Gilman, E., Hall, M. 2015. *Potentially Significant Variables Explaining Bycatch and Survival Rates and Alternative Data Collection Protocols to Harmonize Tuna RFMOs' Pelagic Longline Observer Programmes.* Appendix 1. In Gilman, E., and Clarke, S. Changes to WCPFC Longline Observer Bycatch Data: Proposals in Response to a Minimum Suite of Harmonized Fields for Tuna RFMOs. WCPFC-SC11-2015/EB-IP-05. Western and Central Pacific Fisheries Commission, Kolonia, Federated States of Micronesia.

Potentially Significant Variables Explaining Bycatch and Survival Rates and Alternative Data Collection Protocols to Harmonize Tuna RFMOs' Pelagic Longline Observer Programmes

July 2015

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EXECUTIVE SUMMARY

Scientific observer data are key to conduct robust stock assessments, identify and understand trends and patterns in nominal and standardized catch and survival rates and catch levels, and assess the performance of conservation and management measures. Across disciplines, including fisheries, there has been increasing awareness of the benefits of providing for the interoperability of datasets, metadata catalogues and dataset formats.

The Joint Tuna Regional Fisheries Management Organizations' (RFMO's) Technical Working Group-Bycatch prioritized adopting minimum data fields and standardized collection protocols by pelagic longline observer programmes to enable the interoperability of the RFMOs' observer programme datasets. Standardizing observer programme data fields, data collection protocols and observer database formats facilitates comparisons between RFMOs, enables pooling data necessary to support large spatial scale analyses within and across RFMO convention areas, and enables standardization of training materials and courses within and across regions. Harmonizing the tuna RFMOs' observer data and improving the quality of data collection protocols further promise to improve assessments of fishery effects on bycatch species, identify factors that significantly explain catch and survival rates, evaluate the performance of bycatch mitigation methods, and support other functions of the tuna RFMOs.

A January 2015 meeting of experts on tuna longline fisheries identified a need for a systematic review of existing information collected by the tuna RFMO longline observer programmes in order to identify priority gaps in data that hamper our understanding of longline bycatch. As a starting point, the group recommended developing a comprehensive list of variables that could be collected through tuna RFMO human and electronic monitoring onboard observer programmes that have been documented to have significant effects on catch and mortality rates of taxa susceptible to capture in pelagic longline fisheries, and alternative data collection protocols for each prioritized variable. This report was commissioned by the Western and Central Pacific Fisheries Commission under the ABNJ (Common Oceans) Tuna Project to implement this recommendation.

Variables were identified that have significant effects on catch and survival of taxa susceptible to capture in pelagic longline fisheries and for which information can be collected via onboard human observers or by electronic monitoring systems. A subset of the full suite of variables were selected for inclusion in this report based on their relative importance for standardizing longline catch and survival rates of species of conservation concern, and whether information on the variable is important for bycatch management, including assessing the efficacy of tuna RFMO longline bycatch measures. The following information was compiled for each selected explanatory variable:

- Evidence that it has a significant effect on catch and mortality rates of elasmobranchs, sea turtles, seabirds and/or marine mammals;
- Why the variable affects catch and/or mortality rates;
- Key indicators that reflect the effect of the variable on catch and mortality rates;
- A summary of each tuna RFMO's observer data collection protocol (however, details should be verified with each tuna RFMO Secretariat); and
- A range of minimum to best data collection and recording protocols to support a preliminary recommendation for a harmonized method to collect essential data by observers, given consideration of criteria such as, *inter alia*, current tuna RFMO practices, ease of collection,

expected data accuracy and precision, and relative utility for monitoring and managing pelagic longline bycatch.

Table 1 identifies 28 fields prioritized for inclusion based on their importance for monitoring and managing bycatch. Recommended minimum harmonized data collection protocols are described for each field based on current practices by the five tuna RFMOs, practicality for collection in onboard observer programmes and expected data quality.

Table 1. Priority fields for monitoring and managing bycatch and recommended harmonized minimum data collection protocols for tuna RFMOs' pelagic longline observer programmes.

Field	Minimum Harmonized Data Collection Protocol
Vessel Characteristics and Equipment	
Unique vessel identification	Record the vessel's Unique Vessel Identifier (UVI) issued by the International Maritime Organisation or Lloyd's Register, or if the vessel lacks a UVI, then record the vessel's International Radio Call Sign issued by the International Telecommunications Union.
Gear Characteristics and Fishing Methods	
Hook type: shape	Once per trip, sample 10 branchlines from each tote (bins, hook boxes) in order to determine and record the hook shape, manufacturer code for 'size', narrowest width, and degree of offset for each hook type used. If multiple hook types are used, then estimate and record the percentage of each. For hook shape, determine if the hook is a circle, J, tuna or teracima hook shape, or refer to the manufacturer code for shape. Refer to the manufacturer model number or otherwise use calipers to measure narrowest width to the nearest mm. For offset, record yes or no, or record the manufacturer degree of offset. If a hook catalogue is available, match the hook to the corresponding shape, minimum width and offset degree and record the hook's unique identification number.
Hook type: minimum width	
Hook type: offset	
Bait species	For each set, determine each species and type of artificial bait used for bait. If the species level of a bait type cannot be determined, then record the category (small fish species, squid species, piece of large fish species, piece of marine mammal, piece of sea turtle, other) for that bait type. Record the estimated percent of the total that each species, species category and type of artificial bait made up.
Leader (trace) material	Once per trip, record each material used for leaders and if multiple types are used, then record the proportion of each.
Soak depth: floatline length	Once per trip, measure the length of ten floatlines and record the average length to the nearest cm.
Soak depth: branchline length	Once per trip, measure the length of 10 branchlines from each tote and record the average length to the nearest cm.
Soak depth: number of hooks per basket	For each set, record the predominant number of hooks set between two floats. Only count the number of branchlines attached to the mainline between two floats; do not include branchlines attached to floats.
Soak depth: mainline line shooter speed relative to vessel setting speed (mainline tension)	Once per trip, record the predominant mainline line shooter speed and the vessel average setting speed. Refer to the vessel GPS or speed log over at least several seconds to determine the average vessel setting speed.
Branchline weight amount and distance from the hook (leader length)	Once per trip, sample 10 branchlines from each tote to determine and record the predominant mass of weights attached to branchlines to the nearest gram either by referring to the amount written on the weight or if not recorded on the weight, then by weighing the weight with a scale, and measure the predominant distance from the bottom of the weight and the eye of the hook to the nearest cm. If more than one weight amount and leader length are used during a trip, then describe each

	design and record the percentage of each.
Number of shark lines per set	Record the number of shark lines (branchlines attached directly to floats) included per set.
Hooks per set and proportion of total hooks observed during the haul	Estimate the total number of hooks deployed per set by multiplying the predominant number of hooks between floats (per basket) and the number of baskets set. Estimate the number of hauled hooks observed by counting the number of baskets observed and multiplying by the predominant number of hooks per basket.
Number of light attractors per set and per hook	For each set, record the number of branchlines on which one or more light attractor was attached, and record the total number of light attractors that were attached to branchlines in that set.
Vessel position, date and time at start and end of set and haul	Record the vessel position, date and time at the start and end of each set and haul. Human observers use a GPS to determine vessel position, date and time. Electronic monitoring systems collect information through sensors (e.g., on the mainline line shooter and line hauler) or via review of video showing vessel GPS readings.
Subset of seabird bycatch mitigation methods: Tori pole and line; stern vs. side setting; bird curtain; blue-dyed bait; thawed bait; underwater setting chute; management of discharges of offal, spent bait and dead discards during set and haul	For each set, record whether each of the following was employed: single or paired tori pole and line; side setting; bird curtain; blue-dyed bait; thawed bait; underwater setting chute; all offal, spent bait and dead discards were discharged away from the area where gear entered the water; and all offal, spent bait and dead discards were retained during setting. For each haul, record if all offal, spent bait and dead discards were discharged on the opposite side of the vessel from the hauling station; or if all offal, spent bait and dead discards were retained during hauling.
Catch	
Hook number between floats and shark line	Record the hook number between floats on which each organism was caught or if the organism was caught on a shark line (branchline attached to a float).
Species	Record the FAO species three letter code if available or otherwise by scientific name for all caught organisms and the number caught for each species. A catch event includes both organisms removed from the gear in the water and organisms brought on deck. If an organism frees itself from the gear and is not handled by crew (e.g., throws the hook, breaks the line, becomes untangled from line), this constitutes a pre-catch escapement event and is not to be recorded as catch. For species that an observer cannot identify to the species level, attempt to retain a sample (if not a live species of conservation concern) or take a photograph so that the species might later be identified by experts.
Length	For rare-event species, attempt to measure lengths for all catch. For common species, measure a sample of the catch employing a sampling method that ensures within-strata randomness. Use large calipers or a measuring board to measure small to medium-sized organisms. Use a flexible measuring tape to measure the length of large organisms and sea turtles. Record length to the nearest cm and identify the measurement method employed.
Sex	For rare-event species, attempt to determine sex for all catch. For common species, measure a sample of the catch employing a sampling method that ensures within-strata randomness (e.g., every third caught organism of a common species). Record whether the organism is male, female, could not determine, or did not examine.
At-vessel life status (condition when caught) and depredation	For each caught organism, record the at-vessel (when brought to the vessel during hauling before being handled by crew) life status (alive, dead, unknown), the degree of damage from depredation to the organism (none, minor, moderate,

	high), and what species likely caused the depredation (shark, toothed whale, squid, other, unknown).
Hooked/entangled, position of hook, and gear remaining attached to released organisms	For each caught sea turtle, seabird, marine mammal, shark and ray, record whether each captured organism was entangled in line, hooked, and if hooked, whether it was externally hooked, hooked in the mouth (when the bend of the hook was not posterior to the esophageal sphincter), or deeply hooked (hook was swallowed posterior to the esophageal sphincter or deeper). For organisms of these species groups that were released alive, record whether it was released entangled in line, with trailing line, with a hook, and if hooked, whether it was externally hooked, hooked in the mouth, or deeply hooked.
Hook, bait, leader material and length, branchline weight amount, and light attractor for capture of species of conservation concern	For each caught sea turtle, seabird and marine mammal, record the hook shape, hook minimum width, hook offset, bait type, leader material, leader length, branchline weight amount and light attractor presence of the branchline on which the organism was caught, following the previously described data collection protocols for these gear elements.
Fate and final condition: Retained, shark retained fins and carcass, shark retained fins only, released in the water, landed on deck and released alive, landed deck and discarded dead	For each individual caught organism, record the fate and final condition as either: retained, discarded dead, released alive, or released unknown condition. For retained sharks, record whether fins and trunk were retained, or whether fins were retained and the trunk was discarded. Released and discarded organisms include both those that crew remove from the gear in the water without bringing the organism onto the vessel, and organisms that are brought onto the vessel and then returned to the water. 'Retained' catch includes catch that is landed, transshipped and landed, consumed by the crew, used for bait, and rejected at port and not landed. 'Discarded' catch refers to returning dead caught organisms back to the sea. "Released' catch refers to returning live caught organisms back to the sea. If an organism frees itself from the gear and is not handled by crew (e.g., throws the hook, breaks the line, becomes untangled from line), this constitutes a pre-catch escapement event should not be recorded as a released catch event (however, a field for escapement events may be included where this would then be recorded).
Environmental Parameters and Seabird Local Abundance	
Beaufort scale (sea state)	Observe the sea state and record a Beaufort wind force scale number once during the set and once during the haul.
Wind velocity	Record apparent or true wind speed once during the set and once during the haul.
Number of seabirds attending the vessel during setting and hauling	During daylight, at 30 minutes into the set, at the end of the set, 30 minutes into the haul and at the end of the haul, count the number of individuals of each seabird species or family within 100m of the vessel. For each of the four scan count events per fishing operation, record the number of each observed seabird species or family, the date and time of the scan count, and whether the vessel was setting or hauling.
Sea surface temperature	Do not record this field (public domain databases of satellite-derived estimates of SST are available making observer collection of data for this field a low priority).

