Echwikhi et al., 2011).

Drynan et al. (2025) noted that some studies reported, as a side effect of changing bait, an increased catch rate of sharks, indicating a preference for fish bait in some species (e.g., Foster et al., 2012; Amorim et al., 2015; Gilman et al., 2016; Kumar et al., 2016). However, results varied among and within species and adopting a change in bait type appeared to be cost neutral (Drynan et al., 2025). Changing bait type can reduce catch rates of turtles, but local trials should be conducted before wider implementation in a fishery where detrimental impact on elasmobranchs is likely, with bait type determined by the priority order of the species to be mitigated and balanced with the impact on target catch (Drynan et al., 2025).

Circle Hooks and Fish Baits in Combination

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✓	✗	✓	✓

Overall assessment:	Trade-offs between benefits to turtles and harm (increased capture) of sharks in some fisheries
Gear types tested:	Pelagic longline
Applicability for commercial use:	Both squid and fish baits, and J and circle hooks already in use
Regions/countries where tested:	Atlantic Ocean, Pacific Ocean, Western Indian Ocean
Impact on target catch:	None
Number of studies assessed:	11 (9 tested in commercial gears; 2 meta-analyses)

The joint modification of hook shape and bait type has been shown to be particularly effective in reducing sea turtle bycatch. Numerous studies, field trials, regulatory assessments, and meta-analyses confirm that using wide circle hooks in combination with fish bait significantly reduces both bycatch rates and the likelihood of deep hooking, across a range of turtle species and fisheries while maintaining target CPUE (Watson et al., 2005; Gilman et al., 2007; Gilman, 2011; Santos et al., 2013, 2023; Coelho et al., 2015; Gilman, 2016; Gilman & Huang, 2017; Swimmer et al., 2017; Ochi et al., 2024; Yan et al., 2024).

In the Tropical Northeast Atlantic, a comparative trial showed that leatherback turtle bycatch was reduced by 55% using non-offset circle hooks, with bait type having no statistically significant effect. For hardshell turtles such as loggerhead, olive ridley, and Kemp's ridley, bycatch was reduced by up to 59% with circle hooks and 55% with mackerel bait. Leatherbacks were mostly externally hooked, whereas hardshell turtles were primarily hooked internally, raising concerns regarding post-release mortality (Coelho et al., 2015). A Japanese longline study confirmed the effect of the combined approach. Circle hooks reduced deep hooking and promoted mouth hooking in loggerheads, while fish bait resulted in zero observed turtle mortality. The combination of large circle hooks with squid bait also yielded the lowest CPUE, mortality rate, and mortality per unit effort (MPUE) (Ochi et al., 2024). A review of 25 experimental studies confirmed that wider circle hooks and fish bait each significantly reduce sea turtle catch rates and deep hooking, with the most substantial reductions observed when both were used in combination. Circle hooks favoured non-lethal anatomical hooking positions, enhancing post release survival, particularly for hardshell turtles. Leatherbacks, generally entangled or externally foul hooked, also showed reduced catch rates on circle hooks (Gilman & Huang, 2017). However, gear modifications may also affect other species. In some cases, circle hooks and fish bait increased catch rates and deep hooking risk for sharks and billfishes, particularly in shallow-set fisheries. These trade-offs underscore the need to balance conservation goals across taxa and tailor mitigation strategies to specific fisheries. Furthermore, in deep-set longline fisheries, where turtle mortality post hooking is already high, the benefits of hook and bait changes are diminished (Gilman, 2016).

Large-scale regulatory changes in the Hawaii-based swordfish fishery introduced 18/0 circle hooks with fish bait, replacing J-hooks with squid. This shift reduced loggerhead and leatherback bycatch by 90% and 83%, respectively, and deep hooking in hardshell turtles dropped from 60% to 22%. Post-regulation, all turtles were released alive, swordfish catch increased by 16%, and shark catch decreased by 36%, likely due to the bait change (Gilman et al., 2007). Meta-analyses reinforce these findings. A global synthesis reported significant reductions in bycatch when using circle hooks in loggerhead, leatherback, and olive ridley turtles, while green turtles showed no statistically significant effect. Fish bait instead of squid reduced turtle bycatch overall, with the strongest results for loggerheads and in the Pacific. Notably, the combination of circle hooks and fish bait produced a greater effect than either method alone (Yan et al., 2024). Leatherback turtle bycatch probability was expected to be lowest when using only fish bait and circle hooks (measured separately) and significantly increased when using squid and J-hooks (Swimmer et al., 2017).

