First Sea Turtle Informal Intersessional Working Group Meeting (STIIWG01)

Review of CMM 2018-04 (Sea Turtles)

8 and 10 April 2026 (Pohnpei)| 10 AM-2PM

Virtual Meeting

LITERATURE REVIEW OF SOAK PERIOD BYCATCH MITIGATION MEASURES FOR NEW ZEALAND'S SURFACE LONGLINE FLEET

STIIWG01-2026-IP-10[1]

27March 2026

[1] Reference 10




Literature Review of Soak Period Bycatch Mitigation Measures for New Zealand's Surface Longline Fleet

New Zealand Department of Conservation

NZ3269

Final Report

16th July 2024

Submitted by

MRAG

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Document Control		
Title	Literature Review of Soak Period Bycatch Mitigation Measures for New Zealand's Surface Longline Fleet	
Document ID	Final	
MRAG ID	NZ3269	
Version	V001	
Prepared by	Approved by	
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16/07/2024	16/07/2024	
Internal Use Only	Client Only	General Release
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Acronyms

ACAP	Agreement on the Conservation of Albatrosses and Petrels
ALDFG	Abandoned, Lost or otherwise Discarded Fishing Gear
BMIS	Bycatch Management Information System
CMM	Conservation and Management Measure
CPUE	Catch per unit effort
DOC	Department of Conservation
ETP	Endangered, Threatened and Protected
FAO	Food and Agriculture Organisation (of the United Nations)
FMA	Fisheries Management Area
FNZ	Fisheries New Zealand
GLM	Generalised Linear Model
GPS	Global positioning system
IATTC	Inter-American Tropical Tuna Commission
ISSF	International Seafood Sustainability Foundation
LRP	Limit Reference Point
NMFS	National Marine Fisheries Service (United States)
NOAA	National Oceanic and Atmospheric Administration (United States)
REM	Remote Electronic Monitoring
RFMO	Regional Fisheries Management Organisation
SR	Sagging Rate
TDR	Temperature Depth Recorder
WCPFC	Western and Central Pacifici Fisheries Commission
WCPO	Western and Central Pacific Ocean

1 Executive Summary

New Zealand's surface longline fleet deploys roughly 1.2 million hooks per year in New Zealand waters, targeting high value pelagic species such as swordfish and southern bluefin, albacore, and bigeye tuna. The fishery's impact on both seabird and turtle populations in New Zealand's waters has caused concern amongst fisheries managers and the Department of Conservation. This has prompted the enforcement of stricter bycatch mitigation measures by Fisheries New Zealand (FNZ), with these largely being focused on reducing bycatch of seabirds during the setting phase of longlines. Despite this, seabird bycatch is still widely reported by observers reporting on the fishery, prompting concerns that bycatch events taking place during the soak period of fishing operations have been underestimated and are still threatening vulnerable populations of seabird and turtle.

This literature review provides New Zealand's Department of Conservation (DOC) with an up-to-date synthesis of bycatch mitigation measures for seabirds and turtles during the soak period of surface longline fishing. A series of mitigation measures were collated, summarized, and analysed for their potential efficacy in reducing seabird and turtle bycatch in New Zealand, as well as any barriers to implementation that they may be associated with. The findings from the literature review, collation and analysis stages were summarized into a series of recommendations for the DOC to take forward, with the focus being on future testing of new measures to reduce soak period bycatch of these focal taxa within the surface longline fishery.

This review identified a series of key challenges in reducing seabird and turtle bycatch during the soak, as well as recommendations outlining potential candidate measures to mitigate against the bycatch associated with them. Candidate measures identified to have the ability to reduce the likelihood of mainlines shoaling include proper weighting of the mainline via weights at the base of float lines and the use of increased branchline weighting; using deep-set longlines where possible; and the potential use of line shooters where the mainline is kept out of vessels' propeller turbulence during setting. Measures to reduce the likelihood of seabirds and turtles interacting with baited hooks where they are exposed during the soak include night soaking, bait dyeing, using longer branchlines with weights close to hooks, the use of fish bait, and the use of novel hook designs to prevent ingestion. Finally, where bycatch rates reach concerning levels the use of spatial and temporal management measures may be used to limit fishing effort in specific fisheries management areas, or during periods that are known to be associated with high bycatch rates. However, implementing these closures with any level of confidence around their expected efficacy is challenging where historical observer data on seabird and turtle bycatch is limited. Despite a paucity of literature on experimental measures, this report recommends further investigation of the potential use of automatic release mechanisms, and the use of hook timers alongside TDRs to reveal how mainlines are brought to the surface and the scale of seabird interaction with them where they do shoal to the surface.

2 Introduction

2.1 Project Background

Surface longlining, often referred to as 'pelagic' longlining, is a common fishing method for targeting high-value pelagic fish species such as tunas and billfishes throughout the world's oceans. Its low impact on fish quality compared to large-scale netting methods, along with its potential to target greater depths, make it an effective method for targeting specific high-value species in the water column. One significant disadvantage of longline fishing techniques is their potential for high levels of bycatch of Endangered, Threatened, and Protected (ETP) species groups, including turtles and seabirds. Surface longlines typically catch turtles through direct bait interaction, leading to foul hooking or hook ingestion, or indirectly as a result of entanglement within float, main, and branchlines. Both scenarios present a risk of drowning of those individuals that are caught (Stokes *et al.,* 2011). Given the relative hook exposure time associated with the 'soak period', it is assumed hook ingestion and entanglement are most likely to occur during this phase of fishing, that is the time window during which baited hooks are fishing at their desired set depths. Conversely, longlines have historically been documented as presenting the greatest threat to seabirds during their setting and hauling, where gear is set from and retrieved to the fishing vessel (Brothers *et al.,* 2010). Here, baited hooks are exposed, often only for a short time, to seabirds in proximity to the fishing vessel. These birds use visual cues to dive on and ingest baited hooks as they sink to their intended target depth, often causing them to become hooked to the longline as it descends, pulling them down with it and causing a high risk of drowning. Again, as baited hooks are hauled up to the fishing vessel, they present seabirds with another opportunity to dive on them and potentially become caught as bycatch, however with a higher likelihood of live release given the gear is travelling back to rather than from the fishing vessel.

Surface longlining has been used to target tuna and billfish in New Zealand's commercial fishery since the early 1990s (Murray *et al.,* 2000). Largely targeting southern bluefin, albacore, and bigeye tunas as well as swordfish, today the fleet is made up of 20 vessels between 12 and 23.6 metres in length (Hickox *et al.,* 2024). Collectively, the fleet deploys roughly 1.2 million hooks per year across 1,500 sets (fishing events). Generally, fishing effort increases into the summer (December to February) around the North Island, focusing largely on bigeye tuna and swordfish. Then, as southern bluefin tuna arrive in autumn (around March to April) effort increases further in the South Island, with activity peaking around June and July. During the bluefin tuna season some fishing effort remains focused around the North Island, largely targeting swordfish (Fisheries New Zealand, 2023). Historically, observer coverage for the surface longline fleet has been relatively low at 5-10%, making precise data collection on bycatch a challenge and thereby producing limited fisher compliance data. It is hoped this will be changed with the advent of Remote Electronic Monitoring (REM) within the fleet in the form of cameras.

The surface longline fishery has historically seen high rates of both seabird and turtle bycatch (Fisheries New Zealand, 2023) causing concern at the Department of Conservation (DOC). Turtle species most often caught are leatherback turtles (*Dermochelys coriacea*) and green turtles (*Chelonia mydas*). Leatherbacks are predominantly caught by the surface longline fleet from January to April in Fisheries Management Area (FMA) 1 (the Bay of Plenty) as the fleet targets swordfish (*Xiphias gladius*) and bigeye tuna (*Thunnus obesus*). New research by Dunn *et al.* (2024) shows that the strongest bycatch association is in the swordfish fishery in the Bay of Plenty. Leatherback turtles that have been caught are predominantly hooked in the body or the mouth, leading to their further entanglement in the branchlines. Observer reports show most of these individuals to be cut free from the mainline with most being released alive, however, historically data on these interactions have not been collected. The critically endangered status given to the Western Pacific population of leatherback turtles highlights the need for improved understanding of their interactions with New Zealand's surface longline fleet, particularly given the risk of drowning associated with turtle entanglement in longline fishing gears. Most green turtles caught as bycatch are juveniles inhabiting coastal inshore waters. In the majority of cases, green turtle bycatch in the surface longline fleet is caused by hook ingestion by individuals attempting to feed on baited hooks.

Seabird species that are commonly caught in New Zealand's surface longline fishery include large and small albatrosses (*Diomedeidae*) and shearwaters and petrels (*Procellariidae*). The aforementioned low observer coverage across the fleet has made accurate estimates of mortality based on the data collection on interactions with both these taxa challenging. Despite this, Fisheries New Zealand (FNZ) and the Department of Conservation (DOC) have set out a series of regulations designed to reduce ETP interaction, with particular focus on seabirds and their vulnerability to longlines, particularly during the setting phase of fishing. However, there are concerns among fishers and fisheries managers that not enough focus is placed on the soak period of fishing operations and its role in producing bycatch of both turtles and seabirds. While relatively little is understood about how seabirds become bycaught during the soak period, observers have reported instances where individuals have been hauled onto vessels in condition indicative of a bycatch event after the set but prior to the haul, that is during the soak period (e.g. alive but in significantly worse condition than individuals caught during the haul). As a result, the DOC has commissioned this report to better understand the potential for seabird bycatch during the soak period of surface longline fishing gear, as well as potential measures to help reduce bycatch of turtles by either entanglement or hook ingestion.

2.2 Project Objectives

The main objective of this project is to identify potential bycatch mitigation measures to reduce bycatch levels of turtles and seabirds caught during the soak period of surface longline operations in New Zealand's fleet. For the avoidance of doubt, the 'soak period' is defined in this report as the time window during which surface longline gear fishes at its desired target depth. This excludes both periods either side of the soak where the gear may fish in the water column while it is being either set from or hauled to the fishing vessel. This overall objective has been broken down into two tasks:

Task 1: Literature review of bycatch mitigation measures that may reduce bycatch of turtles and seabirds during the soak period of surface longline fishing.

Task 2: Analysis of potential measures to assess their suitability to being taken forward for testing by the DOC.

3 Methodology

3.1 Task 1: Literature Review

This review collates existing mitigation measures with the potential to mitigate against seabird and turtle bycatch in New Zealand's surface longline fishery. A series of literature searches were undertaken to review existing bycatch mitigation measures for turtles and seabirds, focusing on those applicable to the soak period of longline vessels. To achieve this, the review assessed a wide range of measures using a number of resources including the Bycatch Management Information System (BMIS); an online resource that was conceived by the Western and Central Pacific Fisheries Commission (WCPFC) to centralise information on bycatch mitigation in the Western and Central Pacific Ocean (WCPO). BMIS allows users to search mitigation techniques by species group and by gear type. This was used to establish a base set of 37 mitigation measures that apply to seabirds and turtles (Table 1). To refine this list, measures were further categorised by longline fishing stages, with those that apply to the soak period highlighted green in Table 1.

Table 1. The base set of bycatch mitigation measures for turtles and seabirds and the fishing phase they apply to (n = 37).

NB: Those cells highlighted in green were deemed relevant to this project as they applied to either turtles or seabirds and the soak period for longline fishing (n = 21).