ACKNOWLEDGEMENTS

The participants of an expert meeting held in January 2015 on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs*, which was convened by the Joint Tuna RFMO Technical Working Group-Bycatch, chaired by Simon Nicol of the Secretariat of the Pacific Community, recommended the preparation of this report as a starting point to harmonize longline bycatch data collected in tuna RFMO's observer programmes. This report was commissioned by the Western and Central Pacific Fisheries Commission under the Areas Beyond National Jurisdiction (Common Oceans) Tuna Project. Shelley Clarke, ABNJ Tuna Project, Western and Central Pacific Fisheries Commission, contributed to defining the study scope and assisted with writing and revising drafts of this report.

CONTENTS

1. INTRODUCTION

Scientific observer data are key to conducting robust stock assessments, identifying and understanding trends and patterns in nominal and standardized catch and survival rates and catch levels, and assessing the performance of conservation and management measures (FAO, 2002). Aggregated observer data can be used to implement fleet-wide input and output threshold controls (e.g., to determine when a fishery's total allowable catch level is reached) (FAO, 2002). Data collected from observer programmes can also be used for compliance monitoring, where vessel-specific observer data can be analyzed to determine whether fishing was conducted according to fishery management control rules (FAO, 2002). Having data collected and reported by independent onboard observers to meet scientific and compliance objectives is understood to produce more accurate and detailed information than would be collected and reported in logbooks by crew: crew may lack the time and training to conduct prescribed data collection methods, and may have an economic disincentive to record accurate data, e.g., to avoid catch or size limits (FAO, 2002; Walsh et al., 2002).

Observer data collection methods, including what categories of information are to be collected, and the protocols that are to be employed to collect that information, need to be designed to support robust statistical analyses of what is captured, whether catch is alive or dead when retrieved at the vessel before handling by crew, and whether it is retained, released alive or discarded dead. This includes analyses of interactions with species of conservation concern (endangered, threatened and protected species), conducting fleet-wide extrapolations, and identifying when, where and why interactions occur (FAO, 2002; Gilman et al. 2014a). Objectives of analyses, including desired levels of accuracy and precision of catch and survival rate estimates, require consideration in defining observer data fields and collection protocols, (Hall 1999; FAO, 2002). And observer methods will require periodic adaptation as scientific requirements as well as fishing vessel equipment, gear and practices evolve. Across disciplines, including fisheries, there has been increasing awareness of the benefits of providing for the interoperability of datasets, metadata catalogues and dataset formats (Keune et al., 1991; Burkhauser and Lillard, 2005; Branton et al., 2006; Gilman, 2011; Reich et al., 2012; Sansone et al., 2012).

The second Kobe meeting of the Joint Tuna Regional Fisheries Management Organizations (RFMOs) established a Technical Working Group-Bycatch. The Working Group produced a work plan, which was approved at the third Kobe meeting in July 2011. Included in this work plan is an activity for the "harmonisation of bycatch data collected by tuna RFMOs". The intended purpose of this activity was to identify minimum data standards and data fields that should be collected across all of the tuna RFMOs in order to achieve as much consistency as possible to provide for the interoperability of the RFMOs' observer programme datasets. The work plan recognized that the minimum standards should maximise the detail recorded as much as possible so that data users can aggregate information to suit the questions asked (ISSF, 2015).

The first and second joint meetings of the five tuna RFMOs also recognized the benefits and called for consistency and compatibility in the measures employed to manage marine fisheries, including scientific data collection methods (Fisheries Agency of Japan, 2007; European Community, 2009). Benefits from standardizing observer programme data fields and data collection protocols, as well as observer database formats, within and across the tuna RFMOs, include enabling meaningful comparisons between the RFMOs, facilitating the integration and pooling of datasets within and across regions necessary to support large spatial scale analyses, and allowing training materials and courses for observers to be standardized within and across regions.

The Joint Tuna RFMO Technical Working Group-Bycatch convened an expert meeting in January, 2015 on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* (ISSF, 2015). Meeting participants identified a need for a systematic review of existing information collected by the tuna RFMO longline observer programmes in order to identify priority gaps in data that hamper our understanding of bycatch interactions and mortality rates. As a starting point, the group recommended the development of a comprehensive list of variables that could be collected through tuna RFMO observer programmes that have been documented to have significant effects on catch or mortality rates of taxa susceptible to capture in pelagic longline fisheries, and identify alternative data collection protocols for each prioritized variable. Under the Areas Beyond National Jurisdiction (Common Oceans) Tuna Project, this report was commissioned by the Western and Central Pacific Fisheries Commission to implement this recommendation.

2. METHODS

Variables that have been documented to have significant effects on catch and survival of taxa susceptible to capture in longline fisheries and for which information can be collected via onboard human observers or by electronic monitoring systems were identified through a literature review. Relevant peer-reviewed publications and grey literature, including of controlled and comparative experiments, studies that developed pelagic longline standardized catch and haulback survival rates, and post-release survival studies, were compiled through the WCPFC's Bycatch Management Information System (BMIS), the Consortium for Wildlife Bycatch Reduction's Bycatch Reduction Techniques Database, Google Scholar and by reviewing reference lists of relevant publications and reports.

Higher priority variables were then selected for inclusion in this study based on their relative importance for monitoring and managing bycatch of species of conservation concern of seabirds, elasmobranchs (sharks and rays), marine mammals and sea turtles. Their relative scientific importance for standardizing catch and survival rates, and whether information on this variable is important for bycatch management such as for assessing the efficacy of tuna RFMO longline bycatch measures were considered in prioritizing variables for inclusion in the study. Appendix A identifies the full list of compiled fields and the subset selected for inclusion in the report. The following information was compiled for each selected explanatory variable:

- Evidence that it has a significant effect on catch and mortality rates of elasmobranchs, sea turtles, seabirds, and/or marine mammals;
- Why the variable affects catch and/or mortality rates;
- Key indicators that reflect the effect of the variable on catch and mortality rates;
- A brief description of each tuna RFMO's observer data collection protocol; and
- A range of minimum to best data collection and recording protocols to support a recommendation for a harmonized method to collect essential data by observers, given consideration of criteria such as, *inter alia*, current tuna RFMO practices, ease of collection, expected data accuracy and precision, and relative utility for monitoring and managing pelagic longline bycatch.

Variables were organized into the following categories: vessel characteristics and equipment, gear characteristics and fishing methods, catch, environmental parameters and seabird local abundance. SPC (2014) was used as the basis for determining whether a data collection method can be accomplished by electronic monitoring systems. Information on each tuna-RFMO's current observer programme data fields and observer data collection methods were obtained from the following sources: CCSBT (No Date); IOTC (2010); IATTC (2014); WCPFC (2015); and for ICCAT (which has not produced a regional observer programme manual for observer data collection methods) unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* (ISSF, 2015). We also identify Secretariat of the Pacific Community (SPC)/Pacific Islands Forum Fishery Agency (FFA) observer programme data fields and data collection protocols, obtained from SPC and FFA (2014), which is implemented by a subset of WCPFC members.

Given that observer programme methods change frequently and that these materials reviewed to produce these summaries of tuna RFMO longline observer programmes may not be current or accurate, it is highly recommended that each tuna RFMO Secretariat review them to verify that they are the current practice and that the identified fields and data collection protocols are described accurately.

3. DATA FIELDS AND COLLECTION PROTOCOLS

3.1. Vessel Characteristics and Equipment

3.1.1. Unique vessel identification

a. Evidence of significant effect on catch and mortality
Numerous studies have observed significant individual vessel effects on nominal and standardized catch and survival rates in pelagic longline fisheries. For example, Campana et al. (2009) found that the variable unique vessel explained most of the deviance in a standardized at-vessel mortality rate model for blue sharks, and Punt et al. (2000) found that unique vessel was the most important factor in a school shark standardized catch rate model for the South Australian zone. A large individual vessel effect was observed on standardized swordfish catch rates in the Reunion Island longline fishery (Kolody et al., 2010). Gilman et al. (2007a) observed high variability in sea turtle and target swordfish nominal catch rates by individual vessel in the Hawaii longline swordfish fishery. Klaer and Polacheck (1998) observed high variability in standardized seabird catch rates by vessel in the Australian Japanese-flagged longline fishery. There is anecdotal evidence of resident cetaceans targeting specific vessels to depredate catch when several vessels are fishing in the same area (AFMA, 2005).

b. Mechanism for significant effect
The individual vessel in a fishery can significantly affect nominal catch and survival rates, length frequency distributions, catch composition, hooking position, etc. This is due to unique attributes of a vessel and its equipment that are retained throughout the life of the vessel regardless of change in owner and operators, and unique gear designs and fishing methods employed by the operator and crew of that vessel that are employed somewhat consistently across trips and sets (Sharma and Leung, 1999; Gilman et al., 2007a; Campana et al., 2009; Serafy et al., 2012b). For example, a vessel's well capacity can affect the vessel's fishing power relative to other vessels in a fishery, and will not likely change over the life of the vessel. A vessel's equipment that affects fishing power, such as navigational aids, however, may be periodically upgraded over time. And, for example, a fishing master's targeting strategies, including gear design and fishing methods, and abilities, affect species-specific fishing efficiency of the vessel, where a change in fishing master may occur over the life of a vessel in a fishery.

c. Indicators measurable by human and/or electronic observers
Individual vessels can be assigned a unique vessel identifier, which can be recorded for each observed trip, both for human and electronic monitoring (SPC, 2014). The vessel identification number could be recorded prior to the trip.

d. Brief summary of tuna RFMO's current observer data collection protocol
- **CCSBT**: Vessel name and call sign (CCSBT, no date).
- **IATTC**: Vessel name and registration number (the official identification of the vessel) (IATTC, 2012).
- **ICCAT**: Vessel name and identification number (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Vessel name and IOTC number, if included in the IOTC registry, national register number (the number issued by the country in which the vessel is registered), IMO number if the vessel is registered to the International Maritime Organization, and International Radio

Call Sign (IRCS, number allocated to the vessel by the International Telecommunications Union (IOTC, 2010).