Research priorities for fish bait and circle hook combinations remain for single factor effects of hook shape and hook minimum width, and on effects of individual or combinations of factors on haulback survival rates. There are also few empirical data on effects on anatomical hooking location and post-release survival (Gilman & Huang, 2017), which is critical to understanding the true benefits of applying a circle hook and fish bait fishing strategy.

An evaluation of U.S. regulatory measures across two decades showed that mandatory adoption of circle hooks and fish bait reduced loggerhead bycatch by 61 - 95% and leatherback bycatch by 40 - 84%, depending on region. In one fishing region, the probability of loggerhead and leatherback bycatch was 3.3 - 3.5 times higher using J-hooks with squid bait than with circle hooks and fish bait (Swimmer et al. 2017).

Removal of Fixed Lights and Light Sticks (Light Lures) on Longlines

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✓	✓	?	✓

Overall assessment:	Likely to be beneficial
Gear types tested:	Longline
Applicability for commercial use:	Commercial product/s available; already in use for target species attraction
Regions/countries where tested:	Brazil, Ecuador, Mexico, Northwest Atlantic Ocean, Peru, Reunion, USA (Hawaii)
Impact on target catch:	None
Number of studies assessed:	7 (6 tested in commercial gears; 1 laboratory study)

Light lures are widely used in pelagic longline fisheries since they are thought to increase the catch rates of target species such as swordfish and tunas. Lights may take the form of chemical light sticks, typically green but available in other colours, or as battery-operated LEDs. They attract fish by mimicking bioluminescent prey, thereby increasing catch rates. On longline gear light lures are attached to snoods, usually close to the hook, to create a visual attraction for tuna and other pelagic

species like swordfish and marlin. Chemical light sticks are single-use items and often lost at sea, becoming a significant source of marine pollution. Battery-operated LED lights are a more sustainable alternative to single-use chemical light sticks.

There is evidence that both target and non-target organisms are strongly attracted to lights in the water column, particularly green lights (Alfonso et al., 2021; Swimmer et al., 2017) although the response with turtles may vary between species and age class. One laboratory study showed juvenile leatherbacks, are indifferent or averse to fishing lights, while juvenile loggerheads are consistently attracted to them. However, field observations show the opposite pattern: loggerheads are mostly captured during daylight when lights are not used, while leatherbacks are caught at night when lights are deployed. This discrepancy suggests laboratory behaviours may not reflect natural responses (Gless et al., 2008). In the field, loggerhead sea turtles display strong individual colour preferences when biting, consistently choosing the same colour they first selected. However, at the population level, no clear preference for yellow, red, or blue was identified. Turtles held in captivity for more than six months showed significantly higher biting responses, suggesting that captivity duration is an important variable to consider in behavioural studies. These findings cast doubt on the effectiveness of simply changing bait colours as a universal bycatch reduction measure (Piovano et al., 2013).

In the Atlantic Ocean, green light attractors significantly increased the catch rates of target species, but also led to disproportionately higher bycatch rates, particularly for blue sharks and sea turtles: specifically, 82% of sea turtles were caught on green-lit hooks, while blue and white lights showed lower overall catch rates for both target and bycatch species (Alfonso et al., 2021).

Crognale et al. (2008) reported that LEDs that flicker at >16 Hz may lead to higher catch rates because the light is less detectable to leatherbacks while maintaining its effectiveness for attracting swordfish. Swimmer et al. (2017) reported light stick use was positively correlated with loggerhead bycatch.

Evidence for the impact of light lures on target species is generally lacking, except for two studies in shark fisheries which demonstrated no change to target CPUE (Bielli et al., 2020; Darquea et al., 2020). Given that the addition of light lures to longlines is to directly improve capture rates of target species, it stands to reason that removal of lights from will reduce target CPUE. Avoiding deployment of light sticks in longline fisheries may be a practical and easily implemented bycatch reduction measure but in the absence of strong data on impacts on target species, removal of artificial illumination in fisheries requires local trials on capture rated for target species to confirm efficacy before implementation.