Bycatch Mitigation Measure	Seabird	Turtle	Setting	Soak Period	Hauling	Post Capture
Gear Configuration Measures						
Line Weighting and Bait Sink Rate	✓		✓	✓	✓	
Hook Dimension (Size, Shape, and Offset)		✓		✓		
Deep / Shallow Setting	✓	✓	✓	✓	✓	
Deep-set Buoy Gear	✓	✓	✓	✓	✓	
Monofilament (nylon) / Wire Leaders	✓	✓	✓	✓	✓	
Double-weight Branchlines	✓		✓	✓	✓	
Sliding Weights	✓		✓	✓		
Hook Shielding Devices	✓		✓		✓	
Heavy Hooks	✓		✓	✓	✓	
Line Shooter	✓		✓			
Bait Caster	✓		✓			
Lightsticks / Light Attractors	✓	✓	✓	✓	✓	
Auto-release Technology	✓	✓	✓	✓	✓	
Corrodible Hooks	✓	✓		✓	✓	
Bait Related Measures						
Bait Type	✓	✓	✓	✓	✓	
Bait Condition	✓	✓	✓	✓	✓	
Artificial Bait		✓		✓		
Dyed Bait	✓	✓	✓	✓	✓	
Spatiotemporal Measures						
Fishery Closures	✓	✓	✓	✓	✓	
Closed Areas	✓	✓	✓	✓	✓	
Move-on Rules	✓	✓	✓	✓	✓	✓
Predictive modelling	✓	✓	✓	✓	✓	
Fishing Practices and Procedures						
Night / Day Setting	✓	✓	✓	✓	✓	
Streamer (Tori) Lines	✓		✓		✓	
Brickle Curtain	✓		✓		✓	
Underwater Setting Techniques	✓		✓	✓		

Bycatch Mitigation Measure	Seabird	Turtle	Setting	Soak Period	Hauling	Post Capture
Soak Duration	✓	✓		✓		
Safe Handling and Release	✓	✓				✓
ALDFG.[1] Management	✓	✓				
Side Setting / Underwater Setting	✓		✓			
Management of Offal Discharge	✓					
Other						
Bycatch limits	✓	✓	✓	✓	✓	
Chemical Deterrents / Attractants	✓	✓	✓	✓	✓	
Decoys	✓	✓	✓	✓	✓	
Acoustic Deterrents and Attractors	✓	✓	✓	✓	✓	
Water Cannon or Fire Hose	✓		✓		✓	
Lasers	✓		✓		✓	

The BMIS online resource provides references associated with each bycatch measure, however, to ensure a thorough search of all potential measures a literature search was also completed in Google Scholar to compile all other relevant peer-reviewed and grey literature. Searches used Boolean logic to combine key search terms relating to bycatch mitigation measures for the soak period of fishing and the two key taxa for this project (turtles and seabirds). Additional search terms were used to search specific turtle and seabird species caught as bycatch in the New Zealand surface longline fishery and alternative terms were used for "bycatch mitigation", "soak period", and "surface longline". For example, "sooty shearwater" AND "incidental catch reduction" AND "fishing period" AND "pelagic longline". The first 50 results for each search combination were screened, with all results bearing relevance to the project being collated and saved using the open-source reference management system Zotero. References were saved according to which bycatch taxon they pertained to (turtle or seabird). These search databases were then combined and duplicated references were removed. These final references were deemed to be of direct relevance to this review and were examined in full to extract relevant information.

3.2 Task 2: Analysis

Once all mitigation measures with potential to reduce seabird and turtle bycatch had been identified, collated, and reviewed (as seen in Table 1), an analysis of the potential effectiveness of each measure was carried out. An in depth description of current literature on each mitigation measure is provided for both seabirds (Section 5) and turtles (Section 7). The analysis table (Table 2) includes a description of the effectiveness of measures for both seabirds and turtles, as well as factors affecting ease of implementation and any potential barriers to implementation. This analysis table was used to identify which measures would be best suited to addressing the issue of seabird and turtle bycatch during the soak period of surface longline operations in New Zealand's waters. Measures put forward in recommendations were typically those characterised by effectiveness paired with ease of implementation and limited barriers to their implementation.

[1] Abandoned, Lost or otherwise Discarded Fishing Gear

4 Overview of Factors Affecting Surface Longline Fishing

4.1 Controlling Longlines in the Water Column

Controlling longlines, particularly their depth, is an important factor in pelagic longline fisheries. As with most pelagic fauna, the vertical distribution of the target fish species in these fisheries is influenced by behaviour responding to a host of abiotic and biotic such as the thermocline, the oxycline, light attenuation, as well as distributions of both predator and prey species.

To control a longline, an understanding of longline components and their configurations is needed (described in Domingo *et al.* (2014) and He *et al.* (2021)). It is important to understand that when fishing using longlines, the aim is to set the gear at the depth of the target species composition depth. However, the actual depth that longline gear fishes at is influenced by the set configuration, such as number of hooks between floats, the length of float line and branchlines, distance between branchlines and sagging rate of the mainline, as well as environmental factors such as wind and currents Bigelow *et al.* (2002).

A significant aspect affecting overall set depth of longlines are the sagging or curve within the mainline, between float lines. These curves, depicted in Figure 1, are mathematically described by the geometry and physics calculations of catenary curves. The sections or segments of longline mainline between floats are called baskets, and the curves they theoretical form in the water dictate the minimum and maximum depth range of a longline set. Hook depth starts with the length of float line from the surface, and subsequent hook depths from there are inferred through catenary geometry. However, a difference exists between the inferred depth calculated through catenary geometry and observed depth, a term called "shoaling".

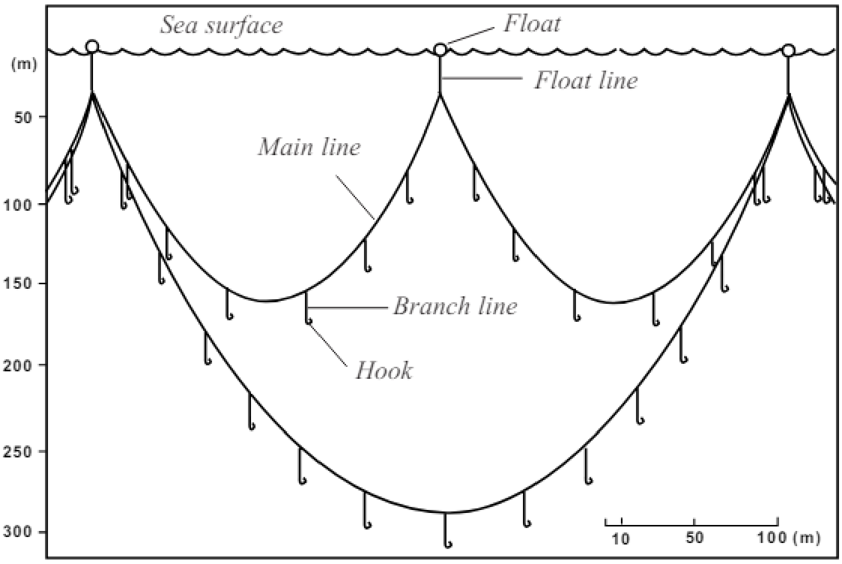

Figure 1. Diagram showing Catenary Curves seen in longline fishing gears (Sakagawa *et al.,* 1987).

4.2 Setting Surface Longline Depth

4.2.1 Number of Hooks and Branchlines Between Floats

The number of branchlines per basket can be highly variable depending on the fishery and target species. As a rule of thumb, when there is an increase in the number of branchlines (i.e. hooks), there will be an increase in the sagging or catenary curve of the mainline between floats, enabling the basket to fish a broader depth range, with the hooks in the middle of the basket able to, theoretically, fish at a greater depth than those near the floats.

4.2.2 Floats

As in Figure 1, floats are attached to the float line and extend from the surface to a desired depth, from where the mainline hangs. The addition of midwater floats, often referred to as “moneymakers in New Zealand’s surface longline fishery, can also be used to ensure the mainline remains at the required depth range. For example, Figure 2 shows the difference between a conventional longline configuration against a setup that includes midwater floats. Using a midwater float setup enables longlines to be fished at a narrower depth range, meaning more of the gear can be set at the desired depth of the target stock. However, the use of midwater floats lightens the weight of the in-water gear, and can make the gear more susceptible to instances of shoaling due to ocean currents (Shiga *et al.* 2008)

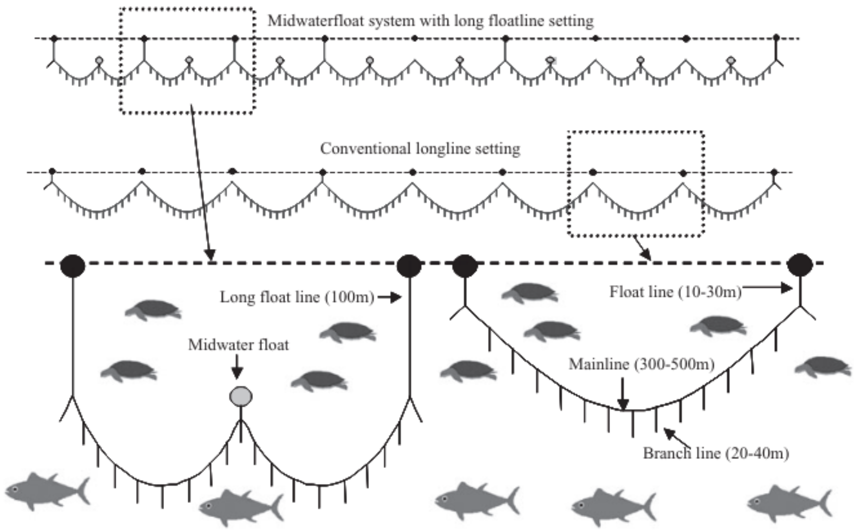

Figure 2. Shows a variety of midwater float longline configurations (Shiga *et al.,* 2008).

4.2.3 Weighting

Weighting is used to both ensure the gear remains at the desired depth, as well as sink the gear in the first place. Typically, fishers will use gear that sinks and to achieve a greater depth may add additional branchlines within a basket to enhance the catenary curve and thus fishing depth. For example, in the Hawaii-based swordfish fishery where shallow sets are used, only 3 to 5 branchline per basket are used (Swenarton and Beverly, 2004). When targeting deeper dwelling species, the number of branchlines is increased, from 7 to 12 and 15 to 18 for targeting bigeye and bluefin tuna, respectively (Miyake *et al.* 2004). These changes result in larger catenary curves and thus creating a deeper set (Figure 1).

However, another weighted system can be used, which does not require the additional float line (which would add to hauling and storage). Instead, this method uses a pair of floats and float lines attached to the mainline, with an empty section of mainline between the floats (50

m) (Figure 3). This mainline then runs down to a weight (3 kg in this example, two per basket), attached with a standard longline clip/snap. The distance between the float and weight can then be set as the shallowest hook in the basket (100 m for example). This essentially enables portions of the mainline to act as additional float line, without having to add more float line. Other methods of adding a single weight to the centre of the basket, runs the risk of collapsing the curve. Beverly *et al.* (2004) describes this method and suggests a rectangular shape should theoretically form when conducted at an at-sea trial, aiming for a sagging rate of 0.85. However, in reality, the trials showed that a significant sag in the line still occurs between the lead weights, meaning the line fished at a range of depths, but importantly, all below the target depth of the shallowest hook (Beverly *et al.* 2004).

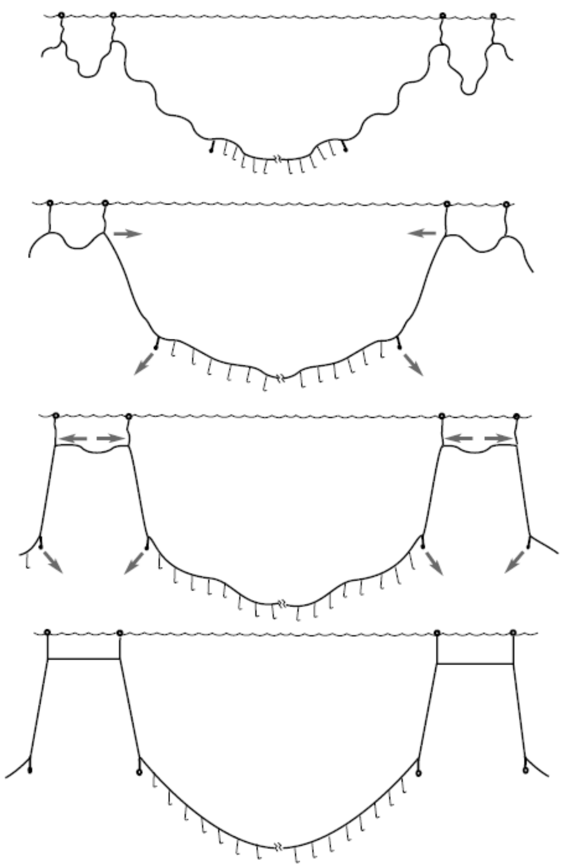

Figure 3. Shows a weighted surface longline configuration (Beverly et al., 2004).

4.3 Setting Speed

The method that the gear is deployed will also have an influence on the depth longline gear fishes at. Longline fishers may use a device called a line setter to control how much line is paid out. Without using a line setter, a method of "towing the line" is used, where the amount of mainline paid out is equal to the distance the vessel has travelled. Typically, this results in shallower set gear, with smaller catenary curves and thus reducing the effective fishing depth range. When using a line setter, the mainline can be shot at a greater speed than when towing the line, with the expectation that catenary curves form, enabling a larger range and greater fishing depth to be achieved. Towing the line and theoretically achieving a "flat" mainline, would correspond to a Sagging Rate (SR) of 1.0, while a deep-set catenary curve might have a SR of 0.5. An average SR would be around 0.75 (Swenarton and Beverly, 2004). Figure 4 provides an overview of how a sagging rate can be calculated using a weighted configuration.