- **WCPFC and SPC/FFA**: Record the vessel name, flag State registration number, and Unique Vessel Identifier (UVI). If the vessel does not have a UVI, then record the IRCS, which is typically issued to the vessel by the flag State. If the vessel does not have an IRCS, then record the WCPFC Identification Number (WIN) (SPC and FFA, 2014; WCPFC, 2015). A UVI is WCPFC's preferred vessel identification number. WCPFC will require all vessels over 100 GRT fishing in the WCPFC zone to have a UVI by 1 January 2016 (SPC and FFA, 2014). The UVI is issued by the International Maritime Organisation or the Lloyd's Register.

e. Alternative data collection methods and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: Record a unique vessel identification number as agreed by the relevant. RFMO. Easy to collect, but may vary between RFMOs.
- **Better**: Record the vessel's UVI, or if the vessel lacks a UVI, then record the vessel's IRCS. Easy to collect, high consistency.

3.2. Gear Characteristics

3.2.1. Hook type: shape, width and offset

a. Evidence of significant effect on catch and mortality

Taxa	Effects
Teleosts	
Hook shape	Few studies have assessed the single factor effect of hook shape on teleosts. Higher at-vessel survival and lower proportion of deep hooking on circle hooks relative to J-shaped hooks has been demonstrated for some species of bony fishes (Cooke and Suski, 2004; Serafy et al., 2009).
Hook minimum width	Studies have observed significant effects of the single factor 'hook narrowest width' on catch rates on some teleost species (Curran and Beverly, 2012). Although confounded by simultaneous differences in both hook width and shape, additional studies have documented significantly lower catch rates of smaller-mouthed teleost fishes, such as dolphinfish and snake mackerel, on wider circle hooks compared to narrower J and tuna hooks (Curran and Bigelow 2011; Pacheco et al. 2011). Studies have also documented significant effects of hook minimum width on haulback survival rates and lengths of some teleosts (Curran and Beverly, 2012).
Hook offset	Studies have observed significant effects of circle hook offset degree on some teleosts' hooking position and haulback condition (Prince et al., 2002; Epperly et al., 2012; Rice et al., 2012).
Sharks	
Hook shape	Significantly higher relative risk of capture on circle vs. J-shaped hooks of the same width (Ward et al., 2009; Andraka et al., 2013; Gilman et al., In Review). Effect of hook shape can be species- and size-specific (Gilman et al., In Review). Significantly lower at-vessel mortality rate on circle vs. J-shaped hooks (Godin et al., 2012; Serafy et al., 2012b; Caneco et al., 2014).
Hook minimum width	Significantly lower blue shark survival rate (Curran and Beverly, 2012) and significantly higher shortfin mako shark catch rate on wider hooks have been observed. Yokota et al. (2006) observed a small but significant difference in blue shark mean length between a narrower tuna hook and wider circle hook.
Hook offset	No significant effect has been observed from degree of offset on some shark species' catch rates or location of hooking (Swimmer et al., 2010; Amorim et al., 2014).
Rays	
Hook shape	Significantly higher pelagic stingray catch rate on circle vs. J-shaped hooks (Andraka et al., 2013). Hook shape has nominal effect on pelagic stingray hooking position, which tend to get hooked in the mouth regardless of hook shape (e.g., Kerstetter and Graves, 2006; Piovano et al., 2010; Pacheco et al., 2011).
Hook minimum width	In a study that enabled an assessment of the single factor hook size based on narrowest width as well as gape, narrower J hooks with a smaller gape had a significantly higher pelagic stingray catch rate relative to wider J hooks with a larger gape (Piovano et al. 2010).
Hook offset	No significant effect observed from degree of offset on pelagic stingray catch rates or location of hooking (Swimmer et al., 2010).
Sea turtles	
Hook shape	Leatherback sea turtles, which tend to get caught by becoming foul-hooked on the body and entangled, have been observed to have lower catch rates on circle hooks than on J-shaped hooks of a similar size (Witzell, 1999; Watson et al., 2005).

	Nominal effect on catch rates of hard-shelled turtles, which tend to get caught by ingesting the hook regardless of hook shape (Epperly et al., 2012). For hard-shelled and leatherback turtles that ingest a hook, circle hooks result in a lower proportion of turtles swallowing the hook deeply, into the esophagus and deeper, and a higher at-vessel survival rate, relative to J-shaped hooks (Gilman et al., 2006b; Epperly et al., 2012; Hall et al., 2012; Andraka et al., 2013; Parga et al., 2015).
Hook minimum width	Wider hooks are understood to reduce captures and deep hooking of hard-shelled turtles, which tend to get caught by ingesting baited hooks (Witzell 1999; Watson et al. 2005; Hall et al., 2012; Parga et al., 2015).
Hook offset	No significant effect has been observed from degree of offset on olive Ridley sea turtle catch rates or location of hooking (Swimmer et al., 2010).
Seabirds	
Hook shape and minimum width	No studies identified assessing the single factor effect of hook shape. Wider circle hooks have been observed to have lower seabird catch rates than narrower J-shaped hooks (Hata, 2006; Li et al, 2012). Another study found no significant difference between albatross catch rates on a wider circle hook vs. narrower 9/0 J-hook, however, there was a small sample size (18 albatross captures) (Domingo et al., 2012).
Hook offset	No studies identified.
Marine mammals	
Hook shape	Circle hooks may result in lower odontocete (toothed whale) catch rates relative to J-shaped hooks of a similar size (Gilman et al., 2006a; Forney et al., 2011). Circle hooks may result in a higher proportion of hooked odontocetes being ‘non-seriously injured’ (e.g., the hooked pulled out of a whale hooked in the mouth or body, or the line became untangled on a whale that was entangled in line with the hook caught on the line) relative to those hooked on J-shaped hooks (Forney et al., 2011).
Hook minimum width	No studies identified.
Hook offset	No studies identified.

b. Mechanism for significant effect

- **Hook Shape**: J-hooks are shaped with the point positioned parallel to the hook shaft. Tuna and teracima hooks have a slightly curved shaft, and like J-hooks, the point is not protected by the shaft, and have therefore been categorized as J-shaped hooks (Serafy et al., 2009). Circle hooks are circular or oval in shape, and the point is turned perpendicularly back toward the shank, making the point less exposed relative to J-shaped hooks. The less exposed points of circle hooks reduce the probability of foul-hooking organisms (FAO, 2010; Gilman, 2011). J-shaped hooks tend to result in deep hookings, while circle hooks with little or no offset, when swallowed, tend to catch in the corner of the mouth (Cook and Suski, 2004; Curran and Beverly, 2012; Epperly et al. 2012; Clarke et al., 2014; Parga et al., 2015). Due to the prevalent hooking location, circle hooks might result in a higher haulback survival rate, result in less trauma and thus increase the probability of post-release survival for organisms released alive (Horodysky and Graves, 2005; Jones, 2005; Kerstetter and Graves, 2006; Diaz, 2008; Carruthers et al., 2009; Graves and Horodysky, 2010; Gilman, 2011; Pacheco et al., 2011; Epperly et al., 2012; Godin et al., 2012; Serafy et al., 2009, 2012a). Furthermore, due to their predominant hooking location, organisms captured on circle hooks that will be released require less handling time, minimizing stress e.g., due to the duration of air exposure (Cooke and Suski, 2004).
- **Hook Width**: For some species, and certain sizes of a species, hooks with a larger narrowest (minimum) width reduce their relative catchability. For species that tend to be caught by ingesting a baited hook, hook size affects susceptibility to capture, as the larger

the hook, the lower the probability that an organism can fit it in its mouth (Yokota et al*.* 2012). Variability in the length frequency of a species that overlaps with a fishery's grounds, the difference between the width of the two hooks being compared, and the difference in the hook widths relative to the species' range of mouth sizes will determine if two hooks of different widths have different catch rates. In general, hook size is more likely to affect catch rates of species with relatively small mouths (Gilman et al., In Review). Hook size has been hypothesized to affect hooking location: larger hooks may be less likely to be ingested and instead be more likely to foul hook (Stokes et al*.* 2011).

- **Hook Offset**: There may be a threshold offset angle above which a circle hook's gape would be sufficiently large to cause it to hook similarly to J-shaped hooks.

See Section 3.2.3 for a discussion of interacting effects of hook type, bait type and leader material on hooking position and catch and survival rates.

c. Indicators measurable by human and/or electronic observers

The percent of in-use hooks, by hook shape, hook minimum width, and offset. For electronic monitoring systems, this information would likely need to be collected dockside prior to vessel departure for each fishing trip, and possibly by review of the video (SPC, 2014).

d. Brief summary of tuna RFMO's current observer data collection protocol

- **CCSBT**: There is no field for hook type (shape, size, or offset) (CCSBT, No Date; unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IATTC**: Observers on longline vessels collect information on hook shape (J or circle), size, straight or curved shanks for J hooks, manufacturer (if known), offset, whether it is a ring hook, and hook material for all hooks used on the mainline during a trip (IATTC, 2012; unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]). Observers can record information on up to three hook types. If more than 3 different types of hooks are used during a trip, the observer is to record the characteristics of the most important hooks (IATTC, 2012). The field 'hook size' refers to the manufacturer code, e.g., a size 16 circle hook (IATTC, 2012). IATTC has prepared a catalogue of all hook models used in the eastern Pacific that includes photographs at a 1:1 scale with an alphanumeric code and a table of measurements (Mituhasi and Hall, 2011). For each set, the observer is to record the number of each of the hook types that are placed in the water (IATTC. 2012).
- **ICCAT**: Observers on longline vessels of some ICCAT member and cooperating non-member national observer programmes record hook shape (type) (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Recommended but not mandatory, observers on longline vessels may record the different types and sizes of hooks used on the branchlines for up to four types (IOTC, 2010; unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]). Observers are to try to obtain the manufacturer's specifications for hook type and size. If this is not possible, then observers are to record the basic type of either Japan tuna, circle or J-hook, and to measure the total hook length, front length and gap and offset. An additional optional field, observers can identify hook shape for each individual caught organism (IOTC, 2010; unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).