Hook Shielding Devices

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✗	✓	✓	✓

Overall assessment:	Unlikely to be beneficial
Gear types tested:	Trawl
Applicability for commercial use:	Modification to existing gears, many designs/configurations already in use
Regions/countries where tested:	Brazil, South Africa
Impact on target catch:	None
Number of studies assessed:	3 (2 tested in commercial gears; 1 captive trial)

Emerging technologies such as hook shielding devices have shown promise in experimental trials. Two systems have been developed, the Smart Tuna Hook (Jusseit, 2010; Baker et al., 2016) and the Hook Pod (ACAP, 2019). Developed originally as a seabird bycatch mitigation measure, the Smart Tuna Hook uses a modified tuna longline hook which accepts a specially designed metal shield that disarms the hook once it has been baited, preventing ingestion and making it impossible for any seabird or turtle to be hooked while the hook shield remains in place. The shield is released from the hook within 15 minutes of being immersed in salt water, allowing fish to be caught after the baited hook has passed through the water column to setting depth, beyond the normal diving and feeding depths of most seabirds and turtles. Laboratory trials demonstrated complete prevention of hooking and flipper entanglement in green and loggerhead turtles while the hook was shielded (Jusseit, 2010).

The Hookpod when deployed is attached directly to the hook and encases the barb and point of the hook in a plastic housing. A pressure release mechanism opens the housing at a depth of at least 10m to release the baited hook (ACAP, 2019).

A field trial of the Hookpod was conducted in Brazilian pelagic longline fisheries. All hooks used were circle hooks, consistent with national regulations. Across over 80,000 hooks deployed, turtle bycatch rates were statistically similar between Hookpod-equipped gear and conventional control gear, with 47 and 43 turtles caught respectively. Seasonal variation was observed, with lower turtle bycatch in the cold season using the Hookpod, but higher in the warm season. Overall, the Hookpod did not significantly affect turtle bycatch rates nor catch rates of target species, suggesting that its use does not introduce unintended ecological trade-offs while providing seabird bycatch reduction benefits (Gianuca et al., 2021).

Dyed Bait

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✗	✓	?	✓

Overall assessment:	Likely to be ineffective or harmful
Gear types tested:	Longline
Applicability for commercial use:	Time consuming to treat bait, feasible but impractical
Regions/countries where tested:	Costa Rica, Tunisia
Impact on target catch:	None
Number of studies assessed:	2 (2 tested in commercial gears; 1 captive trial)

Attempts to further mitigate bycatch through bait colour modifications have been largely ineffective in field conditions. Laboratory preference trials revealed that both loggerhead and Kemp's ridley turtles favoured untreated squid over blue dyed bait, and while loggerheads also preferred untreated squid over red-dyed squid, Kemp's ridley turtles showed the opposite response (Swimmer et al., 2005). However, field trials demonstrated no statistically significant reduction in turtle bycatch rates between blue-dyed and untreated squid baits (Swimmer et al., 2005; Echwikhi et al., 2010). These findings highlight that while bait colour may influence turtle behaviour under controlled conditions, it is insufficient as a standalone field measure. Turtle feeding behaviour in real world settings appears more complex and driven by multiple sensory inputs, including texture, odour, and water movement (Swimmer et al., 2005).

Gillnet and Setnet

Gillnets, also known as setnets, are curtain-like fishing nets designed to catch fish by becoming entangled in their gills. They are deployed vertically and held in place by floats on top and weights on the bottom, forming a wall that fish swim into. Gillnets may be set near the surface to catch pelagic fish or on or near the bottom to catch demersal fish. They can be anchored or fixed to the seabed, or allowed to drift with the current in the water column. While effective for targeting open-ocean pelagic fish like tuna and swordfish, these nets are associated with significant bycatch of non-target species, leading to international bans and restrictions on their use (Gilman et al., 2010; Bielli et al., 2020).

Set net fisheries, including gillnets and trammel nets, are among the most widely used fishing methods globally, particularly in coastal and nearshore areas (Cambiè, 2010; Gilman et al., 2010; Bielli et al., 2020; Gautama et al., 2022). Gillnets are used in both large industrial and small-scale fisheries, often in large fleets fishing intensively in coastal areas with limited regulation and enforcement (Ortiz et al., 2016). Since gillnets are used globally and often lack proper regulation, their overall impact on bycatch is difficult to measure (Wang et al., 2010). However, they are regarded as some of the largest sources of mortality for sea turtles (Bielli et al., 2020) and other marine organisms.