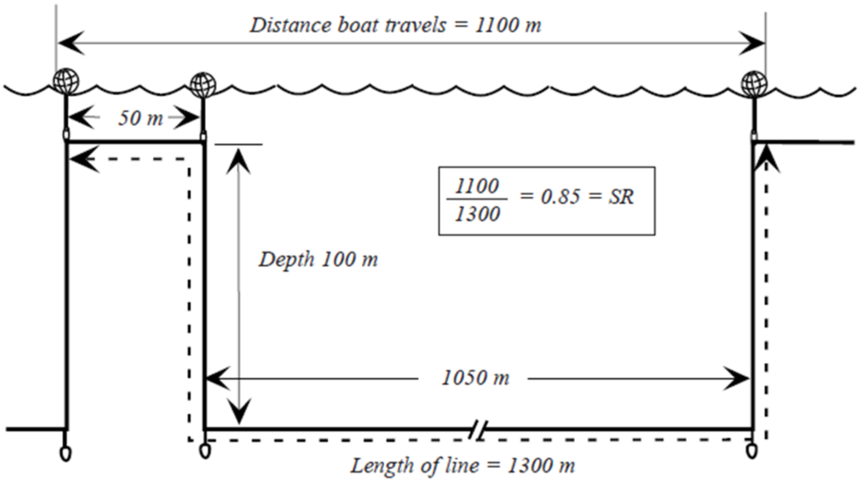

Figure 4. Demonstrates how sagging rate can be calculated using a weighted configuration for surface longlines (Beverly *et al.,* 2004).

4.3.1 Factors Causing Shoaling of Longlines

Where longlines are improperly set or disturbed by biotic or abiotic factors, they may return to the sea surface - this is referred to as shoaling. Shoaling is undesirable for fishers, firstly because it takes baited hooks out of the depths where catches are highest, and secondly, it because it increases the likelihood of bycatch of ETP species associated with the sea surface, such as turtles and seabirds.

Bach *et al.* (2009) completed a study assessing the factors effecting surface longline shoaling, fitting generalized linear models (GLMs) to model the effects of several explanatory variables on longline shoaling. For data collection, longlines composed of 20-26 baskets, each with 25 hooks were deployed with Temperature Depth Recorders (TDRs) to record fishing depth once every minute. The results of the study demonstrate that while catenary geometry can give an idea of expected longline shape, it cannot directly infer maximum fishing depth, nor hook depth distribution. Main predictors of longline shoaling were found to be the shape of the mainline (the greater the tangential angle, the greater the likelihood of shoaling occurring, and the current shear and direction of setting relative to it. Importantly, this study discounted all TDR data obtained on baskets with catches. These were removed from analysis because of the potentially significant impact of fish capture on shoaling and longline depth. Bach *et al.,* states that the depth at the middle of each basket can be "greatly modified by fish capture irrespective of whether the catch occurs near the middle position of the line or not" (Bach *et al.,* 2009). This is confirmed by TDR data from a basket that experienced a capture of a 50kg swordfish on a hook (Figure 5; Okazaki *et al.,* 1997) which demonstrates that fish capture can be a significant factor causing surface longline shoaling, potentially exposing baited to hooks to seabirds.

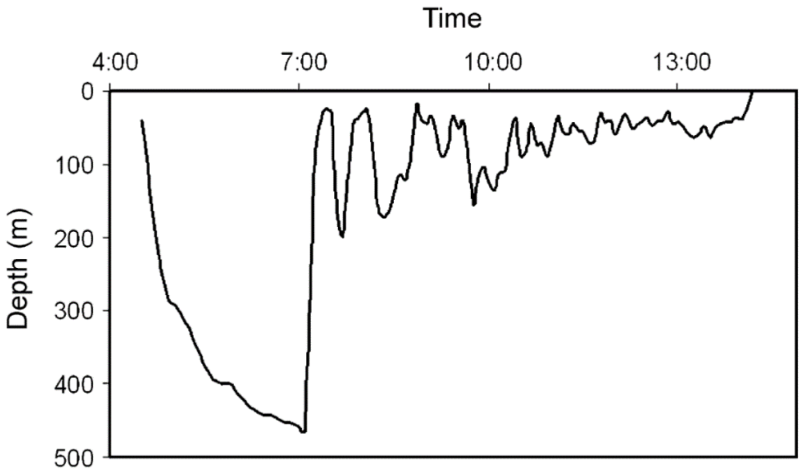

Figure 5. TDR data showing time series data of the depth of a hook that captured a 50kg swordfish (Okazaki *et al.,* 1997).

5 Overview of Seabird Bycatch During the Soak Period of Surface Longlines

New Zealand's highly abundant and diverse seabird populations present a high-level of interaction risk with surface longline fisheries. Approximately 145 seabird species are found throughout New Zealand waters, with roughly a third of these being endemic. As a result, the sound management of fisheries impacts on these seabird populations represents one of the DOCs most important conservation goals. The spatial distribution of these seabird species varies greatly, with some species foraging in inshore waters (e.g. little penguin (*Eudyptula minor*)), and others covering great distances on foraging and migratory trips (e.g. shearwaters and albatrosses). New Zealand represents an important breeding location for many of these species due to its land-based predator-free offshore islands, allowing birds to rear young in a relatively undisturbed setting (Fisheries New Zealand, 2020). Together, breeding populations and species that venture into New Zealand's waters to forage, make the country's waters among the most densely populated by seabirds across the world.

Despite the different biological characteristics found across seabird families, most species' reproductive traits make them vulnerable to anthropogenic effects and human-induced mortality. Many seabirds take between three and six years to reach sexual maturity and once breeding, often lay few eggs per breeding cycle (e.g. albatrosses and petrels typically only lay one egg per cycle) which can be as infrequent as every two years in some species (e.g. Antipodean and Gibson's albatrosses (*Diomedea antipodensi* and *Diomedea antipodensis gibsoni* respectively) (Fisheries New Zealand, 2020). Seabird foraging behaviours also make them likely to interact with longline fisheries, a potential source of human-induced mortality. A common foraging strategy for many seabird species involves scanning the surface of the sea for potential prey items located on, or close to, the surface. Once found, individuals will either land on the water to forage on prey items at the surface or will dive into the water and swim to depths of up to 90 metres (e.g. sooty shearwater (*Ardenna grisea*)) (Taylor, 2009). The vulnerability of seabirds to human-induced mortality, combined with their spatial overlap with longline fisheries throughout New Zealand's waters and their likelihood of interaction with fisheries caused by foraging behaviours, make seabird species a high-risk bycatch species for New Zealand's surface longline fleet (Fischer *et al.,* 2024).

Historically low levels of observer coverage of between 5-10% has made accurately describing New Zealand's surface longline fleet's impacts on seabirds a challenge. It is widely documented in the literature that seabird bycatch is underestimated due to a combination of reliance on haul data (Brothers *et al.,* 2010; Zhou *et al.,* 2019) and limited observer coverage (Fisheries New Zealand, 2023). However, there is a good understanding in the literature of seabird interaction and bycatch in surface longline fisheries during both the setting and hauling of gear. These are widely documented as the periods at which seabirds are at the highest risk of becoming hooked and caught as bycatch, potentially due to likelihood of observing a bycatch event at these phases of longline fishing. As a result, global efforts to curb seabird bycatch across global longline fisheries largely focus on these phases of fishing, particularly during longline setting, where the majority of observed hooking mortality occurs. This is reflected in the Agreement on the Conservation of Albatrosses and Petrels' (ACAP) Advice for Reducing the Impact of Longline Fisheries on Seabirds (ACAP, 2023), which places emphasis on mitigation measures that curb seabird bycatch during these fishing phases such as branchline weighting, night setting, bird scaring lines (tori lines), hook-shielding devices, and underwater bait setting devices (ACAP, 2021). New Zealand, party to ACAP, recently updated its mandatory bycatch measures for the surface longline fleet to bring them in line with ACAP's full "three out of three" policy for mitigation measures to be introduced in October 2024. These new rules will mean fishers who choose not to use hook shielding devices must:

a) Use tori lines (bird scaring streamers);
b) Use line weighting to legal specification[2];
c) Set their gear at night.

(Ministry for Primary Industries, 2024)

These mandatory measures are also supplemented by non-regulatory mitigation measures that are encouraged during times where there is a high risk of seabird interaction, including retention of all used bait onboard for the duration of hauling, decreased setting speed, and additional weights to increase the sink rate of the gear (Fisheries New Zealand, 2023).

While these mandatory and voluntary measures will help achieve New Zealand the vision of working towards zero fishing-related seabird mortalities, as laid out in the National Plan of Action for Seabirds 2020[3] the potential for seabird bycatch during the soak period of surface longline fishing is not described. Historically, this phase of longlining operations has not been associated with bycatch of seabirds, but instead other pelagic ETP fauna such as turtles, cetaceans, and elasmobranchs. However, in New Zealand there have been reports of surface longlines being brought to the surface where they are accessible to seabirds, leading to increased seabird bycatch rates. This may contribute to the higher seabird bycatch rates in New Zealand than in other countries with similar ecological conditions and fisheries.

[2] Legal weight specifications require the application of: 40 grams within 0.5 metres of the hook, 45 grams within 1 metre of the hook, 60 grams within 3.5 metres of the hooks, or 98 grams within 4 metres of the hook.

[3] https://www.mpi.govt.nz/consultations/national-plan-of-action-for-seabirds-2020/

6 Review of Seabird Bycatch Mitigation Measures

To find potential seabird bycatch mitigation measures applicable to the soak period, this section reviews currently applied mitigation measures and longline fishing variables that may be adjusted to minimise bycatch of seabirds during the soak period. There are two key approaches that could be taken either exclusively, or ideally in combination, to reduce the likelihood seabird interaction and bycatch during the soak period. The first is to set deeper longlines with modifications that reduce their likelihood of shoaling to the surface via either hooked marine fauna, or environmental conditions such as currents, tides and winds. The second is to modify longlines such that if they shoal to the surface, the exposure of baited hooks to seabirds is minimised.

6.1 Gear Modifications

6.1.1 Longline Weighting Regime and Set Depth

As discussed in Section 3, there are a variety of surface longline configurations that may help fishing gears remain stable at the intended target depth. As discussed above, the best mitigation measures against seabird bycatch during the soak will either minimize the likelihood of the mainline being exposed at the surface or, where this does occur, minimize the exposure of baited hooks at the surface. Using a combination of line weighting (via weights and the number of hooks) paired with the lengthening of certain constituent parts of the longline, it should be feasible to help better mitigate against bycatch of seabirds during the soak.

Line weighting is already commonplace across surface longline fisheries throughout the world, with well-developed ACAP guidelines in place suggesting specific weightings at various distances from hooks (ACAP, 2023). However, this practice is currently implemented with only seabird bycatch from setting and hauling in mind, with weights designed to increase gear sink rate and hauling angle to minimize the exposure of baited hooks to seabirds (Sacchi, 2021). In the context of this project, weighted hooks and branchlines may play an important role in mitigating seabird bycatch during the soak. In scenarios where portions of the mainline are suspended at the surface, weighted branchlines, particularly at the hook, should help maintain baited hooks below the surface. This should reduce their probability of being detected by seabirds, thereby decreasing diving attempts and likely bycatch of seabirds. Furthermore, the use of weighted branchlines will increase the overall weight of the longline, reducing the likelihood of it shoaling to the sea surface.

As displayed in Figure 3, using weights in conjunction with longer float lines allows longlines to be set at and, crucially, held at greater depths (Beverly *et al.,* 2004). Deeper sets not only reduce the probability of turtle bycatch but would also likely reduce the probability of hook exposure at the surface during the soak. In the event of improper shooting or marine fauna pulling the mainline vertically towards the surface, sufficient weighting should help set and hold the mainline at its correct target depth. Additionally, setting longlines deeper increases the distance hooks must travel during the soak to reach the surface, further reducing the likelihood of exposure. Pierre and Goad's (2013) seabird bycatch progress report for the DOC shows TDR data for a series of sets with depths considerably shallower than 50m (at times as shallow as 25m) (Figure 6) (Pierre and Goad, 2013). Setting longlines this shallow, particularly over daylight hours, poses a greater risk of longline shoaling via marine fauna or water conditions (currents and tides). Furthermore, baited hooks at these depths may even be visible to diving seabirds with the capabilities to comfortably dive to these depths, leading to their bycatch and potential shoaling of the mainline.