- **WCPFC and SPC/FFA**: Observers on longline vessels are to record hook shape, offset or non-offset, size, whether the hook had a ring, and whether the hook had a swivel (ISSF, 2015; unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]). For hook shape, four options for fields are Japan, circle, J and teracima (SPC and FFA, 2014). For each hook shape, observer are to record the size of that hook shape; whether the hook was offset, had a ring, or had a swivel; and the percentage of that hook that is usually used in each set (SPC and FFA, 2014). Record the hook types (shapes) and sizes of hooks used; ask the Bosun if the hook size is not clear (WCPFC, 2015). SPC has produced a guide to longline terminal tackle (Beverly, 2009).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: Sample 10 hooks from each tote (bins, hook boxes, tubs) and determine the proportion of the sample by hook shape, narrowest width and offset. Refer to the manufacturer model number or otherwise use calipers to measure narrowest width to the nearest mm. Determine if the hook is a circle, J, tuna or teracima hook shape, or refer to the manufacturer code for shape. For offset, record yes or no, or record the manufacturer degree of offset. Or, if a hook catalogue is available, match the hook to the corresponding type (shape, width and offset degree) and record the hook's unique identification number (e.g., Mituhasi and Hall, 2011). Record shape (circle, J, tuna, teracima), narrowest width, offset or non-offset, for the predominant hook used. Easy to collect, variable data quality.
- **Better**: Observe all of the hooks to determine the percent of the hooks by hook shape, narrowest width and offset. Use the minimum method protocol for recording shape, width and offset. Record the three most predominant hook types by shape (circle, J, tuna, teracima), narrowest width, and offset, and the percent of the hooks that each of the three types made up. Time consuming to collect, higher data quality.
- **Best**: Observe all of the hooks to determine the percent of the hooks by hook shape, narrowest width and offset. For hook shape, record circle, tuna or J hook. For width, measure minimum width using calipers. For offset, measure offset degree. Or, if a hook catalogue is available, match the hook to the corresponding type (shape, width and offset degree) (e.g., Mituhasi and Hall, 2011). Record the proportion of hooks by shape (circle, J, tuna, teracima), narrowest width and offset degree that each type observed made up. Time consuming to collect, highest data quality.

3.2.2. Bait species

a. Evidence of significant effect on catch and mortality

Taxa	Effects
Teleosts	There have been consistent findings on the effect of fish vs. squid bait on catch rates of albacore, bigeye and yellowfin tuna catch rates being lower on small fish species vs. squid species for bait (Watson et al. 2005; Coelho et al. 2012a; Foster et al. 2012; Amorim et al. 2014). But, there have been conflicting findings for bait type effect on swordfish catch rates (Broadhurst and Hazin, 2001; Watson et al., 2005; Mejuto et al., 2008; Garcia-Cortes et al., 2009; Baez et al., 2010; Coelho et al., 2012a; Foster et al., 2012; Amorim et al., 2014). Using fish vs. squid for bait significantly decreased deep hooking of swordfish (Broadhurst and Hazin, 2001; Watson et al., 2005; Epperly et al., 2012). Broadhurst and Hazin (2001) and Epperly *et* al. (2012) found a significantly larger proportion of caught swordfish were dead upon haulback with squid bait than with mackerel bait. Amorim et al. (2014) observed larger swordfish and blue and shortfin mako sharks, and smaller yellowfin and albacore tunas were caught on squid vs. fish for bait. Mejuto et al. (2008) observed lower catch rates of swordfish on pieces of blue shark for bait than with squid or mackerel for bait.
Sharks	Using small fish species for bait instead of squid species significantly increases both catch rates and deep hooking for some shark species (Watson et al., 2005; Mejuto et al., 2008; Vega and Licandeo, 2009; Coelho et al., 2012a; Epperly et al., 2012; Foster et al., 2012; Amorim et al., 2014; Gilman et al., In Review). Using fish for bait significantly increased the odds of deeply hooking vs. mouth-hooking blue and porbeagle sharks relative to squid bait (Watson et al., 2005; Epperly et al., 2012; Gilman et al., In Review). Mejuto et al. (2008) observed lower catch rates of blue shark and shortfin mako on pieces of blue shark for bait than with squid or mackerel for bait. Echwikhi et al. (2010) observed significantly higher sandbar shark catch rates with pieces of stingray used for bait vs. whole mackerel.
Sea turtles	Significantly lower loggerhead and leatherback sea turtle catch rates on mackerel bait than squid bait have been observed (Watson et al., 2005; Mejuto et al., 2008; Yokota et al., 2009; Foster et al., 2012; Hall et al., 2012). Mejuto et al. (2008) observed higher catch rates of loggerhead and olive Ridley sea turtles on pieces of blue shark for bait than with squid or mackerel for bait. Echwikhi et al. (2010) observed significantly lower loggerhead turtle catch rates with pieces of stingray used for bait vs. whole mackerel.
Seabirds	Only one study was identified that assessed the effect of bait type on longline catch rates of seabirds: Li et al. (2012) found a significantly higher seabird catch rate on mackerel bait than squid bait.

b. Mechanism for significant effect

Different species and sizes of predatory fish have different prey preferences. These preferences are due to differences in prey chemical components, visual stimuli, and differences in the duration of retention of different bait species on hooks during the gear setting, soaking and retrieval operations. These are possible factors explaining differences in catch rates between pelagic species and between sizes of individual pelagic species on fish vs. squid for bait (Lokkeborg and Bjordal, 1992; Broadhurst and Hazin, 2001; Ward and Myers, 2007; Yokota et al., 2009).

The observed effect of bait type on sea turtle catch rates may be due in part to the relative difficulty for hard-shelled turtles to remove the bait from the hook. Fish bait comes free of the hook while being eaten by turtles in small bites. Squid holds more firmly to the hook and tends to result in turtles consuming the hook with the squid (Watson et al*.,* 2005; Gilman et al*.,* 2006b; Stokes et al*.,* 2011). Furthermore, hard-shelled turtles may prefer squid to finfish due to natural chemical attractants present in squid (Piovano et al., 2004, 2012). Bait type is a more important factor in affecting catch rates for hard-shelled turtle species than leatherbacks, as the former tend to get caught by ingesting baited hooks (and therefore tend to get captured by getting hooked in the mouth or more deeply), while the latter tend to become captured via foul-hooking or entanglement (Witzell, 1999; Watson et al*.,* 2005; Gilman et al*.,* 2006b; Epperly et al*.,* 2012). However, depending on the method used by fishers to thread bait onto hooks, fish bait might shield the hook point thus reducing leatherback incidence of foul hooking (Watson et al., 2005).

The observed effect of bait type on haulback condition of swordfish may be due to the prevalent hooking position (Broadhurst and Hazin, 2001; Epperly et al., 2012).

See Section 3.2.3 for a discussion of interacting effects of bait type, hook type and leader material on hooking position and catch and survival rates.

c. Indicators measurable by human and/or electronic observers

The percent of bait on in-use hooks, by species group (small fish species, squid species, pieces of large fish) or to the species level, and for artificial bait. For electronic monitoring systems, if only one bait species is onboard at the start of a trip, then it is not necessary to attempt to obtain information for the field “bait type” for each individual set, where the pre-trip inspection would identify if this is the case. However, this might also require confirmation that no bait species had been taken on-board and used during the trip (SPC, 2014). It may also be possible to determine bait type by reviewing video.

d. Brief summary of tuna RFMO’s current observer data collection protocol

- **CCSBT**: Percentage of bait by categories of: fish, squid, artificial and other (CCSBT, No Date).
- **IATTC**: Observer forms have space for listing information on up to three types of bait. The observer is to record the type of bait and the percent of the total bait that each type made up (IATTC, 2012).
- **ICCAT**: Observers of ICCAT member national observer programmes are not required to record information on bait type (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Record the different bait species used, and the approximate ratio of the different baits used (IOTC, 2010).
- **WCPFC and SPC/FFA**: During each set, record the species and weight in kg of each bait type used (SPC and FFA, 2014). Name the bait species used (pilchards, sardine, squid, etc.) (WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: For each trip, determine and record the predominant category (small fish, squid, piece of large fish, piece of marine mammal, piece of sea turtle, artificial bait, other) used for bait. Easy to collect, low data quality (if bait species is variable between sets in a trip).
- **Better**: For each trip, determine and record the predominant species or artificial bait used for bait. Easy to collect, low data quality.
- **Even better**: For each set, determine and record each category (same as in minimum method) and the percent of the total that each category of bait made up. Easy to collect, higher/adequate data quality.

- **Best**: For each set, determine and record each species and type of artificial bait used for bait. If a species cannot be determined, then record the category for that bait type using the same species categories from the minimum method. Estimate and record the percent of the total that each species, species category and type of artificial bait made up. Easy to collect (assuming a small number of species are used for bait in one set/trip), highest data quality.

3.2.3. Leader (trace) material

a. Evidence of significant effect on catch and mortality

Taxa	Effects
Teleosts	Significantly lower bigeye tuna, black marlin and swordfish catch rates have been observed on wire vs. monofilament leaders (Berkeley and Campos 1988; Afonso et al. 2012).
Sharks	For most (but not all) shark species, studies have found significantly higher catch rates on wire leaders vs. monofilament nylon (polyamide) leaders (Branstetter and Musick, 1993; Ward et al., 2008; Vega and Licanadeo, 2009; Afonso et al., 2012; Bromhead et al., 2013; Caneco et al., 2014; Gilman et al., In Review). Few studies assessed the effect of leader material on haulback survival rates, with most findings observing significantly lower survival on wire than monofilament leaders (Afonso et al., 2012; Caneco et al., 2014; Gilman et al., In Review).

b. Mechanism for significant effect

Species with sharp teeth can sever, by biting through or abrading, monofilament leaders and escape but cannot sever more durable leader materials (wire, multifilament) and remain captured on the line (Ward et al. 2008; Afonso et al. 2012). Species with serrated teeth, like tiger sharks, are more likely to be able to bite through nylon leaders than those with needle-like teeth (Ward et al. 2008). Species that tend to thrash violently when hooked are more likely to abrade and sever a monofilament leader than those with relatively less energetic reactions (Gilman et al. 2008b; Ward et al. 2008).

Furthermore, species with relatively good vision may have lower susceptibility to capture on wire or multifilament leaders relative to monofilament leaders because they can more readily see the wire and multifilament and avoid preying on adjacent hooks (Ward et al. 2008).

For species with teeth that can sever monofilament line or thrash violently when hooked, and that are deeply hooked, individuals caught on monofilament leaders may have a higher probability of being dead upon haulback relative to individuals caught on wire leaders. This is because, while wire leaders tend to indiscriminately retain all deeply hooked organisms, for organisms caught on monofilament leaders, larger, stronger, more vigorous individuals may have a higher probability of escaping than smaller, weaker, seriously injured individuals. Those that do not escape from monofilament leaders may have low resistance to surviving the soak.