Mitigating turtle bycatch in gillnets has been difficult to achieve with only net illumination showing extensive promise (see below). Other approaches can still be considered to be in development and are currently not best practice for gillnet:

a. Limited research has shown that visual deterrents like predator shaped models (shark shaped) achieved bycatch reductions, but also significantly reduced target catch (Wang et al., 2010). Captive-reared juvenile loggerhead turtles exhibited defensive behaviour toward a shark model in a controlled laboratory setting, taking significantly more time to bite squid bait beneath the shark model (Bostwick et al., 2014). Within the Indian Ocean shark silhouettes were considered impractical for widescale use due to the bulkiness of the silhouettes (Pilcher et al., 2025).

b. Changes to net configuration, such as lowering net height or removing tiedowns, were also effective. However, these methods are still rarely applied in practice due to limited field testing, context specific effectiveness, and lack of regulatory support (Gilman, 2010).

c. Buoyless gillnets, which eliminate surface flotation and sink deeper into the water column, have been trialled in a field study in Mexico, where they reduced sea turtle bycatch, especially of olive ridley turtles, by over 60%, without negatively affecting the catch rates of target species such as sharks and rays (Peckham et al., 2016).

d. Installation of visual panels into gillnet panel have been proposed by Martin and Crawford (2015) to alert turtles and other non-target species to the presence of nets. They recommended trialling of panels containing a pattern of low spatial frequency and high internal contrast, which 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. These believed that panels would be effective as a mitigation measure for all bycatch species, relatively easy to deploy and of low-cost. This suggestion has not been taken up and evaluated to date.

e. Use of sound signals to warn about the presence of gillnets was not recommended by Martin and Crawford (2015) because of the poor sound localisation abilities of bycatch species such as turtles.

Overall, we found that few of these measures were supported by studies that reported empirical data and are unlikely to be adopted by fishers at this stage because they reduce target catch, have deleterious impacts on other species or still require significant investment to resolve technical issues.

Net Illumination

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✓	✓	✓	✓

Overall assessment:	Likely to be beneficial
Gear types tested:	Gillnet, trammel net
Applicability for commercial use:	LEDs and alternative light sources commercially available, many designs/configurations already in use
Regions/countries where tested:	Gulf of Mexico, Indonesia, Mediterranean Sea, Western Indian Ocean
Impact on target catch:	No effect except in one study (reduction, Jančič et al., 2020)
Number of studies assessed:	11 (10 tested in commercial or artisanal fisheries; 1 review)

An overall review by Gilman (2010) found that increasing net visibility, through UV-reflective materials, high-contrast panels, or illumination, can significantly reduce turtle entanglement, as turtles rely on vision for movement and foraging.

Among the most widely studied mitigation measures for gillnets is the use of net illumination. Studies have been caried out for the use of green (Wang et al., 2010; Ortiz et al., 2016; Bielli et al., 2020; Jančič et al., 2020; Gautama et al., 2022, Snape et al. 2024), violet (Darquea et al., 2020) and ultraviolet (Wang et al., 2013; Lucchetti et al., 2019) LEDs across several fisheries. The principle is grounded in visual physiology studies showing that certain species, like sea turtles, can detect illuminated nets and avoid entanglement. UV-LEDs (outside most fish visual ranges) are particularly preferred for marine turtle bycatch reduction as they remain visible to them but less conspicuous to fish (Horodysky et al., 2010, cited in ICES 2025).