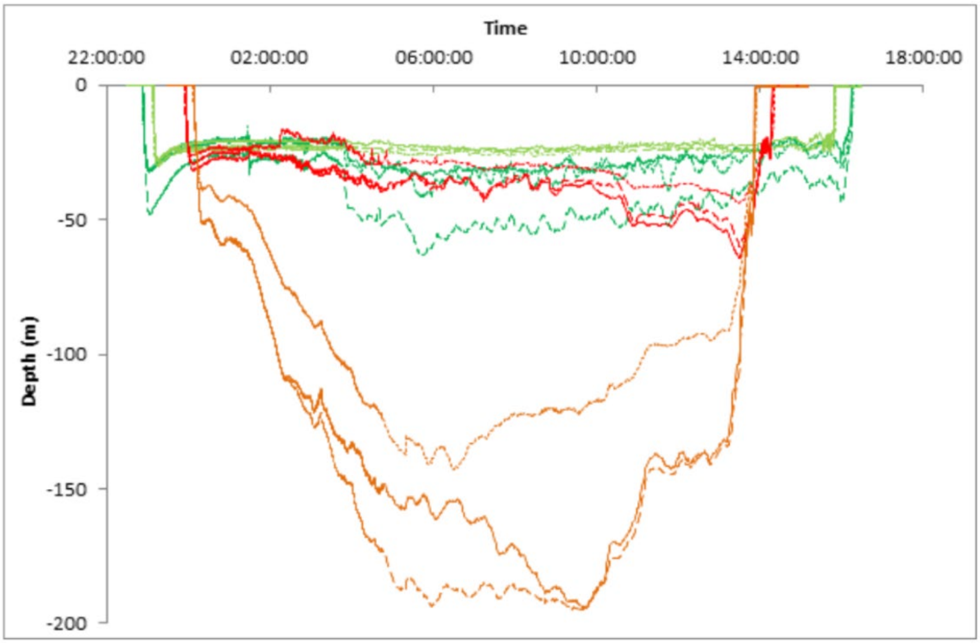

Figure 6. Shows TDR data (depth against time) for a series of sets fished by the New Zealand surface longline fleet in 2013 (Pierre and Goad, 2013).

Hook number and spacing are also an important factor to consider with respect to longline weighting. Number of hooks, hook spacing, and hook size are all factors that affect the weight and shape of a longline when it is soaking. For the purposes of reducing seabird bycatch during the soak, there is a trade-off between reducing the likelihood of the mainline shoaling to the surface, and reducing the number of hooks available to birds should the mainline end up at the surface. In theory, having a larger number of hooks per basket should increase the overall weight of the line per unit length, meaning where hooks are brought to the surface by marine fauna, the remaining hooks should be kept submerged as the line sags significantly into deeper waters. Work by Seco Pon *et al.* (2007) found semi-pelagic longline configurations in the Argentine kingclip fishery to have hooks located too close to surface floats, presenting an opportunity for seabird bycatch during setting. Although no tests were carried out, suggestions included the removal of 24 hooks either side of each buoy. This may be applied to help mitigate against seabird bycatch during the soak, where hooks at either end of the basket are closest to the surface (Seco Pon *et al.,* 2007). Employing a deep-set or midwater float configuration should also provide an alternative solution to the issue.

There are some potential disadvantages to using longlines with additional weights, particularly on branchlines. Firstly, gears with increased weight put greater strain on vessels and their machinery during hauling and setting, while also requiring greater space for storage. Secondly, gears with more weights, particularly on branchlines, potentially increase the risk of crew becoming injured by flyback events. These occasionally happen where either a 'bite off' occurs where a branchline is bitten off, or a 'tear out' occurs where the hook is torn out of a fish. Both may cause the tensioned branchline, with weights and hooks attached, to fly towards the vessel and crew at speed. Though flyback events are rare, they have the potential to lead to severe injury and even deaths onboard longline vessels (ACAP, 2021; Rawlinson *et al.*, 2018). One potential safety measure to reduce the dangers of flybacks is the use of sliding weights instead of fixed weighted swivels. This measure, along with others, is outlined in ACAP's advice on improving safety during the hauling of surface longlines (ACAP, 2021).

6.1.2 Longline Configuration

Longline configuration presents an important factor in reducing hook exposure to seabirds during the soak period. Length of the mainline, float lines, and branchlines will all have an impact the longlines likelihood of shoaling either by improper setting, or by vertical force exerted by captured from marine fauna. One simple configuration adjustment, discussed in the previous section, is the use of elongated float lines to ensure the first hooks along the mainline are set at, or close to, the target depth (Beverly *et al.,* 2004). This may be paired with a deep weighted longline set up (Figure 2) or may be part of a midwater float setup as seen in Figure 2. From the standpoint of minimising the risk of shoaling, the weighted deep longline set up in Figure 3 would be preferable, as the mainline is held at lower depths, and there aren't any floats incorporated into the system to exert a buoyancy force on the mainline, potentially encouraging shoaling.

Another potentially important variable in longline configuration for seabird bycatch prevention is the length of branchlines. These are unlikely to have a particularly significant effect on mainline shoaling but have the potential to effect baited hook exposure where longline shoaling does occur. Longer branchlines with weights towards the hook will ensure hooks remain submerged, potentially to the depth of the full length of the branchline. This may prevent the majority of seabirds with poorer diving capabilities (e.g. *Diomedeidae*) from accessing and ingesting these baited hooks, leading to reduced bycatch levels per mainline shoaling event.

6.1.3 Hook Size and Modifications

The literature contains little research on the impacts of hook type or dimension. Suggestions around which hook type is most effective in reducing seabird bycatch should tempered by the difficulty in dissociating the influence of hook type from bait choice (Sacchi, 2021). Despite the challenges in demonstrating a hook's effectiveness in reducing seabird catches, there are suggestions that circle hooks are better designed to reduce hooking of seabirds. This is due to their wide bend potentially inhibiting ingestion, as well as their inward-facing barbs reducing the risk of hooking the body or wings of seabirds (Sacchi, 2021). Perhaps a more compelling factor is circle hooks' efficacy in reducing bycatch of other species in surface longlining (e.g. turtles).

6.2 Temporal and Spatial Measures

6.2.1 Night Setting

Night setting is well documented as an effective seabird bycatch mitigation measure that requires no gear modification, simply a change in fishing time. The effectiveness of night setting may be the result of lower seabird activity in offshore areas during the night, or due to seabirds being unable to rely on visual cues to help them locate baited hooks (Bull, 2006). Previous studies conducted on Japanese and New Zealand surface longline fleets have found seabird catches during the day to be up to five times greater than those seen at night (Klaer and Polacheck, 1998). One study by Gilman *et al.* (2023) assessing the effects of set depth as well as night setting in a surface longline fishery in the Pacific Ocean targeting albacore tuna, with an apparent high rate of albatross bycatch. It was found that both time-of-day and fishing depth did not significantly affect the catch rate of albacore tuna but drastically reduced albatross and seabird bycatch rates (by more than 99%) (Gilman *et al.,* 2023).

While night setting is largely implemented to ensure baited hooks remain undetected by seabirds as they sink to the intended target depth, ensuring the soak period is during darkness hours should have the same effectiveness in reducing in soak bycatch, as seabirds will be unable to detect baited hooks at the surface and thus will not dive on and interact with them. Applying the theory behind night setting to the soak period would require longlines to be set an hour or so after dusk and retrieved before dawn. While this method might increase the potential exposure of hooks to seabirds at the setting phase, there are now effective mitigation measures that are specifically designed to mitigate against seabird bycatch at this stage of fishing (hook-shielding devices, underwater bait setting etc.). However, there are some limitations to this measure that may result in fisher resistance to implementation. Enforcing dusk setting and night soaking not only puts crews under strenuous conditions, fishing through the night, but it also drastically reduces the available window in which vessels would be allowed to fish, particularly during summer when there be as few as eight hours of darkness. As a result, it is expected very few crews would voluntarily adopt this measure. In fact, Kroodsma *et al.* (2023) applied machine learning to four years of GPS[4] data on the global longline fleet (roughly 5,000 vessels) and found that only 3% of all longline sets take place at night, with many vessels setting during dawn; an active time of day for many seabirds (Kroodsma *et al.,* 2023). While soaking gear overnight is a potentially powerful mitigation measure to reduce seabird bycatch in the soak, it may be challenging to implement and as a result, should be reserved as an emergency measure where a limit reference point (LRP) is reached.

6.2.2 Fishery Closures

Fishery closures are a highly effective bycatch mitigation measure and are used by fisheries managers across the world. Closures may take on a variety of forms. Firstly, they may vary spatially as areas in which fishing is prohibited or may be set vertical depths between which vessels must not set their gears. They also may vary temporally, with some closures being applied on a permanent basis, some during seasons where high bycatch rates are expected, and others where a bycatch LRP is reached over a given timeframe. For the purposes of this review, it is likely that any seabird bycatch LRP reached will be the result of seabird bycatch levels being unacceptable due to high bycatch rates during setting and hauling, where rates are at their highest. However, closures still present an absolute mitigation strategy for seabird bycatch during the soak, albeit an indirect one. Seasonal closures around seabird breeding sites have been cited as a key tool in reducing seabird bycatch in Antarctic demersal toothfish fisheries (Trebilco *et al.,* 2010; Waugh *et al.,* 2008). These types of spatio-temporal closures could be applied to New Zealand's surface longline fishery, either through LRPs for each given Fisheries Management Area (FMA), or through the closing of certain areas known to have high seabird bycatch at certain times of the year, for example, closing areas along the west coast of the South Island during the autumn and early winter months where high bycatch rates of white-capped albatross, Buller's albatross, and Westland petrels are observed (Fisheries New Zealand, 2023).However, a key barrier to implementation of these spatial closures is the broad distribution of vulnerable seabirds throughout the fishing grounds of the surface longline fishery in New Zealand (Fischer *et al.,* 2024), making the decision of which areas to close and which to leave open a challenging one. Furthermore, limited historical observer data on the spatial distribution of seabird bycatch rates means it would be hard which areas should be prioritised for fishery closures.

[4] Global Positioning System

6.3 Fishing Practices and Procedures

6.3.1 Bait Type and Condition

The literature on seabird bycatch mitigation measures does not contain many studies into the effects of bait type on seabird bycatch rates. However, a 2020 study by Gilman *et al,* conducted a global meta-analysis of existing estimates of risk of capture for bycatch species on different longline baits. Of the seven records assessing bait effects on seabirds used in the study, albatross were the main species in five. The meta-analysis identified difficulty in removing bait from the hook as a potential risk factor for bycatch. Squid bait was identified as being more difficult to remove compared to fish bait, causing a higher degree of competition between seabirds and therefore an increase in individual risk taking and concomitant catch risk during scavenging (Gilman *et al.,* 2020).

Bait condition is another factor that should be considered, bait is stored frozen on fishing vessels, before being either applied to hooks while frozen, or being left to thaw prior to baiting. It has been documented in several studies that thawed baits sink faster than frozen baits (Bull, 2006). While this largely applies to the setting of gears, properly thawing bait will help the mainline sink to its desired target depth allowing proper soak depth. Another potential alteration that can be made to fish bait is the puncturing of the swim bladder to increase sink rate. Again, this is unlikely to have an effect on seabird bycatch during the soak, but to improve sink rate during the setting phase, these should be punctured (Gilman *et al.,* 2019).

6.3.2 Dyed Bait

Results from bait dyeing studies have shown mixed results. The theory behind this practice is to help conceal bait when in the water by soaking bait in a mixture of blue food colouring and water (ACAP, 2021). Boggs (2001) found blue dyed bait to significantly decrease interaction rates for black-footed albatrosses compared to undyed bait. Ochi *et al.,* 2011 also found blue-dyed bait to reduce incidental catches of seabirds for both blue dyed squid and fish compared to non-dyed bait. Gilman *et al.* (2005) also presents evidence of the potential effectiveness of blue dyed bait across other studies (McNamara, 1999; Gilman *et al.,* 2003). One key advantage to blue-dyed bait is that any positive effects seen at the set, should also carry over through the soak and into the hauling phase, as Gilman *et al.* (2016) found 98% of records showing dyed bait to retain its blue dye upon hauling. Despite the potential effectiveness of blue dyed bait, the literature does cite some potential disadvantages. Firstly, its effectiveness is still debated, with some studies demonstrating other measures to be more effective (Gilman *et al.,* 2007b). Secondly, bait cannot be bought pre-dyed, meaning it must be dyed for twenty minutes prior to hooks being baited. And finally, without observer presence or REM enforcement and compliance monitoring is very difficult. However, despite potential issues, bait dyeing throughout fishing hours should be seen as a potential supplementary measure where seabird interaction is highest and could be taken forward by the DOC for efficacy testing in the fishery.