Leader material may affect practices for branchline weighting designs: Due to crew safety concerns, fishers are less likely to attach weights close to hooks when the leader is not made of wire or other durable material (Gilman, 2008). Thus leader material, by affecting line weighting designs and hence baited hook sink rates, might affect seabird catch rates (Section 3.2.5).

There may be synergistic effects of leader material, hook design and width, and bait type on catch rates of species capable of severing monofilament leaders (Afonso et al. 2012; Epperly et al. 2012; Hannan et al. 2013; Clarke et al. 2014; Gilman et al., In Review). Discussed in Section 3.2.1, circle hooks tend to catch organisms in the mouth and jaw, while J and tuna hooks tend to result in deep hookings, and the wider the hook of a given shape, the lower the probability that an organism can ingest it. And, discussed in Section 3.2.2, fish bait has been observed for some fish species to result in a significantly higher proportion of deep hooking than squid bait. Thus, observations of lower catch rates on J-shaped vs. circle hooks, and lower catch rates on fish vs. on squid species used for bait, might have been due to the differences in hooking position between the hook shape and bait types when monofilament leaders were used. This is because mouth- and jaw-hooked fish capable of severing monofilament leaders are less likely to be able to bite through a monofilament leader because their teeth cannot reach the leader, while deeply-hooked fish have a higher likelihood of biting through monofilament leaders and hence a lower catch rate (see Afonso et al. [2012] for evidence of this interacting effect).

There may also be an interacting effect between circle hook narrowest width and wire leader length. When wire leaders are used, there might be a higher probability that hooked organisms can sever branchlines above the leader and escape when smaller circle hooks are used: there is a higher likelihood that smaller circle hooks will be swallowed than wider circle hooks, which enables biting through the branchline above the wire leader, depending on the leader length and size of the fish, before the hook slides back up to the mouth (pers. comm., John Peschon, National Marine Fisheries Service, 23 May 2015, cited in Gilman et al., In Review). And, soak duration might have an interacting effect with leader material. The longer the gear soak, higher escapement rates are likely when nylon monofilament leaders are used for species that can sever the monofilament leaders, as they will have a longer time to abrade or bite through the leaders, while this effect of soak time would be smaller for vessels using wire and multifilament leaders (Ward et al*.* 2008).

Section 3.2.5 discusses the mechanism for the effect of leader length as this relates to the location of attachment of weights on the branchline.

c. Indicators measurable by human and/or electronic observers

Leader material (wire, wire sheathed by plastic or nylon coating, monofilament nylon, multifilament nylon, multifilament material other than nylon, other). Office-based ‘dry’ observer analysis of electronic monitoring video could determine the predominant leader material used (SPC, 2014). Dockside inspection of a vessel’s leader material could also be conducted.

d. Brief summary of tuna RFMO’s current observer data collection protocol

- **CCSBT**: Record the material of branchlines (nylon, cotton thread, other) (might include leaders/trace) (CCSBT, No Date).
- **IATTC**: For each observed trip, if there is a leader (“a metal portion of the lower gangion used in the shark fishery”) on the branchline, record the material (IATTC, 2012).
- **ICCAT**: Leader details (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Optional, record the material of the leader, including if steel wire trace is used (IOTC, 2010).
- **WCPFC and SPC/FFA**: Indicate if the vessel used wire trace on branchlines, yes or no response, for each observed trip (SPC and FFA, 2014).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: Once per trip or during each set, determine and record the predominant material used for leaders by sampling 10 branchlines from each tote. Easy to collect, variable data quality.
- **Better**: Once per trip, sample 10 branchlines from each tote, determine and record the proportion of the sample by leader material. Easy to collect, variable data quality.
- **Even better**: Once per trip, look at all branchlines in the totes to determine each material used for leaders and determine and record the proportion of branchlines using each type of leader material. Time consuming to collect, high data quality.
- **Best**: For each set, look at all branchlines to determine each material used for leaders and determine and record the proportion of branchlines using each type of leader material. Very time consuming to collect, highest data quality.

3.2.4. Soak depth: floatline length, branchline length, number of hooks per basket, mainline line shooter speed relative to vessel setting speed (mainline tension)

a. Evidence of significant effect on catch and mortality

Species-specific effects on catch and survival rates of gear soak depth have been observed for bony fishes (Nakano et al., 1997; Ward and Myers, 2005; Galeana-Villasenor et al., 2008; Beverly et al., 2009; Walsh et al., 2009; Musyl et al., 2011; Watson and Bigelow, 2014), elasmobranchs (Galeana-Villasenor et al., 2008; Walsh et al., 2009; Musyl et al., 2011; Bromhead et al., 2012; Caneco et al., 2014; Gallagher et al., 2014; Watson and Bigelow, 2014) and sea turtles (Polovina et al., 2004; Rice and Balazs, 2008; FAO, 2010; Hall et al., 2012; Clarke et al., 2014; Watson and Bigelow, 2014).

b. Mechanism for significant effect

Pelagic species, and in some cases individual age classes and sexes, have habitat preferences that are vertically dynamic, causing the depth of longline gear soak to result in variability in susceptibility to pelagic longline capture by individual species, age class and sex. For species that exhibit vertical segregation by sex (e.g., pelagic stingrays; Ribeiro-Prado and Amorim, 2008), gear depth can have sex selectivity, which can affect haulback survival rates (Coelho et al., 2012b).

Gear soak depth may also significantly affect haulback condition. Because shallower, warmer water depths have lower dissolved oxygen concentration, higher stress might occur for fish caught at shallower depths due to higher metabolic rates (Gallagher et al., 2014). Turtles caught on deeper hooks are more likely to drown before gear retrieval if they cannot reach the surface to breathe during the gear soak (Gilman et al., 2006b).

Fishing method and gear design variables with potentially large effects on gear soak depth include the number of hooks between floats, branchline weight amounts (see Section 3.2.5), length of floatlines and branchlines, distance between floats, and mainline tension, determined in part by the method employed for setting the mainline. Environmental variables such as wind velocity, current strength, and surface waves affect the shape and soak depth of longline gear (Boggs, 1992; Beverly and Robinson, 2004; Ward and Myers, 2005, 2007; Bigelow et al., 2002, 2006; Vega and Licandero, 2009).

The ratio of the vessel setting speed to the line shooter speed is one variable used to get terminal tackle to target soak depths (Anderson and McArdle, 2002; Beverly et al., 2003). When a mainline is set through a line shooter that is set at a speed that exceeds the vessel speed, the mainline will be set slack. When a mainline is set without use of a line shooter, the friction of the line on the sea surface is used to pull the mainline into the water, and the mainline is set taught. Deploying the mainline slack increases the catenary angle of the mainline and increases the soak depth. Setting the mainline taught results in a smaller catenary angle and shallower soaking depth (Anderson and McArdle, 2002; Beverly et al., 2003). See Section 3.2.4 for a discussion of the effect of pelagic longline soak depth on catch and survival rates.

The sink rate of baited hooks has been observed to not be affected by mainline tension until after the branchline has almost reached its full extent, where *ca.* 15m length branchlines are typical for pelagic longline fisheries (Brothers et al., 2001; Gilman et al., 2003, 2007b). Below this depth, the mainline may have a slowing influence on the hook sink rate. As a result, in regions where pelagic longline fisheries overlap with the distributions of seabird species that can dive relatively deep, the effect of the mainline setting method on baited hook sink rate might affect seabird catch rates. However, other factors can override the effect of mainline tension on terminal tackle sink rate, including whether the mainline and branchlines enter the sea within or outside of the area affected by prop turbulence (Robertson et al., 2010a). In addition, branchline swivel weight amount and branchline length have been observed to significantly affect seabird standardized catch rates (e.g., Gilman et al., 2014b) but this is due to the effect on baited hook sink rates and not due to the gear soak depth.

There are also synergistic effects of soak depth and temporal and spatial distribution of effort (the latter variables are discussed in Section 3.2.9). Vertical habitat preferences are temporally and spatially variable by species, and within species by age class and sex, and therefore the effect of pelagic longline soak depth on catch rates and haulback condition will vary temporally and spatially. The effect of soak depth on pelagic longline catch rates will vary spatially both at relatively small scales such as whether gear is set near a shallow submerged feature or in the open ocean, and over very broad scales due to differences in pelagic species' distributions and due to regional differences in variables that determine habitat preferences. The effect of soak depth will also vary temporally over periods of hours (Section 3.2.9) to broad periods spanning cyclical events and trends from climate change. Vertical habitat preferences can vary temporally, within a day, due to diel vertical migration cycles, time of day of active foraging, and temporal variability in diving behavior (Section 3.2.9) and spatially due to variability in thermocline and oxygen gradients and other variables that determine habitat preferences (Carey et al., 1990; Boggs, 1992, Sedberry and Loefer, 2001; Schaefer and Fuller, 2002; Nakano et al., 1997, 2003; Weng and Block, 2004; Ward and Myers, 2005; Bigelow and Maunder, 2007; Beverly et al., 2009; Hyder et al., 2009; Musyl et al., 2011; Gilman et al., 2012). For example, blue sharks forage only near the sea surface at night and make deep dives during the day, making them susceptible to capture primarily in shallow-set longline gear, but also in deep daytime sets, while thresher sharks infrequently come near the surface and thus are largely at risk of capture only in deep-set longline gear (Carey et al., 1990; Boggs, 1992; Nakano et al., 2003; Weng and Block, 2004; Musyl et al., 2011; Curran, 2014). Primarily in deep set longline fisheries, where terminal tackle passes through a relatively large section of water column for a relatively large time period, the time of day of setting and hauling can significantly affect catch rates (Boggs, 1992; Kerstetter and Graves, 2006).

c. Indicators measurable by human and/or electronic observers

All of the variables can be directly measured by an onboard observer, who can record for each set the average or predominant floatline length, branchline length, and number of hooks per basket, and can record for each set the mainline line shooter speed (if used) and the vessel setting speed. Number of hooks between floats could be determined from office-based 'dry' observer analysis of electronic monitoring video. The mainline line shooter speed and vessel speed during setting could be collected by electronic monitoring systems if sensors are installed (SPC, 2014). Lengths of floatlines and branchlines could be collected prior to departing port for a trip to be observed via an electronic monitoring system (SPC, 2014).

d. Brief summary of tuna RFMO's current observer data collection protocol

Tuna RFMO	Floatline length	Branchline length	No. hooks per basket	Mainline line shooter speed relative to vessel setting speed
CCSBT	Record the actually used buoyline length (CCSBT, No Date).	Record the actually used branchline length (CCSBT, No Date).	Record the total number of hooks per set and the total number of baskets per set (CCSBT, No Date).	Was a line shooter used (CCSBT, No Date). Information on line shooter speed and vessel speed during setting are not required to be collected (CCSBT,