The use of green LEDs was significantly effective in reducing sea turtle bycatch across multiple studies in small-scale fisheries. In Peru, green LED equipped nets with LEDs attached every 10 metres along the float line significantly reduced sea turtle bycatch, as well as the bycatch of small cetaceans and seabirds. In surface driftnets, the bycatch probability of sea turtles per set decreased by 74.4% (from 8.6% to 2.2%), and in bottom set nets by 70.0% (from 1.0% to 0.3%). Catch rates of target species were not negatively affected (Bielli et al., 2020). A separate study in a Peruvian bottom-set gillnet fishery reported a 63.9% reduction in green turtle bycatch using the same LED configuration, also without affecting the catch rates of target species (Ortiz et al., 2016). Similar results were observed in Mexico, where green LED lights attached every 10 metres along the float line reduced green turtle catch rates in experimental gillnets by 40% compared to control nets (Wang et al., 2010). A study in a small-scale surface drift gillnet fishery in Indonesia showed that the use of LED lights led to a 61.4% reduction in total sea turtle bycatch and a 59.5% reduction in green turtle bycatch, without affecting catch rates or value (Gautama et al., 2022). A similar effect was observed in a small-scale set net fishery in Northern Cyprus, where flashing green LED NetLights were tested. The use of NetLights reduced sea turtle catch by 42%. Green turtles were predominantly caught in shallow nets, while loggerhead turtles were more frequent in deeper sets. Bycatch rates increased with the proportion of daylight soaking, though this pattern was consistent across both control and illuminated nets (Snape et al.,

2024). However, in the Northern Adriatic Sea, a study using green LEDs in bottom-set gillnets and trammel nets found no significant reduction in loggerhead turtle bycatch, likely due to the low number of captured turtles. Moreover, in trammel nets, green LEDs significantly reduced target catch and value (by 23% and 27%, respectively), raising concerns about the economic viability of this mitigation method in some fisheries (Jančič et al., 2020).

Violet coloured LEDs with a 12–14 m spacing on gillnets in Ecuador's small-scale driftnet fishery showed that green turtle bycatch was reduced by 93.3%, and overall sea turtle bycatch declined by 62.2% in illuminated nets compared to controls. No significant reduction was observed for olive ridley turtles. Catch rates of target species were not affected (Darquea et al., 2020).

A study with ultraviolet LEDs found that UV illuminated nets reduced green sea turtle bycatch in Mexico by 39.7% without affecting the catch rates or market value of target fish (Wang et al., 2013). In the Adriatic Sea, UV illuminated bottom-set gillnets caught no turtles compared to two in control nets, while catch rates and species composition of target fish remained unaffected (Lucchetti et al., 2019). An additional study in the northern Adriatic Sea tested UV-LEDs in bottom-set gillnets targeting rays and flatfish. Over 18 sea trials, all 16 loggerhead turtles were caught in unlit control nets, with none in the UV illuminated nets, suggesting strong deterrent effects. Target catch rates and size distributions were unaffected (Virgili et al., 2018). They also specifically highlighted water turbidity and transparency as key environmental considerations for UV-LED effectiveness, noting that dredging activities typically decrease water transparency in the Mediterranean, increasing turbidity. As a result, they recommended UV-LEDs, which "have increased ability to penetrate through turbid conditions" compared to visible-light LEDs and chemical light-sticks (ICES, 2025).

To improve the practicality and sustainability of net illumination in small-scale gillnet fisheries, solar powered illuminated buoys were designed in collaboration with fishers in Mexico. These buoys address key limitations of conventional LED systems, such as battery cost, waste, and gear entanglement. Although the effectiveness of the solar buoys has not yet been quantified in field trials, they were designed to replicate the bycatch reduction levels of conventional LEDs (Senko & Nalovic, 2021).

c. Operational Measures

Gas Embolism and Decompression Sickness

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	?	?	?	?

Overall assessment:	Unknown effectiveness
Gear types tested:	Trawl, gillnet, longline
Applicability for commercial use:	Modification to existing gears (TEDs in trawl), operational solutions require testing – reduced soak time (all gears), controlling ascent time of gear on hauling (all gears), hyperbaric oxygen therapy at sea impractical.
Regions/countries where tested:	Mediterranean Sea, Brazil,
Impact on target catch:	None
Number of studies assessed:	13 (observational studies, none tested in commercial gears)

While sea turtle mortality is traditionally ascribed to drowning or injuries caused by fishing gear, it has been shown that sea turtles can suffer gas embolism (GE) and decompression sickness (DCS) when incidentally caught in fishing gear. The first confirmation was documented in loggerheads caught in trawls and gillnets in the Mediterranean (García-Párraga et al., 2014) and loggerheads remain the most studied species in this regard (Fahlman et al., 2017; Portugués et al., 2018; Parga et al., 2020; Franchini et al., 2021; Robinson et al., 2021; García-Párraga et al., 2023). Subsequent studies have confirmed cases across other species including leatherback, green, and olive ridley turtles (Crespo-Picazo et al., 2020; Robinson et al., 2021). GE and DCS represent an often-hidden source of mortality, primarily in trawl and gillnet fisheries and could be easily missed in fishing operations where animals are not landed but cut away in the water. If not considered, numbers of sea turtle mortality could be significantly underestimated (Fahlman et al., 2017).