6.3.3 Underwater Setting and Side Setting

Underwater and side setting are both measures to help reduce seabird interaction during the setting phase of longline fishing. As a result, no research examining their potential to reduce seabird interaction and bycatch during the soak was found during the literature review. Both measures are intended to help sink the mainline while it is in proximity to the fishing vessel where seabirds are less likely to attempt to dive on and interact with the baited hooks. Underwater setting is carried out using a chute leading directly into the water, meaning hooks are deployed immediately into the water without being exposed to the sea surface, thereby reducing the timeframe in which birds can interact with sinking hooks. While side-setting refers to the setting of the mainline over the side of the vessel instead of over the stern, meaning the baited hooks are in the water before they pass the stern of the vessel, again reducing the window of opportunity for seabirds to dive on and interact with the baited hooks (Sacchi, 2021). While both measures are designed to minimize seabird interactions and bycatch in surface longline fishing during the set, properly setting gears at the appropriate depth will reduce the likelihood of shoaling of the mainline, leading to potential seabird bycatch during the soak.

6.3.4 Line Shooters

Similar to underwater setting and side setting, line shooters represent a bycatch mitigation measure used during the setting phase of longline fishing. The mainline is a hydraulic device designed to deploy the mainline at a greater speed than the fishing vessels speed through the water. This removes tension from the mainline, altering the shape and depth profile of the mainline in the water column by allowing a greater sagging rate, caused by baited hooks sinking at a faster rate to increased depths (Clarke *et al.,*2014). As such, theoretically, line shooters should potentially reduce the likelihood of longline shoaling by ensuring proper setting of the mainline. However, some experiments have shown line shooters to have the opposite effect on sink rate, causing the mainline to sink at a slower rate. Robertson *et al.,* (2010) observed this result when setting a loose mainline with a line shooter. This was thought to be the result of turbulence from vessel propeller interfering with the mainline sink rate (Robertson *et al.,* 2010). Line shooters could present an effective seabird bycatch mitigation measure for the New Zealand surface longline fleet, but further research should test the use of line shooters forward of the stern corner to avoid interference from propeller turbulence (Clarke *et al.,* 2014).

6.4 Other

Other mitigation measures that have previous been tested and may be applied to reduce seabird bycatch during the soak period include acoustic, visual, and magnetic deterrents. Acoustic deterrents that have previously been tested include firing shotguns or canons, beating on steel hulls, commercial devices emitting high frequency noises or distress calls at high volume. However, none of these devices or noises have been shown to significantly reduce bycatch of seabirds and, given they are designed to mitigate against bycatch in the vicinity of fishing vessels, their implementation during the soak period would be challenging, with little infrastructure from which acoustic deterrents could be emitted. Even in cases where such deterrents were to work, there are concerns that habituation would cause any positive observed effects to be short lived (Sacchi, 2021).

Visual deterrents include the use of lasers and innovative buoys with static visual stimuli to deter seabirds. Rouxel *et al.* 2023 attempted to use a 'looming-eyes buoy' to deter seabirds from interacting with gillnet fishing gears (Figure 7). No effects of this buoy were detected on seabird bycatch rates. Furthermore, as discussed above, the soak period provides limited buoyage on which deterrents can be mounted to reduce seabird bycatch. Finally, an experimental magnetic deterring device designed to interfere with birds' magnetoreceptors was trialled on a Japanese tuna longliner, however no effects on seabird behaviour were detected (Bull, 2007).

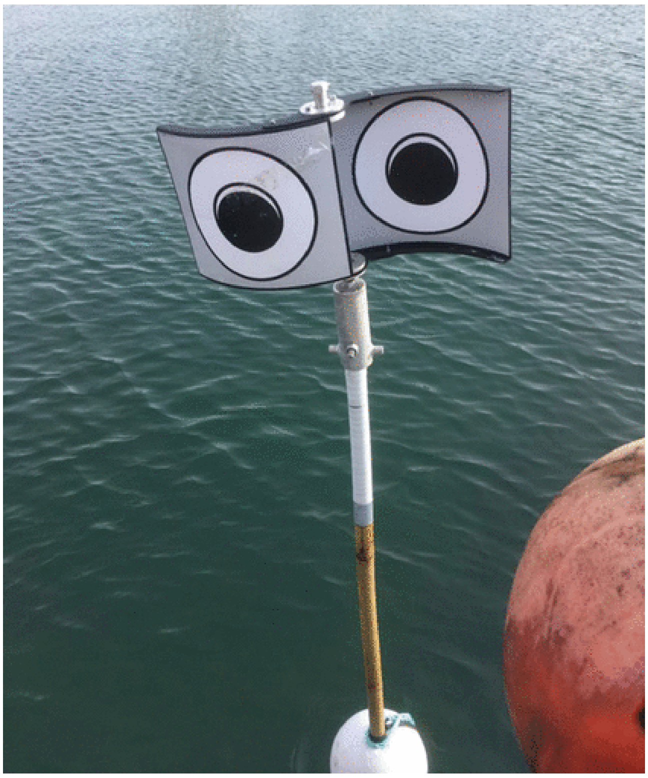

Figure 7. Shows an example of the 'Looming-eyes buoy' trialled in gillnet fisheries (Rouxel *et al.,* 2023).

7 Overview of Turtle Bycatch During the Soak Period of Surface Longlines

Bycatch of marine megafauna in pelagic fisheries has long been recognised as an issue, with impacts upon turtle populations and mitigation measures frequently reviewed (Clarke *et al.*, 2014; Gilman *et al.*, 2006; Kiyota *et al.*, 2004; Swimmer *et al.*, 2017; Wallace *et al.*, 2013). Surface longlines in particular, such as those targeting bigeye tuna and swordfish, are believed to pose the greatest risk to marine turtles during various stages of gear deployment (Godoy, 2016), with heightened levels of interactions during the soak period, and when gear is set at shallow depths (<60m) (Swimmer *et al.*, 2017).

Leatherback (*Dermochelys coriacea*), green *(Chelonia mydas)*, hawksbill *(Eretmochelys imbricata)*, loggerhead *(Caretta caretta)* and olive ridley *(LepdocChelys olivacea)* turtles occur in New Zealand waters, and are protected by the Wildlife Act 1953[5] (Godoy, 2016). Across New Zealand fisheries, a reported 19.5 sea turtles were caught per year between 2007-08 to 2020-21, averaging at 0.019 turtles per 1000 hooks – just meeting the WCPFC interaction limit recommendation of 0.019 turtles per 1000 hooks (Brouwer and Bertram, 2009). The most frequently interacted with were leatherbacks (n=217; 79.5%), followed by green turtles (n=25; 9.2%), and most captures occurred in surface longline fisheries targeting bigeye tuna *(Thunnus obesus)* or swordfish *(Xiphias gladius)*, through January to April (Dunn *et al.*, 2022). Research by Dunn *et al.* (2024) highlights that the strongest association with leatherback bycatch is in the swordfish fishery, which is consistent with international findings for this species. Leatherback turtles are estimated to have declined by 95% since the 1980s (Tapilatu et al., 2013), with incidental bycatch in fisheries identified as a primary cause, in line with the above recorded interactions that show leatherbacks as one of the most frequently encountered turtle species in New Zealand fisheries. This, coupled with decreasing population rates in the eastern and western pacific, that are projected to decline 96% by 2040 (Benson et al., 2020), thus highlights the urgent need to find a solution to mitigate their bycatch rates. This section will therefore primarily pertain to leatherbacks and green turtles, the two species also most frequently interacted with across the New Zealand surface longline fishery Loggerhead turtle interactions are also considered due to the greater abundance of research compared to green turtles. Since both species belong to the same hardshell family *(Cheloniidae)*, inferences can be made from the available data.

Observer reports from longline fisheries in New Zealand demonstrate that, out of the recorded interactions, most turtles were caught hooked in their flipper or body, and only a couple hooked in the mouth or tangled with gear (Dunn *et al.*, 2022). Data gaps exist around how most turtles were captured and whether they were released with or without hooks, as these details are often undocumented. Despite this paucity in data, turtle interactions are a known issue, and Godoy (2016) estimated that turtle interactions have previously exceeded WCPFC recommendations in the 2009 – 2015 fishing periods, across New Zealand Fisheries Management Areas (FMAs) 1, 2 and 9. Moreover, studies by Coelho *et al.* (2015) and Santos *et al.* (2013) on turtle bycatch in the Atlantic found species-specific interactions with gear; leatherbacks were primarily caught externally hooked on flippers or entangled with the gear, whereas hardshell species were more often hooked in the mouth or oesophagus. In line with these observations, most studies investigating turtle bycatch mitigation measures for longline fishing gear focus on hook modifications (type, size, and offset), and bait type. This review

5 https://www.legislation.govt.nz/act/public/1953/0031/latest/whole.html

therefore considers these factors in most detail. Other relevant mitigation measures specified by the Bycatch Management Information System[6] (BMIS) have also been explored, with the depth of their analysis proportional to the amount of research available on each technique.

Aside from physical abiotic factors, foraging behavioural patterns also influence turtle bycatch rates, as their long life-histories, coupled with large-scale habitat area usage, increases their risk of interacting with fishing vessels (Riskas *et al.*, 2016). A neritic species, green turtles in the Pacific live in shallow bays, feeding on algae and associated species. However, subadult and adults have also been documented in deeper oceanic foraging grounds (Kelez Sara, 2011). A 2011 meta-analysis of turtle bycatch and foraging ecology concluded that for turtles feeding in the open ocean, studies are difficult to conduct thus large amounts of their behaviours remain unknown (Kelez Sara, 2011). Some studies have begun to show links with turtle interaction rates and sea surface temperatures. For instance, Foster *et al.*, (2012) found temperature to be a highly significant variable affecting leatherback turtle catch rates; with every 0.6°c increase in sea surface temperature, catch rate increased by 16-31%. In this study, the effect of temperature was more significant than that of total soak time, results of which were inconclusive for this species. Swimmer *et al.*, (2017) also emphasizes sea surface temperature as a strong predictor of turtle foraging behaviour, suggesting it could be used to predict the presence of leatherbacks, and mitigate turtle captures. In this Atlantic study, bycatch rates were highest for leatherbacks in sea surface temperature ranges of 23°C to 27°C. However, Dunn *et al.* (2022) suggest that the movement of fishing vessels into warmer waters is a better predictor of bycatch rates than sea surface temperature alone.

It is worth caveating across studies that slight differences in gear configurations, as well as seasons and areas, spanning different temperature ranges, are all important confounding variables that can significantly affect differences seen throughout research and literature. Conclusive differences are therefore likely related to fleet and fishery-specific factors, and the extent to which data can be extrapolated therefore remains limited.

7.1 Current Regulations and Measures

Few mandatory measures are currently in place to mitigate bycatch. Most measures revolve around the adoption of best practice, such as the general DOC guidelines for the safe handling and release of protected species[7] that are captured, hooked, or entangled in longline gear.

Increased turtle interactions over the past three years prompted New Zealand to review and remove its previous exemption to mandating the WCPFC Conservation and Management Measure (CMM) 18-04 regarding turtle mitigation[8]. Following this, measures such as the implementation of circle hooks in all longline fisheries were adopted and brought into force by New Zealand in 2023.

6 https://www.bmis-bycatch.org/mitigation-techniques

7 https://www.DOC.govt.nz/globalassets/DOCuments/conservation/marine-and-coastal/marine-conservation-services/resources/resources-for-fishers/csp-protected-species-handling-and-release-guide-2024.pdf

8 https://cmm.wcpfc.int/measure/cmm-2018-04

Both the FNZ and DOC have developed a turtle fact sheets[9, 10] providing best practice methods for the handling and release of sea turtles hooked or entangled in surface longline gear, which was distributed to fishers via the DOC Liaison Programme at the beginning of the summer season in December 2022. Despite these efforts, New Zealand still lacks comprehensive mandatory mitigation measures to prevent turtle bycatch, relying more on recommendations and best practice rather than enforceable regulations.

This approach contrasts with countries like the USA, Hawai'i, and Australia, where more stringent measures are in place. For instance, the National Oceanic and Atmospheric Administration (NOAA) plays an instrumental role in informing and implementing turtle bycatch reduction measures. Hawai'i has implemented various hook and bait restrictions, maintains 100% observer coverage on shallow-set longline vessels, and uses environmental data to predict turtle distribution, which informs fishery closures[11]. Australia also enforces strict bycatch mitigation measures, including seasonal and permanent closures of fishing areas with high turtle densities, particularly during nesting or migration periods.

While New Zealand has made some progress, there is a clear need for more robust and enforceable measures to effectively mitigate turtle bycatch in its longline fisheries. Fisheries can however adopt voluntary measures to this effect, such as those reviewed in this report.