				No Date).
IATTC	Record the length in cm of the floatline (dropline) (IATTC, 2012).	Record the length in fathoms of the upper, middle and lower gangion (IATTC, 2012).	Record the number of hooks between floats. If the number of hooks varies, record the number of hooks between floats that is most prevalent (IATTC, 2012).	Record if a line shooter was in place to avoid capture of birds (IATTC, 2012). Information on line shooter speed and vessel speed during setting are not required to be collected (IATTC, 2012).
ICCAT	Dropline details are recorded in some national observer programmes of member parties (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).	Gangion length is recorded in some national observer programmes of member parties (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).	Observers of ICCAT members' national observer programmes are not tasked with recording information on the number of hooks between floats (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).	Observers of ICCAT members' national observer programmes are not tasked with recording information on line shooter speed and vessel speed during setting (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
IOTC	It is optional for observers to record floatline length (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).	Record the average length of branchlines. It will not be possible to measure this at the time of setting and observers will have to get this information during the hauling operations when the branchlines are being made up. There could be several different types or construction of branchlines, made	It is optional for observers to record the number of hooks between floats (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).	Record the speed setting of the line setter (meters/second) (IOTC, 2010). Recommended but not mandatory, record the vessel's average setting speed. Record the speed from the GPS several times during the operation and take the average (IOTC, 2010).

		up from different materials. Observers should keep a record of each specification. The average lengths can then be determined from the observed branchlines set (IOTC, 2010).		
WCPFC and SPC/FFA	Measure the length of the line that is attached to the floats. Floatline length usually remains the same throughout the trip (WCPFC, 2015).	Measure the length of a sample of the majority of branchlines used; there may be slight variability in branchline length due to repairs conducted during an observer trip (WCPFC, 2015).	Count the number of hooks that are set from one buoy to another. Include any branchlines attached directly to floats in the count of the number of branchlines between two floats (WCPFC, 2015). The number is usually constant along the line, but can vary in some cases (WCPFC, 2015). If the vessel attaches a branchline directly to the buoy (a 'shark line'), do not count this as one of the hooks per basket (SPC and FFA, 2014).	Record the mainline line shooter speed, if the vessel has a line shooter. The line shooter will normally have an indicator to show its running speed (WCPFC, 2015). Record the vessel speed during setting by watching the GPS or speed log over several seconds to estimate the average speed of the vessel. Record to one decimal point (SPC and FFA, 2014).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

Floatline length

- **Minimum**: Once per trip, measure the length of ten floatlines and record the average length to the nearest cm. Easy to collect, variable data quality.
- **Better**: Once per trip, measure the length of all floatlines on in-use floats and record the average length to the nearest cm. Time consuming to collect, high data quality.
- **Best**: For each set, measure the length of all floatlines on in-use floats and record the average length to the nearest cm. Time consuming to collect, highest data quality.

Branchline length

- **Minimum**: Once per trip, measure the length of 10 branchlines from each tote and record the average length to the nearest cm. Easy to collect, variable data quality.
- **Best**: Once per trip, measure all of the branchlines and record the average length to the nearest cm. Time consuming to collect, higher data quality.

No. hooks between floats

- **Minimum**: Once per trip, record the predominant number of hooks set between two floats. Only count the number of branchlines attached to the mainline between two floats; do not include branchlines attached to floats. Easy to collect, variable data quality.
- **Better**: During each set, record the number of hooks set between two floats for at least 20% of the baskets set and record the average hooks between floats. Only count the number of branchlines attached to the mainline between two floats; do not include branchlines attached to floats. Time consuming to collect, higher data quality.
- **Best**: During each set, record the number of hooks set between two floats for the entire set, and record the average hooks between floats. Only count the number of branchlines attached to the mainline between two floats; do not include branchlines attached to floats. Time consuming to collect, highest data quality.

Mainline line shooter speed (if used) relative to vessel setting speed

- **Minimum**: Once per fishing trip, during setting, record the mainline line shooter speed and the vessel setting speed. Refer to the vessel GPS or speed log over at least several seconds to determine the average vessel setting speed. Easy to collect, variable data quality.
- **Better**: Once per set, record the mainline line shooter speed and the vessel average setting speed. Refer to the vessel GPS or speed log over at least several seconds to determine the average vessel setting speed. Easy to collect, higher data quality.
- **Best**: During each set, record the mainline line shooter speed and the vessel average setting speed. Have the crew notify you if they change the line shooter speed during the set, and if so, record each different line shooter speed during the set to determine the average. At the start and end of the set, refer to the vessel GPS or speed log over at least several seconds to determine the average vessel setting speed. Very time consuming to collect, highest data quality.

3.2.5. Branchline weight: amount and distance from hook (leader length)

a. Evidence of significant effect on catch and mortality
Branchline weight amount and distance from the hook have been observed to significantly affect seabird catch rates during setting (Boggs, 2001; Gilman et al., 2008a; Melvin et al., 2013, 2014) and hauling (Gilman et al., 2014b) in pelagic longline fisheries. The effect of pelagic longline soak depth, which is determined in part by branchline weight amount, is reviewed in Section 3.2.4.

b. Mechanism for significant effect
Branchline weight amount and the distance the weight is from the hook affect the sink rate of the baited hook, and contribute to determining the eventual gear soak depth (Brothers et al., 2001; Gilman et al., 2005; Robertson et al., 2010b, 2013; Melvin et al., 2013, 2014; Wolfaardt, 2015). The further a weight is located from the hook, the more time it takes for the weight to affect the sink rate and concomitant availability of the baited hook to seabirds during setting. Similarly, the further the weight is from the hook, the less likely the weight is to have an effect on the availability of baited hooks to surface-foraging seabirds during hauling (Brothers et al., 2001; Robertson et al., 2010b; Gilman et al., 2014b). Prescribed weight amounts and distance from the hook are included as an option for meeting seabird bycatch mitigation requirements by some tuna RFMOs (Clarke et al., 2014; Gilman et al., 2014a). See Section 3.2.3 for a discussion of interacting effects of leader material and branchline weighting designs (crew is less likely to place weights close to hooks when monofilament leaders are used). Section 3.2.5 discusses the mechanism for observed effects of pelagic longline soak depth on catch and survival rates.

c. Indicators measurable by human and/or electronic observers
For each trip, observers can record the mass of weights attached to branchlines, and the distance the weight is located from the hook. For electronic monitoring systems, this information can be collected prior to vessel departure from port (SPC, 2014). The location of weights on branchlines might also be detectable by office-based ‘dry’ observers when analyzing video of the set and haul.

d. Brief summary of tuna RFMO’s current observer data collection protocol
- **CCSBT**: Observers do not collect information on branchline weight amounts and distance from the hook (CCSBT, No Date).
- **IATTC**: Observers provide a fishing gear diagram where they can identify the locations of weights attached to the gear (IATTC, 2012). Observers record whether branchline weighting was employed as a form of seabird bycatch mitigation (IATTC, 2012).
- **ICCAT**: Observers of national observer programmes of member parties do not record the mass of branchline weights or the distance between the weights and the hook (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Record the ratio of branchlines with vs. without weights attached; the average weight in grams of weights attached to branchlines, and the distance of the weights from the hook (IOTC, 2010). Wire trace and integral weighted cord are not considered branchline weights (IOCT, 2010).
- **WCPFC and SPC/FFA**: For each trip, record in grams the mass of weights attached to branchlines, and record in cm the distance in meters from where the bottom of the weight is attached on the branchline to the eye of the hook (WCPFC, 2015). For each individual set, record if approximately 60 to 100g of weight were placed on branchlines 1-3 m away from the hook (SPC and FFA, 2014).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: Once per trip, sample 10 branchlines from each tote and determine the mass of attached weights to the nearest gram either by referring to the mass amount written on the weight or by weighing the weight with a scale, and measure the distance from the bottom of the weight and the eye of the hook to the nearest cm. Record the predominant weight amount in grams and predominant distance between weights and hooks in cm. Easy to collect, variable data quality.
- **Better**: Once per trip, sample 10 branchlines from each tote and determine the mass of attached weights to the nearest gram either by referring to the mass amount written on the weight or by weighing the weight with a scale, and measure the distance from the bottom of the weight and the eye of the hook to the nearest cm. Record the three most predominant weight amounts and distances between weights and hooks, and the percent of branchlines that each of the three weight amounts and distances made up. Easy to collect, higher data quality.
- **Even better**: Once per trip, measure all branchlines that are in the totes to determine the mass of attached weights to the nearest gram either by referring to the mass amount written on the weight or by weighing the weight with a scale, and measure the distance from the bottom of the weight and the eye of the hook to the nearest cm. Record the predominant weight amount in grams and predominant distance between weights and hooks in cm. Time consuming to collect, high data quality.
- **Best**: Once per trip, measure all branchlines that are in the totes to determine the mass of attached weights to the nearest gram either by referring to the mass amount written on the weight or by weighing the weight with a scale, and measure the distance from the bottom of the weight and the eye of the hook to the nearest cm. Record the three most predominant weight amounts and distances between weights and hooks, and the percent of branchlines that each of the three weight amounts and distances made up. Time consuming to collect, very high data quality.

3.2.6. Number of shark lines per set

a. Evidence of significant effect on catch and mortality

Catch rates of some shark species on shark lines have been found to be significantly higher and haulback survival rates significantly lower than on hooks between floats (Bromhead et al., 2012, 2013; Caneco et al., 2014). See Section 3.3.1 for additional information reviewing the effect of terminal tackle soak depth catch and survival rates in pelagic longline fisheries.

b. Mechanism for significant effect

Combined with information on the number of caught organisms on shark lines per set (Section 3.3.1) and at-vessel condition of caught organisms on shark lines per set (Section 3.3.3), information on shark line effort (number of shark lines per set) is needed to determine shark line catch and survival rates. In some pelagic longline fisheries targeting tuna and tuna-like species, fishers will use 'shark lines' to also target sharks (Bromhead et al., 2012, 2013; Gilman et al., 2013a; Caneco et al., 2014; Clarke et al., 2014). Shark lines place baited hooks near the surface by attaching branchlines directly to floats instead of to the mainline, and large pieces of tuna or incidental catch may be used for bait (Bromhead et al., 2012; Caneco et al., 2014). See Sections 3.2.4 and 3.3.1 for reviews of the mechanism for the effect of soak depth and shark lines, respectively, on catch and survival rates in pelagic longline fisheries.

c. Indicators measurable by human and/or electronic observers

Number of shark lines per set. This information could be obtained via electronic monitoring systems through review of the video of the setting operation (SPC, 2014).

d. Brief summary of tuna RFMO's current observer data collection protocol

- **CCSBT**: Observers are not tasked with recording the number of shark lines used per set, but are to record the intended depth of the shallowest hook (CCSBT, No Date).
- **IATTC**: Observers are not tasked with recording the number of shark lines used per set (IATTC, 2012).
- **ICCAT**: Observers of national observer programmes of member parties are not tasked with recording the number of shark lines deployed per set (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: It is optional for observers to record the number of shark lines per set (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **WCPFC and SPC/FFA**: Number of shark lines per set (SPC and FFA, 2014).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: Record whether shark lines (branchlines attached directly to floats) were used during each set. Easy to collect, variable data quality.
- **Better**: Record the number of shark lines used during each set. Easy to collect, high data quality.