Incidence rates can be high, with between 40–100% of turtles caught in bottom trawls and gillnets observed to exhibit GE, and mortality levels ranging from 20–50% depending on severity and handling (Parga et al., 2020; Franchini et al., 2021; García-Párraga et al., 2023). GE has been observed at depths as shallow as 19–37 m, while mortality probabilities reach approximately 50% at 45 m in gillnets and 110 m in trawls (Crespo-Picazo et al., 2020; García-Párraga et al., 2023). Ascent speed during hauling is a critical factor as rates of 3.5 m/min (~0.06 m/s) or greater are associated with nearly triple the risk of death compared with slower ascents (Franchini et al., 2021). Prolonged net residence times of more than three hours and larger body size further increase susceptibility (Parga et al., 2020; García-Párraga et al., 2023).

In contrast, natural dive profiles show that sea turtles ascend slowly and in a controlled manner. Ascent rates range between 0.12 and 0.28 m/s, generally faster than descent but moderated by buoyancy and gliding before surfacing (Reina et al., 2005; Hochscheid, 2014). Behavioural state analysis confirms that gradual ascents are characteristic of energy-saving “resting dives” and that extended surface intervals

often follow dives involving higher activity or ascent effort (Harvey-Carroll et al., 2025). Leatherbacks show mean descent rates of 0.32 m/s, with longer surface durations after dives involving greater vertical movement (Migneault et al., 2023).

Potential mitigation measures have been identified at both the operational and post-capture level. At sea, the most effective strategies include reducing net residence time and soak duration, controlling ascent speeds during gear hauling, and installing TEDs to prevent prolonged retention in trawls (Franchini et al., 2021; Franchini et al., 2021; Crespo-Picazo et al., 2020). Adjusting gear depth has also been recommended, either to avoid overlap with typical turtle diving ranges or to deploy nets deeper than routine dive limits (Crespo-Picazo et al., 2020). However, the likelihood of fatal DCS increases with depth (Fahlman et al., 2017). All operational measures require experimental work at sea to demonstrate efficacy.

For turtles brought on board, survival is thought to highest when active animals are released immediately, unless hyperbaric treatment is available (Parga et al., 2020). Animals that appear in good condition may nonetheless carry severe GE (Franchini et al., 2021). Where facilities exist, hyperbaric oxygen therapy has been shown to reverse GE, restore respiratory function, and allow full recovery in many cases (García-Párraga et al., 2014; Portugués et al., 2018). However, this is not a feasible mitigation measure for the majority of fishing fleets and cannot be recommended for the broader mitigation of sea turtle mortality.

Spatial and Temporal Closures.

Overall Research Quality	Mitigation Effectiveness	Harm	Impact on Target Catch	Feasibility
✓	✓	✓	✗	✓

Overall assessment:	Beneficial
Gear types tested:	Applicable to all gears
Applicability for commercial use:	Application of existing provisions in most fisheries
Regions/countries where tested:	Used globally to manage fish stock
Impact on target catch:	Reduction
Number of studies assessed:	Assessed theoretically

Time and area closures have been widely used in fisheries management to prevent overfishing and to reduce bycatch of finfish or protected species such as turtles. Intrinsically, closures are an effective bycatch mitigation measure because if fishing operations are not occurring it is not possible to catch either target species or other animals in the water column. Closures may be used to enforce management-imposed catch limits and may result in the early closure of otherwise sustainable fisheries when bycatch quotas are exceeded (Dunn et al., 2011). As plans are put forth, fishers and regulators will want to ensure that areas of persistently high fishing efficiency and selectivity remain

open to fisheries. In such a situation they are often unpopular due to the consequent economic hardship to fishers and the economy.

Designing effective bycatch mitigation programmes requires an understanding of the life histories of target and non-target species, interactions of fish and fishing gear, effects of spatial and temporal shifts in fishing effort, and socio-economic impacts to the fishery (O'Keefe et al., 2014). Parameters such as surface temperature (SST) and vertical use of the water column relating to turtle habitat provide scope for consideration in the design of suitable closures for turtles.