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9 https://www.mpi.govt.nz/dmsDOCument/54925-Turtle-Handling-Release-Information-for-longline-fishers

10 https://www.DOC.govt.nz/globalassets/DOCuments/conservation/marine-and-coastal/marine-conservation-services/resources/protected-species-handling-guide-20192.pdf

11 https://www.fisheries.noaa.gov/pacific-islands/bycatch/hawaii-shallow-set-longline-fishery-interactions-leatherback-sea-turtles

8 Review of Turtle Bycatch Mitigation Measures

8.1 Gear Configurations

8.1.1 Hook design

Longline hooks can be characterised by numerous parameters, including but not limited to, hook shape (J or circle), dimensions (length, diameter point and shank gap, width, barb size etc.), offset (plane of deviation of hook shank from hook point) and material. A number of studies have been conducted on possible gear modifications to reduce fishery interactions with turtles, notably focusing on hook shape and dimensions. Hook offset has been less studied in isolation and is often included alongside other, more prominent measures in research, making it difficult to attribute significant results solely to the offset angle. The effect of the offset angle alone has not be reliably measured, and therefore it is difficult to review its efficacy as a turtle bycatch mitigation measure. Regarding hook shape and dimension, J-hooks tend to be smaller (i.e. 9/0), since the point of the hook is parallel to the shank, rendering the hook narrower. Meanwhile circular hooks are wider (i.e. 16/0) and are curved inward with the hook perpendicular to the shank (Foster *et al.*, 2012). Thus, J-hooks are more exposed, increasing the likelihood of turtle foul hooking. In this regard, it has been evidenced numerous times that circle hooks, measuring a minimum 16/0, significantly reduce the rate of turtle throat hooking and ingestion when compared to J hooks (Alessandro and Antonello, 2010; Coelho *et al.*, 2015; Foster *et al.*, 2012; Gilman *et al.*, 2007a; Long and Schroeder, 2004; Parra *et al.*, 2023). Coelho *et al.*, (2015) found this measure to have the most significant effect upon leatherbacks compared to other hard-shelled species in the Atlantic, and Foster *et al.*, (2012) also showed circle hooks (18/0 – 20/0) to significantly reduce leatherback and loggerhead bycatch. Parra *et al.*, (2023) investigated incidental sea turtle capture in a Northeast Atlantic Portuguese longline fishery, focussing on loggerheads and leatherbacks. Of the turtles seen to interact with the fishery and where hooking was detailed, 81% were recorded as hooked externally or foul-hooked in the flippers, 16% were hooked in the mouth and 1 was deeply hooked. For leatherback turtles, this was recorded alongside hook type, of which a J hook was used in 91% of turtle interactions. A study by Sales *et al.*, (2010) goes further to suggest that circle hooks may increase the catch rate of certain target species, including albacore and bigeye tuna. Moreover, Read (2007) demonstrated that larger circle hooks (18/0) may be even more effective to reduce hook ingestion due to the aforementioned increased width of the hook and turtle physiological constraints (Alessandro and Antonello, 2010), while also recommending a more precautionary approach, testing the use of circle hooks on a case-by-case basis before enforcement as a standardised conservation measure. Circle hook gear has been mandated in certain countries' longline fisheries, such as Australia's Eastern and Western longline fisheries[12], and WCPFC CMM 2018-04[13] which provides Regional Fisheries Management Organisation (RFMO) level measures.

Light sticks are another type of gear modification potentially applicable here, have limited research available. Swimmer *et al.*, (2017) found a positive relationship between loggerhead turtle bycatch probability and light stick use, with evidence that loggerheads are drawn to the

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[12] https://www.afma.gov.au/commercial-fishers/management-arrangements/management-booklets#referenced-section-15

[13] https://cmm.wcpfc.int/measure/cmm-2018-04

baited hooks when illuminated. There is limited research available here, but studies suggest avoiding their use.

A final gear configuration technique listed the BMIS is that fishing vessels should use corrodible or degradable hooks made from materials that rust or degrade quickly, so that if a turtle is hooked and escapes, long-term injury is in theory reduced. However, similar to light sticks, this is a limited area of research, and further studies are required to note potential benefits.

8.1.2 Bait

For bait, it is clear that a use of fish compared to squid bait is effective in significantly reducing turtle capture rates for some species (Clarke *et al.*, 2014; Foster *et al.*, 2012; Swimmer *et al.*, 2017). This is due to the differences in bait composition and how bait is ingested. The muscular structure of squid creates a tough yet malleable texture, whereas mackerel, with its different muscular and connective tissue composition, is much more firm and easier to remove from the hook in layers. For these reasons, some turtles tend to consume squid whole, whereas fish bait requires several, smaller bites, encouraging grazing around the hook (Clarke *et al.*, 2014; Foster *et al.*, 2012; ISSF, 2023). To this end, a study by Yokota *et al.*, (2009) showed loggerhead interactions with shallow-set longline fisheries in the Pacific to decrease by 75% when mackerel was used as an alternative to squid bait. Foster *et al.*, (2012) found that leatherback bycatch significantly decreased with mackerel bait, and other species were also affected; mackerel used with both J and circle hooks increased catches of swordfish, porbeagle and shortfin mako sharks, while blue shark, bigeye tuna and albacore tuna catch rates decreased. The use of fish bait over squid has been mandated by certain fisheries across USA, Brazil, Australia, the Inter-American Tropical Tuna Commission (IATTC), and is encouraged by Hawaii and the WCPFC. Baiting technique is an understudied factor which could also assist mitigating turtle bycatch. Results from (Stokes *et al.*, 2011) began to show that loggerhead turtles were ~2.5 times less likely to attempt swallowing hooks that were single-baited (hooked once through bait) as opposed to threaded (hooked twice through bait), since single baited is easier to strip from the hook. However, Richards *et al.*, (2012) argues that baiting technique does not show significant effects on turtle bycatch, in part due to the rarity of these events, and suggests that target catch may instead be inadvertently affected. It is worth noting that the study conducted by (Stokes *et al.*, 2011) was conducted in a laboratory, and therefore results produced reflect turtle feeding processes under controlled circumstances. Consequently, other fishery-related factors such as target species retention, were not considered within the scope of the study.

The use of both larger hooks (18/0 or greater for shallow-set fisheries), and small fish species as bait over squid are recommended by the International Seafood Sustainability Foundation (ISSF) as 'best-practice' methods to reduce turtle interactions (ISSF, 2023). Combining both gear modifications and bait type may further increase the effectiveness of gear modifications in reducing turtle interactions. This was seen by Watson *et al.*, (2005) in a North Atlantic fishery targeting swordfish. A combination of circle hooks (18/0) and mackerel bait, instead of squid-baited circle or J hooks, proved more effective in reducing turtle bycatch than single modifications. Loggerhead interactions decreased by 90%, and leatherbacks by 65%. This combined alteration also showed no negative effect on swordfish Catch Per Unit Effort (CPUE). Watson *et al.*, (2005) also begins to show that circle hooks may positively affect target catch survivability. This could potentially lead to increased survival probability of undersized discards and retained catch, as well as enhancing catch quality and market value, though these are very preliminary results. Swimmer *et al.*, (2017) also shows evidence in favour a combined approach. In this study, Northeast Atlantic and North Pacific longline fisheries were used as case studies. Capture probabilities of turtles were lowest when circle hooks were combined with fish bait, this was most pronounced in the Pacific fishery. Regarding the Atlantic fishery, leatherback and loggerhead bycatch rates respectively decreased 64% and 55%, and in the Pacific, rates decreased by 84% and 95%. Foster *et al.*, (2012) demonstrated a case of an Atlantic swordfish fishery that significantly reduced loggerhead and leatherback interaction rates by using a combination of mackerel bait and circle hooks (≥87% and ≥63% respectively), and an increase in species such as bluefin tuna, blue shark, porbeagle, and shortfin mako shark bycatch.

Conversely, Coelho *et al.*, (2015) demonstrates species-specific reductions in turtle interactions as a result of testing different mitigation techniques, reinforcing the need for fishery case-by-case implementation, as suggested by Read (2007) in Section 7.1.1. This study found that while hook size showed a significant effect in reducing leatherback interactions, bait type was not a significant factor. These results were in line with Foster *et al.*, (2012), who reported that both bait and gear type in isolation significantly reduced leatherback turtle bycatch, but their efficacy significantly increased when used in combination. It is worth noting that these two studies were conducted in the North Atlantic. A separate study on the same fishing fleet operating in the South Atlantic and Equatorial regions instead showed that bait was more effective than hook size in reducing turtle bycatch where turtle bycatch was primarily composed of hardshell turtle species. The importance of cautioning recommendations based on fishery-specific parameters is therefore highlighted, with highly variable effects across regions and therefore turtle species.

There is limited evidence of dyed and artificial bait in successfully reducing turtle interactions and bycatch, with studies showing mixed results. Early captivity studies of bait preference among turtles used blue-dyed squid for its known effects in longline fisheries in reducing seabird interactions without adversely affecting catch rates of target catch (Swimmer *et al.*, 2005). The study found hardshell turtle species to prefer untreated squid over squid dyed dark blue. In the field however, the same results were not produced. Echwikhi *et al.*, (2012) found neither bait dyeing nor artificial bait to reduce turtle bycatch in longline fisheries.

With regards to bait condition, this generally refers to fresh vs frozen, or live vs dead bait. There are very limited studies or evidence bases to suggest how this may impact bycatch, even less so specific to turtles. This bycatch mitigation measure is therefore not analysed here, despite being listed on BMIS as a mitigation technique.

8.1.3 Lines and leaders

An additional gear modification is the use of nylon monofilament lines instead of traditional wire multifilament lines. In general, monofilament lines provide a smoother surface, which could make it harder for turtles to get caught and thereby potentially reduce entanglement risks. However, there is limited data on leader materials impacts upon turtle bycatch and further research is needed to better understand the effects on turtle interactions. Despite this, monofilaments are nonetheless recommended as 'best practice' to mitigate turtle bycatch by ISSF (ISSF, 2023). Moreover, from the 1st January 2024, WCPFC CMM 2022-04[14] prohibits vessels targeting tuna and billfish to use wire traces as branchlines or leaders. Though in place to address shark interactions and bycatch, it would also indirectly work to reduce turtle interactions. Although the extent to which monofilament gear could reduce turtle interactions with longline fisheries has not been quantified, when handling techniques are correctly applied,

[14] https://cmm.wcpfc.int/measure/cmm-2022-04

monofilament lines could assist maximising survivability since it is more flexible and could therefore reduce line knotting, facilitating the release of entangled turtles.

8.1.4 Deep / shallow setting

Deep and shallow setting as measures to mitigate turtle bycatch requires consideration of trade-offs between those that reduce interaction rates, and those that don't but instead increase post-release survival (Swimmer *et al.*, 2020b). As demonstrated by Gilman *et al.*, (2006), setting hooks deeper in the water column has been effective in reducing bycatch of neritic species such as turtles, while targeting fish inhabiting greater depths. However, shallow-set gear while displaying higher rates of turtle interactions, also often shows greater rates of at-vessel and post-release survival rates (Swimmer *et al.*, 2020b).

8.2 Temporal and Spatial Measures

Spatio-temporal measures have the potential to be based upon turtle behaviours such as foraging patterns, with the available literature suggesting that certain sea surface temperatures are favoured by certain species of turtles (Dunn *et al.*, 2022; Foster *et al.*, 2012). Some available studies use satellite tagging to show turtle migratory routes and quantify associated environmental parameters. New Zealand leatherbacks have been seen to migrate directly from their breeding grounds to offshore oceans, following areas of high planktonic productivity. The meta-analysis conducted by Dunn *et al.*, (2022) suggests that leatherback turtles have a preference for sea surface temperatures of 14°C – 22°C, specifically in the first 8 months of the year. Leatherbacks however have been known to exhibit 'gigantothermy', and are able to tolerate cooler waters more so than other species, with tagging data showing them in waters with temperatures as low as 3.6°C. This was also supported by Parra *et al.*, (2023), whose study on turtle bycatch in the northeast Atlantic showed leatherback turtles to experience temperatures ranging from 9°C -33°C. However, there is high variability even within species across populations. For instance, studies have correlated western Pacific leatherback behaviour to chlorophyll levels and water temperature, whereas eastern Pacific leatherback foraging grounds were conversely associated with lower temperatures and weaker productivity (Dunn *et al.*, 2022). Juvenile green turtles exhibit different migratory patterns to leatherbacks, recruiting to coastal habitats and reefs and remaining in New Zealand waters for 5-6 years before migrating to tropical areas. Again, there is high variability in behavioural patterns within this species.

The effectiveness of static spatio-temporal fishing measures are therefore uncertain, due to the dynamic nature of sea turtle foraging patterns and environmental preferences. Sherker (2017) therefore suggests that small-scale closures on a case-by-case, event-triggered basis are more effective in reducing turtle bycatch. This is explored in the section below.