3.2.7. Hooks per set and proportion of total hooks observed during the haul

a. Evidence of significant effect on catch and mortality
Fishing effort is routinely included in catch rate standardization models where the number of hooks deployed per set is used as a measure of relative pelagic longline fishing effort (e.g., Lynch et al., 2012; Brodziak and Walsh, 2013). Use of standardized units for measuring fishing effort is necessary for meaningful comparisons and for pooling datasets (Gilman, 2011). Related to hooks per set, see Section 3.2.9 for a review of the effect of soak duration on catch and survival rates. Information on the proportion of hooks deployed that was observed is needed to document the amount of effort that was sampled.

b. Mechanism for significant effect
In general, in fisheries catch rate models where catch is a dependent variable, a measure of effort should be included as either an explanatory variable or as an offset (Maunder and Punt, 2004). It is a fundamental approach to standardizing pelagic longline catch rates to account for hooks per set as an index of fishing effort in statistical models that are designed to account for changes in factors and covariates that that affect effective pelagic longline fishing effort (Maunder and Punt, 2004; Lynch et al., 2012). This is because the number of pelagic longline hooks deployed per set will affect the catchability of organisms that are susceptible to capture in this gear type, as the number of hooks per set is one measure of relative fishing effort between sets (Brodziak and Walsh, 2013). Furthermore, the larger the number of hooks per set, the longer it likely takes to set and haul the gear, hence increasing the gear soak time (see Section 3.2.9 for a discussion of the mechanism for the observed effect of soak duration on catch and survival rates). The number of hooks per set also is an index for the area covered by the gear when soaking, which might also affect longline catch rates.

c. Indicators measurable by human and/or electronic observers
Observers can record the proportion of the haul observed either as the number of baskets observed, number of hooks observed, or amount of time during hauling operations observed. Number of hooks between floats and number of floats deployed per set, or a direct count of the total number of hooks deployed per set can be used. Electronic monitoring systems can be used to observe the number of hooks deployed per set via office-based ‘dry’ observer analysis of video (SPC, 2014).

d. Brief summary of tuna RFMO’s current observer data collection protocol
- **CCSBT**: Number of hooks set, and number of hooks observed (CCSBT, No Date).
- **IATTC**: Record the total number (maximum) of hooks that the entire mainline contains when it is completely rigged. For each set, record the total number of hooks placed in the water during the initial setting of the mainline. Record the number of each type of hook lost during the set (IATTC, 2012).
- **ICCAT**: While protocols are highly variable between national observer programmes, some collect the number of hooks (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Record the total number of hooks set. This information can be obtained from the Fishing Master. Also, if hooks are stored in totes, these can be counted at the end of the setting operation and multiplied by the average number of hooks stored in each. The total length of line set and spacing can also be used to determine the number of hooks set. Record the number of hauled hooks observed for catch composition and by-catch. Note this must not include the time that the observer spent on the deck measuring and collecting biological data on the catch. Observers should be in a position during these observations to

record the hooks coming directly out of the water and record the fate of released species (IOTC, 2010).

- **WCPFC and SPC/FFA**: Observers are to record the period when they monitored the haul, and the total number of baskets observed per haul (SPC and FFA, 2014). For each set, observers are to record the total number of hooks (SPC and FFA, 2014). Observers are to record the total number of hooks used in a set, usually calculated by multiplying the number of baskets included in a set by the number of hooks per basket (WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

Hooks per set

- **Minimum**: For each set, estimate and record the number of hooks per set by multiplying the predominant number of hooks between floats (per basket) and the number of baskets set. Easy to collect, variable data quality.
- **Better**: For each set, count and record the number of hooks set by counting each hook as it is hauled, or otherwise by counting the number of branchlines stored in totes at the end of the haul. Time consuming to collect, highest data quality.

Observed hauled hooks

- **Minimum**: For each set, estimate and record the number of hauled hooks observed by counting the number of baskets observed and multiplying by the predominant number of hooks between floats. Easy to collect, variable data quality.
- **Better**: For each set, count and record the number of hauled hooks observed by counting each hook as it is hauled. Time consuming to collect, highest data quality.

3.2.8. Number of light attractors per set

a. Evidence of significant effect on catch and mortality

Light attractors have been observed to significantly explain shark, teleost and sea turtle pelagic longline catch rates (Bigelow et al., 1999; Witzell, 1999; Wang et al., 2007; Ward et al., 2009; Poisson et al., 2010). Bigelow et al. (1999) found that the factor lightsticks per hook significantly affected blue shark catch rates, but it was a weak effect relative to other modeled variables. Poisson et al. (2010) observed a significant but also a weak effect of lightsticks on catch composition and catch rates in a shallow-set pelagic longline swordfish fishery. Ward et al. (2009) found a significant effect of lightsticks on yellowfin tuna catch rates. Significantly higher nominal sea turtle catch rates were observed on vessels that used lightsticks relative to those that did not (Witzell, 1999). Captive loggerhead sea turtles have been observed to be attracted to illuminated lightsticks (Wang et al., 2007).

b. Mechanism for significant effect

Light attractors, including chemical and battery-powered lightsticks, are attached to some or all branchlines in some longline fisheries to target billfishes and possibly other market species. Light attractors may affect longline catch rates because they attract predators to the terminal tackle, and/or because they attract small fish and squid to the gear which in turn attracts predators (Hazin et al., 2005; Poisson et al., 2010). Poisson et al. (2010) hypothesized that light attractors likely influence billfish catch rates because visual cues over short distances (meters) influence their feeding behavior and ambient light conditions including from light attractors will affect their ability to visually detect prey. However, given that swordfish and other longline-caught apex predators have efficient vision in dim light, the light produced by the attractor may be a more important factor in attracting swordfish and other predators to the gear than an increase in ability to see the bait (Hazin et al., 2005). Sea turtle attraction to light attractors might be influenced by the flicker rate or wavelengths emitted (Crognale et al., 2008).

c. Indicators measurable by human and/or electronic observers

During each set, observers can record whether light attractors were attached to the gear, the number of branchlines on which light attractors were attached and the total number of light attractors used per set. When combined with information on the total number of branchlines included per set, the field number of light attractors per set can be used to determine the number of light attractors per hook. Electronic monitoring systems could have office-based ‘dry’ observers analyze video during the set or haul to determine this information.

d. Brief summary of tuna RFMO’s current observer data collection protocol

- **CCSBT**: Observers are not required to record whether light attractors were used in longline gear (CCSBT, No Date).
- **IATTC**: Record the maximum number of lights used during any set of the trip (IATTC, 2012).
- **ICCAT**: Some national observer programmes of ICCAT members collect information on light stick use (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Record whether lightsticks were attached to the branchlines and the total number used (IOTC, 2010).
- **WCPFC and SPC/FFA**: For each set record the total number of lightsticks that were attached to the gear (SPC and FFA, 2014). Record where along the mainline the crew attach lightsticks to the branchlines (WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: For each set, record whether or not light attractors were attached to the gear. Easy to collect, variable data quality.
- **Better**: For each set, record the number of branchlines on which one or more light attractor was attached. Time consuming to collect, higher data quality.
- **Best**: For each set, record both the number of branchlines on which one or more light attractor was attached, and the total number of light attractors used. Time consuming to collect, highest data quality.

3.2.9. Vessel position, and date and time at start and end of set and haul

a. Evidence of significant effect on catch and mortality

The temporal and spatial distribution of fishing effort, from fine (time of day of fishing operations, location of the start and end of the set and haul) to broad (season, year, region) scales, have been observed to significantly affect catch rates, length frequency distributions and sex ratios of all taxonomic groups in pelagic longline fisheries (e.g., Lokkeborg and Bjordal, 1992; Bigelow et al., 1999; Andrade et al., 2005; Mejuto et al., 2008; Nakano and Stevens, 2008; Megalofonou et al., 2009; Walsh et al., 2009; Carvalho et al., 2011; Curran and Bigelow, 2011; Bromhead et al., 2012; Gilman et al., 2012; Ferrari and Kotas, 2013; Mitchell et al., 2014; Selles et al., 2014).

Soak duration (the time between the start of the set and the end of the haul) can affect longline catch and survival rates, typically increasing catch and reducing survival rates (Ward et al., 2004; Diaz and Serafy, 2005; Watson et al., 2005; Gilman et al., 2006b; Erickson and Berkeley, 2008; Campana et al., 2009; Carruthers et al,, 2009; Vega and Licandeo, 2009; FAO, 2010; Poisson et al., 2010; Foster et al., 2012; Gallagher et al., 2014).

The area covered by the gear when soaking (the polygon formed by the four positions of the start and end of the set and haul) might also affect longline catch and survival rates, as this variable relates to both hooks per set (Section 3.2.7) and soak duration.

b. Mechanisms for significant effect

The spatial and temporal distribution of fishing effort affects catch and haulback survival rates because both the local abundance of longline-caught species and environmental factors that affect haulback condition vary over fine to broad spatial and temporal scales, based on the distribution of coupled and de-coupled static and hydrodynamic features that influence the distribution of chemical, physical and biological properties and productivity of all components of marine trophic webs within pelagic ecosystems (Gilman et al., In Review). See Section 3.2.4 for a discussion of the synergistic effects of soak depth and temporal and spatial distribution of effort on catch and survival rates.

There is natural and anthropogenic-caused temporal and spatial variability in pelagic species', populations' and stocks' local (relative) and absolute abundance, size structure and sex ratios. For example, seasonal and spatial variability in local abundance for some shark populations results from complex temporal and spatial segregation by life stage and sex, including from forming aggregations at pupping grounds, and at nursery and mating areas, and from undergoing seasonal migrations (e.g., Strasburg, 1958; Litvinov, 2006; Nakano and Stevens, 2008; Carvalho et al., 2011; Vandeperre et al., 2014). There can also be spatial and seasonal variability in local abundance due to temporal and spatial variability in fishing mortality rates (Bigelow et al., 1999; Gilman et al., 2008b; Coelho et al., 2012a).