Much of the expected bycatch probability for turtle species relates to time and space, which is largely a function of the fishery effort and the overlap between target species and sea turtle foraging habitats (Swimmer et al., 2017). As plans are put forth, fishers and regulators will want to ensure that areas of persistently high fishing efficiency and selectivity remain open to fisheries. Avoiding preferred habitat has potential as a mitigation option but in many cases, what constitutes preferred habitat is difficult to understand or predict, especially when related to dynamic oceanographic variables (WCPFC-SPC, 2016).

Multiple studies suggested that SST can be a strong indicator of turtle bycatch. Fishing in cooler waters below 20 °C can mitigate bycatch (Gilman, 2011; Swimmer et al., 2017), as turtles aggregate in warm surface waters (>20°C) and along thermal fronts (Kiyota et al., 2004). The highest rate of loggerhead turtle bycatch in Canadian pelagic longline fisheries occurred in warmer months in warm waters above 20 °C (Brazner & McMillan, 2008). Sea surface temperature had a strong influence on turtle catch rates; higher temperature increased catch risk (Watson et al., 2005). In an analysis of two decades of observer data from USA pelagic longline fisheries the frequency of sets with sea turtle bycatch in the Atlantic was highest within SST ranges between 22°C to 26°C and 23°C to 27°C for loggerheads and leatherbacks, respectively, but more protracted in the Pacific where bycatch was highest when SST ranged between ~17 and 19°C for both loggerheads and leatherbacks (Swimmer et al., 2017).

A study of the relationship between sea turtle abundance and temperature in the North Atlantic attempted to define thermoclines of risk for all species and suggested that a conservative approach would be to require mitigation measures when 25% of each 0.5 degree latitudinal zone was warmer than 11°C (Braun-McNeill et al., 2008, cited in Clark et al., 2014). However, one weakness to this approach noted by that study is that some individuals, particularly larger loggerheads, may be able to tolerate colder waters compared to the other hard-shelled turtles due to their enhanced thermoregulatory ability (Braun-McNeill et al., 2008). Another potential weakness is that if sea turtles and target species both prefer similar oceanographic conditions it may be difficult for fishers to operate in areas inhabited only by target species (Clarke et al., 2014).

Sales et el. (2010) and Clarke et al. (2014) noted that in experimental data from southern Brazilian vessels experienced higher bycatch rates during the warm seasons (spring and summer) compared to cold seasons (autumn and winter). Conversely, another study found higher sea turtle bycatch numbers in spring and autumn during offshore experiments in the southwestern Atlantic, with lower bycatch observed in summer and winter (Sales et al., 2010). Despite these discrepancies, both results suggest a correlation between sea turtle bycatch and seawater temperature, indicating temporal variation, which could inform future policymaking to regulate the fishing seasons for longline fishing vessels.

d. Conclusion and Research Needs

Trawl

Trawl fisheries pose a major threat to sea turtles due to their low selectivity, particularly in tropical shrimp fisheries.

TEDs are among the most effective mitigation tools, reducing turtle bycatch by up to 97% in some regions.

Hard grids are more effective in excluding turtles, while flexible grids offer advantages for smaller vessels and are more easily stowed.

TED effectiveness depends on correct design, installation, and industry compliance; escape opening size and bar spacing are critical.

Long-term success requires collaboration with all stakeholders, fishers, fishery managers, and scientists, together with training, monitoring, and enforcement.

Purse Seine

Purse seine fisheries have relatively low turtle bycatch; most individuals are released alive. As a consequence, research and development over the last 15 years has focussed on the design of FADs, particularly in non-entangling designs.

Use of non-entangling and biodegradable FADs (e.g., made from canvas, cotton, bamboo, and not containing netting) reduces bycatch and ghost fishing risks.

Avoiding the encirclement of turtles during fishing and crew training on safe handling of turtles will enhance post-capture survival.

Systematic monitoring and reporting are crucial for assessing and improving mitigation efforts.

Longline

Use of large circle hooks and fish bait significantly reduces sea turtle bycatch.

Combining both measures yields the lowest capture probabilities.

Demersal longlines currently lack effective mitigation measures for turtles: we found no studies that addressed recent mitigation development for this gear type.