8.2.1 Fishery Closures

Limit Reference Points (LRPs) have been used as a tool to manage turtle interactions, for instance in Australia[15] and the USA (Hawaii)[16]. Australia uses seasonal closures in areas with high turtle densities, particularly during nesting or migration periods, when turtles are more vulnerable. Some areas are also permanently closed to longline fishing. Hawaii on the other hand demonstrates a different approach of both fleet-wide and vessel-specific LRPs. With

15 https://www.afma.gov.au/

16 https://www.wcpfc.int/

regards to the whole fleet, a hard cap is in place of 16 leatherback turtles for shallow-set longline fisheries. Once this is reached, fishery closures are enforced (NOAA Fisheries, 2022). More specifically, vessels have an interaction limit of two leatherback and five loggerhead turtles per fishing trip. Once a vessel reaches this limit it must return to port and must not fish for the following five days. Reaching this limit twice per calendar year will prohibit the vessel from shallow-set fishing for the remainder of the year. In these countries, once the LRP has been met, management actions are triggered, enforcing fishery closures or restrictions protecting sea turtles and ensuring compliance with Conservation Measures, reflecting an adaptive management strategy.

While New Zealand currently does not implement any LRPs for turtle bycatch, fisheries are able to enforce move-on rules to their own vessels, or closures in certain fishing areas or at certain times of year, that could be applied when interaction rates exceed limits. Spatiotemporal measures, however, face some criticism as the closure of a fishing ground to one fleet does not necessarily reduce total fishing effort of the area, since other vessels may enter the space, though this would be better controlled in NZ domestic waters than in international waters. Also, displacing fishing effort does not always have desired results, and unintended consequences may arise on species in other fishing areas (Stokes *et al.*, 2011). In a New Zealand context, research by Dunn *et al.* (2024) has shown leatherback bycatch risk to be greatest in the swordfish fishery in the Bay of Plenty region where fishers also target bigeye tuna. It is unknown how any shifting of fishing effort away from leatherback bycatch hotspots would impact target species catch rates. Move-on rules are similarly not guaranteed to obtain satisfactory results, as these rules apply to individual vessels rather than entire fleets. When one vessel moves on, another may enter the same area and continue fishing until it too catches a turtle, repeating the interaction cycle. Combined with potential economic social and economic impacts, these measures are often controversial.

8.3 Fishing Practices and Procedures

8.3.1 Soak period duration

Soak duration can be categorised as the time gear is spent deployed, or by daylight hours of gear deployment. For the latter, it is known that reducing soak duration during daylight hours is effective in reducing turtle bycatch (Swimmer *et al.*, 2020b). The Food and Agriculture Organisation (of the United Nations) (FAO) (2009) recommends setting gear before sunrise as a means of reducing daylight soak duration. Studies have also shown that, in the North Pacific, gear deployed with longer night hours and retrieved after sunrise, showed reduce loggerhead bycatch compared to gear deployed with longer daylight hours and retrieved before sunrise. Similarly, in the western North Atlantic, loggerhead turtle bycatch increased with a longer daylight hook soak duration (Swimmer *et al.*, 2020b). Moreover, Echwikhi *et al.*, (2012) found that soak duration was a predictor of at-vessel hooking mortalities, and the median time for mortalities to occur was between 14 and 15 hours, with most interactions occurring at depths of 20-40 m.

8.4 Other

Other mitigation techniques to reduce turtle bycatch includes the potential use of acoustic or chemical deterrents and decoys.

8.4.1 Deterrents and Decoys

Acoustic and chemical deterrents work to discourage turtles from approaching fishing vessels, without affecting the target species. These methods are in early stages of research with limited results. Lucas and Berggren, (2022) conducted a review of 116 papers examining the effectiveness of sensory deterrents as a mitigation measure for turtle bycatch in tuna species. The study highlights the challenges in generalising the use of such methods due to their highly context-dependent nature varying by species, fisheries, and environmental factors. At present, further field studies are needed to evaluate their use to draw conclusive results. Functioning in a similar way to deter turtle activity, is the use of decoys. Likewise, their use is also limited.

8.4.2 Dynamic Modelling and Alert System

In some data-rich fisheries it may be possible to use historical data on bycatch rates alongside environmental and time parameters to predict bycatch risk areas. Here, fishers may receive real-time warnings of these hotspots so they might avoid fishing near them to reduce the risk of bycatch. However, these dynamic modelling systems not only require a high level of resources within fisheries management authorities, but also must draw on historical data running over a substantial time series to ensure the model is representative of the conditions seen in the fishery.

9 Analysis of Mitigation Measures

A summary of potential mitigation measures is presented in Table 2. The effectiveness of each measure is assessed for both turtles and seabirds, as well as their ease of implementation and any potential barriers to their implementation.

Table 2. Analysis of all measures identified within the literature review.

Mitigation Measure	Demonstrated Effectiveness for turtles	Demonstrated Effectiveness for seabirds	Ease of Implementation	Potential Barriers to Implementation
Increased branchline weighting	N/A	Increased weighting of branchlines has not been tested in relation to mitigating bycatch during the soak period but has been shown to be an effective measure for reducing seabird interactions during the set and the haul (Sacchi, 2021). The theory behind its efficacy still applies to soak mitigation, that is holding hooks as deep as possible where longline shoaling occurs.	The addition of heavier weights should be a simple shore-based modification of gear. Any costs incurred should be largely fixed at the point of implementation where additional weights must be purchased.	Increased branchline weighting may be met with resistance from fishers due to potential risk from fly backs, however, the use of sliding weights on branchlines should alleviate these concerns (ACAP, 2021)
Deep/ shallow setting	Shallow setting may increase turtle interactions, however, may also demonstrate greater at-vessel and post-release survival rates (Swimmer *et al.*, 2020b)	Increasing set depth via proper weighted longline configuration (Beverley *et al.*, 2004) should reduce the likelihood of longline shoaling.	Deep-setting may already be in place for vessels, particularly while targeting swordfish, albacore, and bigeye tuna. Increasing the proportion of deep-set longlines may require more weights and line per vessel.	It would be expected that increasing the proportion of deep-set longlines would incur a cost to vessels due to additional weights and lines required. Fishing at deeper depths may also not maximise catch rates of certain species.

Mitigation Measure	Demonstrated Effectiveness for turtles	Demonstrated Effectiveness for seabirds	Ease of Implementation	Potential Barriers to Implementation
Circle hooks	Circle hook shape and dimensions reduce turtle interactions compared with J hooks Studies show a significant decrease in turtle interactions (foul hooking, ingestion) Alessandro and Antonello, 2010; Coelho *et al.*, 2015; Foster *et al.*, 2012; Gilman *et al.*, 2007a; Long and Schroeder, 2004; Parra *et al.*, 2023	Little research on hook shape and dimension has been conducted assessing potential impacts on seabird bycatch, particularly during the soak period. However, it is suggested that circle hooks’ shape may help inhibit ingestion by seabirds as well as reduced likelihood of foul-hooking (Sacchi, 2021).	N/A – measure already in place	N/A – measure already in place.
Wider circle hook dimensions (minimum 18/0)	Increased width of hook can reduce turtle bycatch due to physiological constraints (Alessandro and Antonello, 2010; Foster *et al.*,2012)	N/A	Replacing current hooks in the fleet with wider hooks will present an initial cost to implementation however, once implemented, maintenance cost of hook replacement should be similar to current costs to fishers.	There are limited barriers to implementation, with the only potential issue being fleet-wide reconfiguration. Case-by-case basis required as measure efficacy and results can be very fishery-specific (Read, 2007). There is some concern amongst fishers that the use of larger hook sizes may decrease CPUE of target species (DOC Liaison

Mitigation Measure	Demonstrated Effectiveness for turtles	Demonstrated Effectiveness for seabirds	Ease of Implementation	Potential Barriers to Implementation
				Pers Comms., July 18, 2024).
Light sticks	Very limited research, suggested evidence of a positive correlation between turtle bycatch and light stick use (Swimmer *et al.*, 2017)	N/A	N/A	N/A – difficult to review efficacy with limited research, early-stage studies advised against its use.
Corrodible hooks	N/A – data deficient	N/A	N/A	N/A
Finfish bait, e.g. mackerel or sardine	Muscular structure and composition of finfish is consumed differently than squid, resulting in decreased turtle interactions with gear, reducing probability of hook ingestion (Clarke *et al.*, 2014; Foster *et al.*, 2012; ISSF, 2023; Stokes *et al.*, 2011; Swimmer *et al.*, 2017; Yokota *et al.*, 2009)	As with turtles, squid bait is more challenging to remove from hooks, potentially increasing concomitant catch risk due to seabird scavenging (Gilman *et al.,* 2020). Fish bait is stripped from hooks more easily, reducing the likelihood of hook ingestion.	This bait switch should be relatively affordable for fishers, presenting few barriers to implementation	New Zealand fishers have reported increased shark bycatch where mackerel bait has been used (DOC Liason *pers comms.,* July 18, 2024).
Hooking technique	Single-baited fish or squid is easier to strip from hook than threaded bait, reducing turtle attempts of swallowing hooks (Stokes *et al.*, 2011)	Although no information on this was found in the literature review, where single baited hooks are more easily stripped, their use should help reduce seabird hooking and bycatch.	Adjusting the hooking technique used during baiting costs nothing and may save time for crew during fishing.	Limited field studies support single-baited hooks. Single baiting may also increase bait loss. Behavioural changes can be difficult to enforce and/or controversial

Mitigation Measure	Demonstrated Effectiveness for turtles	Demonstrated Effectiveness for seabirds	Ease of Implementation	Potential Barriers to Implementation
				Richards *et al.*, 2012; Stokes *et al.*, 2011
Combining circle hooks with finfish bait	The combined effect of circle hooks and finfish bait can strengthen their individual efficacy in reducing turtle bycatch (Foster *et al.*, 2012; ISSF, 2023; Swimmer *et al.*, 2017; Watson *et al.*, 2005)	No study testing the combined impacts of using both measures together was found. Based on the separate testing of measures, there does not seem to be a reason why applying them in combination would have a negative impact on seabird bycatch rates.	See above measures (circle hooks and finfish bait).	Results can be species and fishery-specific, depending on geographic locations, turtle populations and environmental parameters; Highly variable effects and therefore result replicability uncertain (Coelho *et al.*, 2015; Read, 2007)
Bait dyeing (dark blue)	Captivity studies show turtle species preference untreated bait over dark blue-dyed bait (Swimmer *et al.*, 2005. N.B: laboratory study)	Studies reviewing blue-dyed bait present mixed results on seabird bycatch rates. However, a good proportion of studies reviewed present positive findings (Gilman *et al.*, 2005; 2003; McNamara, 1999).	The low cost to dyeing bait during the thawing process means its implementation should be straightforward. Dyed bait is highly likely to hold its colour throughout the soak period, offering the potential for positive effects on bycatch rates during the soak	Results on studies investigating its effects show mixed results. (Echwikhi *et al.*, 2012)

Mitigation Measure	Demonstrated Effectiveness for turtles	Demonstrated Effectiveness for seabirds	Ease of Implementation	Potential Barriers to Implementation
			period (Gilman *et al.,* 2003).	
Bait condition	N/A – limited area of research	Limited research was found assessing effects of bait condition on seabird bycatch, however, baits encouraging a higher sink rate should be favoured so they help facilitate proper longline setting at the desired depth. This means baits should be properly thawed and, where fish bait is used, swim bladders should be punctured (Bull, 2006; Gilman *et al.,* 2019).	Bait thawing should not create additional costs but may add an additional step in fishing procedure for fishers that do not already thaw their bait.	There are no expected barriers to implementation for this measure.
Nylon monofilament lines	Nylon monofilament lines are less visible and smoother than wire lines and can reduce entanglement risks. Moreover, nylon lines are more flexible and reduce line knotting, facilitating release of entangled turtles. (ISSF, 2023)	No studies were found assessing this mitigation measures impact on seabird bycatch rates.	WCPFC CMM 2022-04 prohibits vessels targeting tuna to use wire branchlines or leaders and therefore, as of the 1st January 2024, this is now a mandated requirement. There will be a cost to replacement of multifilament lines, however the benefits	There are a limited number of studies on this mitigation measure. Quantifying the effects of interaction rates is also challenging.

Mitigation Measure	Demonstrated Effectiveness for turtles	Demonstrated Effectiveness for seabirds	Ease of Implementation	Potential Barriers to Implementation
			to monofilament line. However, improved release of sea turtles and lower bycatch rates should make this cost worthwhile.	
Spatio-temporal measures e.g. area/ seasonal closures, LRPs	Allows for management of fishery-specific interactions with turtles, implementing measures on a case-by-case vessel basis (NOAA Fisheries, 2022; Sherker, 2017). Consider establishing a turtle bycatch limit and establishing a vessel-specific Limit Reference Point, so that entire fleets will not be penalised for the fishers with more reported turtle interactions.	There is evidence, particularly from the Southern Ocean, that closures around seabird breeding sites can significantly reduce seabird bycatch (Trebilco *et al.,* 2010; Waugh *et al.,* 2008).	Good for reducing fishery-specific interactions, on a vessel-by-vessel basis. Implementation is simple; however surveillance of vessel behaviour is required for monitoring, control, and enforcement.	There is high intraspecific geographic variability in bycatch species behaviours, impacting the repeatability of results. Fisheries closures and limit reference points are likely to be unpopular with the fishery due to the potentially negative socio-economic consequences of these measures. One key challenge in identifying areas for closure is the ubiquitous nature of vulnerable seabird populations throughout New Zealand's surface longline fishing grounds.
Night Soaking	N/A	Night setting has been shown to be effective at reducing seabird bycatch, likely due to	Night soaking requires no gear modification, simply	Night soaking may be unpopular with fishers, due to the limited

Mitigation Measure	Demonstrated Effectiveness for turtles	Demonstrated Effectiveness for seabirds	Ease of Implementation	Potential Barriers to Implementation
		either reduced availability of visual stimuli for seabirds or due to reduced seabird activity at night (Gilman *et al.,* 2023; Klaer and Polacheck, 1998). Appling this same theory to the soak period may reduce seabird bycatch rates during this fishing phase.	a different setting and hauling schedule.	availability of fishing hours during the day it imposes, particularly during summer months (where the window for night soaking may be as short as eight hours). Actively fishing more at night may also increase safety risk to crew.
Soak period duration	Reducing soak duration during daylight hours is effective in reducing bycatch Soak duration a possible predictor of turtle interactions, median time for mortalities to occur between 14 – 15 hours (Echwikhi *et al.*, 2012; FAO, 2009; Swimmer *et al.*, 2020a)	Though limited research covering the soak duration and its impacts on seabird bycatch during the soak. It can be inferred that increased soak time increases bycatch risk, as the potential for longline shoaling during to fish capture or environmental factors will increase with time.	Adjusting soak time does not require any modification to gear, just changes to the setting and hauling schedule.	Fisher behavioural changes may be difficult to implement and met with resistance if they do not optimise catches of target species.
Acoustic or chemical deterrents	Early stages of research, limited results to demonstrate effectiveness of deterrence as a means to discourage turtle interactions (Lucas and Berggren, 2022)	No studies were found demonstrating significant positive effects of these measures on seabird bycatch rates. For stimuli-based deterrents, there are concerns around habituation causing deterrents to eventually have	These measures are typically challenging to implement.	Measures are highly context-dependent, with efficacy varying by species, fishery, and environmental factors. Furthermore, there is limit infrastructure available from which to release these deterrent stimuli, particularly for seabirds.

Mitigation Measure	Demonstrated Effectiveness for turtles	Demonstrated Effectiveness for seabirds	Ease of Implementation	Potential Barriers to Implementation
		the opposite effect to what is intended (Sacchi, 2012).		Where these deterrents are emitted directly from fishing vessels, the radius of their range of effectiveness would be limited.
Decoys	N/A – limited area of research	One study was found, employing a 'looming-eyes buoy', intended to distract and scare birds away from fishing gear. No significant impact was observed (Rouxel *et al.,* 2023).	Buoys present an opportunity to implement these measures.	There are relatively few buoys along the mainline, meaning where the mainline shoals hooks may be available to seabirds with no decoy in sight.
Dynamic modelling and alert system	Upwell Turtles (Aimee Hoover) South Pacific Turtle Watch model[17] for eastern Pacific leatherback population is a potentially useful tool in mitigating turtle bycatch in fisheries. A similar model is nearly complete for the western Pacific leatherback population and includes NZ bycatch data. These integrated species	Limited evidence of demonstrated effectiveness.	Allows real-time alerts to be sent to fishers making avoiding bycatch hotspots easier.	New Zealand's surface longline fishery does not currently have enough historical data on bycatch paired with environmental data. South Pacific Turtle Watch model is currently only at monthly scale and needs much finer resolution to be suitable for trialling in NZ

[17] https://www.upwell.org/sptw

Mitigation Measure	Demonstrated Effectiveness for turtles	Demonstrated Effectiveness for seabirds	Ease of Implementation	Potential Barriers to Implementation
	distribution models use telemetry data (e.g. sea surface temp, bathymetry, residence times of leatherbacks, tracking data) and observations (fisher and observers and in the future EM).			fisheries for conservation/management . Implementing such a system would require an upgrade to both the fisheries management centre and the fleet to incorporate the alert system.

10 Recommendations

This section sets out a series of recommendations for the DOC to take forward as they progress with the testing of potential bycatch mitigation measures for both turtles and seabirds during the soak period of fishing. Recommendations are based on findings from the literature reviews, found in Sections 5 and 7, and the analysis of measures, found in Section 8, and are listed below.

Increased deep setting across the surface longline fleet where possible, using weighted longline configurations as described in Figure 3.

Though shallow setting coincides with turtle foraging depths, and interactions may increase, there is a trade-off in improving the post-release survival rates of turtles caught in shallow waters. However, deeper setting is generally more effective in reducing seabird bycatch and may be a preferable option overall, with limited evidence on the efficacy of shallow setting for turtles (Swimmer *et al.,* 2020a). The use of deep-set longline configurations with longer float lines and heavier weights anchoring them is expected to reduce the likelihood of the mainline shoaling towards the surface via capture of marine fauna, or environmental factors such as shear caused by currents and tides (Bach *et al.,* 2009). Where deep setting is not viable, baskets should be set such that hooks are centred away from the floats at either end of the basket, minimising the likelihood of their exposure at the sea surface.

Increased branchline length and weighting, particularly towards the hook, using sliding weights to reduce the risk to crew in the event of fly back events.

Increasing branchline weighting not only increases sink rate of longlines (Sacchi, 2021) but will also ensure that, where mainlines shoal to the surface, baited hooks are held at the deepest depth possible, out of reach of some seabird species. Increasing the overall weight per branchline will also increase the SR of baskets (Swenarton and Beverly, 2004) meaning fewer hooks should be exposed where shoaling does occur. Furthermore, increasing the weight of branchlines will also increase the overall weight of each basket and the entire longline, reducing the risk of shoaling due to the increased sinking force applied to the longline. Finally, sliding weights are an appropriate option as they provide the added weight required to offer the benefits listed above, but also reduce the potential dangers of fly back events where 'bite off' or 'tear out' occurs (ACAP, 2021). ACAP currently recommends the use of either: a 40 gram (g) or greater weight attached within 0.5 metres of the hook; a 60g or greater weight attached within 1 metre of the hook; or an 80g or greater weight attached within 2m of the hook (ACAP, 2019). Combining the 40g weight nearest the hook with a weighted swivel at the mainline attachment point may present the best option. The use of weighted Procella hooks has been trialled in New Zealand's surface longline fleet (DOC Liaison *Pers Comms.,* July 18, 2024). These may present an elegant solution to the issue of branchline weighting, at least partially.

Increasing branchline length could also present an important bycatch mitigation measure. In the event that a mainline does shoal to the surface, having elongated branchlines paired with the weighting configuration detailed above will help hold baited hooks beyond the reach of some diving seabirds, helping to mitigate against seabird bycatch.

Continued use of circle hooks, with testing of larger hook dimensions with a minimum size 18/0.

New Zealand already adheres to the WCPFC mandate[18] requiring circle hooks. Extensive literature, and the Fisheries Act, support the effectiveness of circle hooks as a measure to reduce sea turtle bycatch, significantly reducing turtle interactions (both foul hooking and ingestion) (Coelho *et al.,* 2015). Circle hooks are also thought to potentially reduce the risk ingestion and foul hooking in seabirds, although limited research has been conducted (Sacchi, 2021). We therefore recommend continuing to encourage this practice, allowing time for thorough implementation, and recording observed results to evaluate its efficacy over time. Moreover, studies demonstrate the benefits of increasing the width of circle hooks to a minimum of 18/0 (Alessandro and Antonello, 2010; Foster et al., 2012). Implementation can decrease turtle bycatch rates due to physical constraints around ingestion (Alessandro and Antonello 2010) and is recommended on a case-by-case basis since results are likely to be very fishery-specific and can have different results across target and bycatch species. Given the accessibility and ease of testing this measure, it is recommended with observation to monitor its effectiveness (Read, 2007).

Further testing of the effects of bait dyeing and hooking technique.

Bait dyeing is commonly implemented in the New Zealand surface longline fleet during high-risk fishing periods, such as full-moon night-setting. Bait dyeing has been shown to have potential to reduce interaction rates of both turtles and seabirds. Where this measure is currently only implemented under a full moon during night setting, it should be considered as a potentially important measure that could be tested for fishing in during high-risk fishing periods (Swimmer *et al.,* 2005; Gilman *et al.,* 2005; McNamara, 1998). Further testing of baiting methods should be completed, with single baiting being compared to threading bait. Adopting a single-baited hooking technique could reduce turtle interactions, and potentially seabirds, by allowing the bait to be more easily stripped from gear (Stokes *et al.*, 2011). Despite limited research, the simplicity of this technique makes it worth testing, potentially saving crew time during fishing operations.

Test replacing squid bait with finfish bait and assess the extent which finfish bait increases shark bycatch.

The New Zealand surface longline fleet bait choice is substantially influenced by economic factors such as bait price weighed up against effectiveness and bycatch risk. This means the fleet largely uses squid bait with some use of finfish bait. However, due to the grazing of turtles on fish bait (usually mackerel or sardine) rather than squid which are ingested whole, the likelihood of turtles being caught on hooks is much reduced if finfish bait is used instead of squid, with little impact on catch rates.

Finfish bait, due to its muscular composition, is easier for turtles to strip from hooks, and encourages grazing around the gear, rather than engulfing the hook whole, as is a common behaviour seen with squid bait. This is therefore an effective strategy to reduce the likeliness of turtles ingesting hooks. This switch is affordable and easy to implement, though it may be necessary to monitor results closely to understand specific effects on target stocks and other bycatch (Clarke *et al.* 2014; Foster 2012; ISSF 2023; Stokes 2011; Swimmer 2017; Yokota 2009). There are some concerns among New Zealand's surface longline fleet that finfish bait

[18] CMM 2018-04 - https://cmm.wcpfc.int/measure/cmm-2018-04

increases shark bycatch rates, potentially presenting an increased risk of longline shoaling due to capture – this should be tested for in the field.

Where bycatch levels are at their highest, FNZ and the DOC might consider the use of LRPs and spatio-temporal closures or restrictions.

Despite their potential unpopularity with fishers, spatio-temporal closures have been shown to be highly effective at reducing bycatch. Closures implemented around seabird breeding sites in the Antarctic have been particularly effective at reducing longline fisheries' impacts on seabirds (Trebilco *et al.,* 2010; Waugh *et al.,* 2008). Such spatio-temporal closures could be applied to certain areas known to have high seabird bycatch at certain times of the year, for example, closing areas along the west coast of the South Island during the autumn and early winter months where high bycatch rates of white-capped albatross, Buller's albatross, and Westland petrels are observed (Fisheries New Zealand, 2023). For the purposes of turtle bycatch reduction, LRPs potentially resulting in spatial or temporal closures could be introduced for enhanced protection of endangered leatherback turtles. However, the implementation of such measures is likely to be met with strong resistance from fishers due to the potential socio-economic impacts of fishing restrictions. Given the high association with swordfish fisheries and leatherback bycatch, greater understanding of the impacts of shifting fishing effort would need to be investigated. Careful assessment of closures implemented elsewhere (e.g. Hawaii), along with thorough stakeholder engagement, is important when designing these measures.

Adjusting fishing operations to increase the proportion of the soak period in darkness hours ('night soaking').

Night setting can significantly reduce seabird bycatch due to decreased visibility of visual stimuli, or reduced seabird activity (Gilman *et al.*, 2023; Klaer and Polacheck, 1998). This mitigation method requires no gear modification, but a shift in the setting and hauling schedule. Though it may be less popular amongst fishers due to reduced daylight working hours, and challenges around on-board vessel safety, night soaking remains an effective and low-cost measure for bycatch reduction, provided operational concerns are thoroughly addressed.

Investigate the use of hook timers to link target and bycatch capture

Pilot studies utilising hook timers to determine when a hook is taken are recommended. When combined with TDR recorders these could show when neighbouring hooks catch seabirds, for example if the hook is brought to the surface. Current studies employing TDRs alone can measure the number of bycatch events, but not the causal effect (e.g. whether a hook was taken at the surface or at a certain depth). If hooks around a fish on a line brought to the surface are shown to be only active after a fish has been hooked this can be clearly shown. It should be noted that these timers may be costly and may not be a top priority in the DOCs research.

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