Measures that are highly effective in one region or gear type may be ineffective or impractical elsewhere.

Tailored, evidence-based approaches, along with stakeholder collaboration, are essential for successful implementation.

Gillnet

Set and gillnet fisheries, especially in small-scale coastal operations, are among the most significant sources of turtle mortality.

Turtles are especially vulnerable to fine mesh, which offers low escape chances with high mortality rates reported.

Net illumination using LEDs (green, violet, UV) is one of the most effective and tested mitigation measures with high rates of reduction in turtle bycatch achieved in some studies and no significant impact on target catch in most cases, though exceptions exist.

Additional visual strategies (e.g., use of predator models, high-contrast panels) and net modifications show potential but require further field validation before they can be considered as best practice

Adoption of mitigation remains low due to limited field testing, economic concerns, and lack of regulatory frameworks.

Operational

While sea turtle mortality is traditionally ascribed to drowning or injuries caused by fishing gear, turtles can suffer gas embolism and DCS when incidentally caught in fishing gear. The true level of post-release mortality due to DCS is unquantified but may be a lot higher than currently thought.

Operational modifications to reduce soak time and control ascent time on hauling in all gears require testing to prove efficacy at minimising turtle DCS. Installing TEDs in all trawls provides an opportunity for all caught turtles to escape 'naturally' in a timeframe that should allow normal rates of ascent after dives.

Designing effective bycatch mitigation programmes requires an understanding of the life histories of target and non-target species, effects of spatial and temporal shifts in fishing effort, and socio-economic impacts to the fishery. Parameters such as SST and vertical use of the water column relating to turtle habitat provide scope for consideration in the design of suitable spatial and temporal closures for turtles.

Final summary and conclusions

Effective technical mitigation measures are a crucial element of any robust, integrated bycatch management program, which usually includes other management directives such as temporal and spatial fishing restrictions and appropriate operational 'codes of practice'. For some gear types, there are currently limited technical options with strong evidence they effectively reduce bycatch, and substantial development and research of best practice mitigation options is needed to address marine turtle bycatch in many fisheries.

Appropriate operational and technical mitigation measures should be used for all fisheries where turtle bycatch is problematic. For demersal longline gear, there are currently no technical options with strong evidence they effectively reduce bycatch, and substantial development and research of best practice mitigation options is needed to address marine turtle bycatch in fisheries deploying such gear.

Tailored, evidence-based approaches, combined with stakeholder collaboration, enforcement, and training, are essential for successful implementation and long-term conservation outcomes. It is notable that uptake of mitigation in many fisheries still remains low despite widespread acknowledgement of the severity of the impact on turtle populations (Pilcher et al., 2025).

For mitigation to be considered effective, a significant reduction in bycatch mortality needs to be demonstrated, together with maintenance of target catch quality and quantity, while ensuring no negative effects on bycatch rates of other protected species.

Fishing industry engagement to ensure design, development and effective implementation of practical solutions is essential to creating good outcomes.

All fisheries should adopt an adaptive approach to managing turtle bycatch. Operational characteristics of most fisheries are dynamic and updating and improving knowledge of the biological and behavioural characteristics of target and bycatch species, including temporal and spatial overlap of bycatch species with fishing activities should be continually evaluated to assess efficacy of bycatch mitigation solutions, and change these as appropriate.

Systematic monitoring and reporting are crucial for assessing and improving mitigation efforts for turtles in all fisheries. Determining mitigation efficacy should include species- and fisheries-specific testing with adequate scientific rigour, and a quantitative target to enable efficacy assessment.

Overall, this review confirms that effective turtle bycatch reduction is fishery-specific, as has been found for mitigation of bycatch of other non-target species including seabirds, marine mammals and sharks. Measures that are highly effective in one region or gear type may be ineffective or impractical elsewhere. Selecting measures to minimise marine turtle bycatch should ensure their implementation does not increase bycatch of other non-target species such as seabirds, marine mammals or sharks.

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Glossary

CCSBT	Commission for the Conservation of Southern Bluefin Tuna
IATTC	Inter-American Tropical Tuna Commission
ICCAT	International Commission for the Conservation of Atlantic Tunas
IOTC	Indian Ocean Tuna Commission
tRFMOs	Tuna Regional Fishery Management Organizations
WCPFC	Western and Central Pacific Fisheries Commission