Pelagic apex predators, and in some cases sizes and sexes within species, have different predictable pelagic habitat preferences for foraging and breeding (Polovina et al., 2004; Hyrenbach et al., 2000, 2006; Bailey and Thompson, 2010; Mitchell et al., 2014; Vandeperre et al., 2014). Various environmental parameters have been used to define these static and dynamic pelagic habitats. Some of these variables are static, such as the location of topographic features including shallow submerged features like seamounts and reefs, areas with steep seabed gradients and proximity to coastal features that can create small-scale eddies and fronts, where the influence of these static features in concentrating productivity may be coupled with hydrodynamic conditions such as current direction (Bailey and Thompson, 2010; Bromhead et al., 2012; Gilman et al., 2012). Others are dynamic, associated with short-lived, ephemeral and persistent, basin-, meso- and finer-scale oceanographic features and conditions that vary temporally and spatially, from fine (days, kilometers) to meso- (tens to hundreds of days, tens to hundreds of kilometers), and broad- (years to decades, entire ocean basin) scales. Dynamic environmental parameters employed to predict the location of preferred forage habitats of individual pelagic predator species, a response to the distribution of their prey, have included sea surface temperature (SST), sea surface concentration of chlorophyll-a, thermocline depth, sea surface height anomalies, and range of sea surface temperature occurring within the area around the fishing grounds (where a large range in SST indicates the presence of an oceanic front) (Bigelow et al., 1999; Polovina et al., 2001; Andrade et al., 2005; Hyrenbach et al., 2000, 2006; Amorim et al., 2009; Bailey and Thompson, 2010; Walsh and Clarke, 2011; Bromhead et al., 2012; Mitchell et al., 2014). Spatial and temporal distribution of top predators are affected by the distribution of oceanic hydrodynamic features, such as persistent, basin-wide currents and frontal systems, meso-scale upwelling plumes, eddies and frontal systems, and fine-scale and ephemeral fronts and eddies. This is because these features structure the distribution of nutrients, distribution of levels of primary productivity, and distribution of aggregations of mid-trophic level species, which attract pelagic apex predators (Bigelow et al., 1999; Hyrenbach et al., 2000, 2006; Megalofonou et al., 2009; Carvalho et al., 2011; Mitchell et al., 2014; Selles et al., 2014; Vandeperre et al., 2014).

The effect of the time of day of fishing operations on catch and survival rates of some species is likely because species composition, vertical and horizontal distribution, size structure and foraging behavior can vary by time of day (e.g. Boggs, 1992; Bigelow et al., 2002; Ward et al., 2004; Gilman et al., 2008a; Musyl et al., 2011). For example, gear retrieval during daytime has been observed to significantly affect sea turtle catch rates (Watson et al., 2005; Gilman, 2011). And, for instance, night setting can reduce catch rates of diurnal foraging seabird species (Gilman, 2011). For pelagic apex predator fishes, including some pelagic shark species, the time of day of fishing operations may significantly affect catch rates because some species conduct diel vertical migration cycles (Carey et al., 1990; Boggs, 1992, Sedberry and Loefer, 2001; Schaefer and Fuller, 2002; Nakano et al., 1997, 2003; Weng and Block, 2004; Hyder et al., 2009; Musyl et al., 2011). For example, blue sharks have been observed to make frequent deep dives during the daytime, and at night remain in shallower waters (Carey et al., 1990). Sea turtles might also exhibit diel vertical migration patterns, making time of day of fishing operations a significant explanatory factor for turtle catch rates: Turtles might conduct relatively deeper dives during dusk and dawn to reach zooplankton as it migrates vertically through the water column, but during the daytime prey might be too deep or not worth the energy investment for sea turtles to reach (Hays et al., 2006).

Longer soaks might increase catch rates as organisms have a longer time period and hence risk of capture. However, longer soak duration might also result in higher depredation rates, falloff due to mechanical action, and escapement rates, and thus longer gear soaks might result in lower catch rates for some species (Ward et al., 2008; Clarke et al., 2014). Longer soak times might increase capture stress, and for species with ram-ventilation, might result in higher rates of asphyxiation when captured on short branchlines for prolonged periods.

The area covered by the gear during the soak is an index of fishing effort as well as soak duration. See Section 3.2.7 for a discussion of the mechanism for the effect of the variable hooks per set on catch and survival rates, which may be similar to the mechanism for the effect of the area fished during the gear soak. Also, see Section 3.2.3 for a discussion of interacting effects of leader material and soak duration on catch rates.

c. Indicators measurable by human and/or electronic observers

Observers can record latitude, longitude, date and time at the start and end of each set and haul (SPC, 2014). In electronic monitoring systems, this information could be collected by a sensor (e.g., on the mainline shooter for the start and end of the set, and on the line hauler for the start and end of the haul) or via review of the video, both of which would rely on GPS equipment (SPC, 2014).

d. Brief summary of tuna RFMO's current observer data collection protocol

- **CCSBT**: Date and time at the start and end of sets and hauls, using 24 hour clock, UTC. Latitude and longitude at the start and end of sets and hauls to one minute of accuracy (CCSBT, No Date).
- **IATTC**: Latitude and longitude in degrees and minutes, date, and time using a 24 hour clock, of the start and end of each set and haul (IATTC, 2012).
- **ICCAT**: Date, time, latitude and longitude of the start and end of the haul are collected by observers of some national observer programmes of member parties (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Date, time (in GMT), latitude and longitude at the start and end of sets and hauls (IOTC, 2010).
- **WCPFC and SPC/FFA**: Date, time, longitude and latitude of the start and end of the set and haul. The start and end of the set is when the first and last buoys are thrown into the water, respectively, and start and end of the haul is when the first and last buoys are removed from the water, respectively. Latitude and longitude are to be recorded in degrees, minutes and decimal minutes (dd^{o} mm.mmm') and note North or South latitude and East or West longitude. Date and time are to be recorded following ISO 8601 (year/month/day – hour:minute) with hours using a 24 hour clock, both using the ship's clock (and the observer's watch) that they are set to, and the UTC date and time as read from a GPS (SPC and FFA, 2014; WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum and best**: Human onboard observers use a GPS to determine vessel position, date and time at the start and end of each set and haul. The start and end of the set is when the first and last buoys are thrown into the water, respectively, and start and end of the haul is when the first and last buoys are removed from the water, respectively. Easy to collect, high data quality. Use a standardized method for which time zone is to be used and whether 12 or 24 hour clock is used. And use a standardized method to record longitude and latitude.

3.2.10. Seabird bycatch mitigation methods: Tori pole and line, stern vs. side set, bird curtain, blue-dyed bait, thawed bait, underwater setting chute, practices for discharging offal/bait/dead discards during setting and hauling

a. Evidence of significant effect on catch and mortality

Effective employment of combinations of certain seabird avoidance methods has been observed to significantly reduce seabird catch rates to close to zero (Gilman, 2011; Gilman et al., 2007b; Clarke et al., 2014). Previous Sections have reviewed the effect of branchline weighting in interaction with the distance of the weight from the hook (prescribed weight amounts and distance from the hook are included as an option for meeting seabird bycatch mitigation requirements by some tuna RFMOs, Clarke et al., 2014; Gilman et al., 2014a) (Section 3.2.5); time of day of setting (night setting is an option for meeting seabird bycatch mitigation requirements by some tuna RFMOs, Clarke et al., 2014; Gilman et al., 2014a) (Section 3.2.9); and mainline line shooter (deep setting line shooter is included as a tuna RFMO option for meeting seabird bycatch mitigation requirements by some tuna RFMOs, Clarke et al., 2014; Gilman et al., 2014a) (Section 3.2.4) on longline catch and survival rates.

Single and paired tori lines of various designs have been observed to significantly reduce seabird interaction and catch rates in pelagic longline fisheries (McNamara et al., 1999; Boggs, 2001; Yokota et al., 2008; Domingo et al., 2013; Yokota et al., 2011; Sato et al., 2013a,b; Clarke et al., 2014; Melvin et al., 2004, 2013, 2014).

Stern vs. side setting in combination with a bird curtain has been observed to significantly reduce seabird catch rates in the Hawaii longline swordfish and tuna fisheries (Gilman et al., 2007b, 2008a).

Blue-dyed bait, and blue-dyed and thawed bait have been observed to significantly lower seabird catch rates, where blue-dyed squid bait has a larger effect in reducing seabird catch rates than blue-dyed fish bait (McNamara et al., 1999; Boggs, 2001; Minami and Kiyota, 2001; Cocking et al., 2008; Gilman et al., 2003, 2008a; Clarke et al., 2014).

Underwater setting chutes have been observed to significantly reduce seabird catch rates (O'Toole and Molloy, 2000; Gilman et al., 2003).

Practices for handling offal, spent bait and dead discards (either retain these discards during setting and hauling, or discard them on the opposite side of the vessel from where setting or hauling operations are occurring) have been observed to affect seabird catch rates (Cherel et al., 1996; McNamara et al., 1999; Gilman et al., 2005; Clarke et al., 2014).

Some of the seabird bycatch mitigation methods included here might affect catch and survival rates of other taxonomic groups. E.g., see Section 3.2.9 for a review of the effect of time of day on pelagic longline catch and survival rates. Blue dyed bait has been observed to not significantly affect longline catch rates of sea turtles, teleosts or elasmobranchs (Swimmer et al., 2005; Yokota et al., 2009). Tori lines, side vs. stern setting, bird curtain, and underwater setting chutes are not likely to affect catch rates of species other than seabirds as these methods only affect access to baited hooks at and near the sea surface.

b. Mechanism for significant effect

Primarily while gear is being set but also during hauling in some fisheries, seabirds are hooked or entangled and drown as pelagic longline gear sinks (Anderson et al., 2011; Gilman, 2011; Gilman et al., 2005, 2014b).

Bird scaring tori lines might deter birds from accessing the area where baited hooks are entering the water and the area above where they can dive and reach the baited hooks underwater. Bird curtains, required in combination with side setting by some tuna RFMOs, prevent birds from employing a flight pattern that allows them to get close to the vessel hull where side set baited hooks are entering the water. Blue-dyed bait and underwater setting chutes might reduce seabird catch rates by reducing seabird detection of baited hooks (Gilman et al., 2005). Blue-dyed bait might be more difficult for seabirds foraging from above to see as the contrast between the bait when dyed blue and the seawater is reduced. The bait type (squid soaks up the dye better than fish with scales) and amount of dye that the bait soaks up (e.g., thawed bait soaks up dye better than frozen bait, and the longer the bait soaks, the more dye it will soak up, up until some threshold), sea color, and ambient light levels are factors that determine whether the dyed bait will have reduced contrast to the sea surface (Cocking et al., 2008). Alternatively, the blue color of the bait may make it unattractive to seabirds perhaps because they might be less likely to recognize it as a prey item (Lydon and Starr, 2005). The underwater setting chute, by having baited hooks enter the water below the sea surface, may make it more difficult for seabirds to detect the baited hooks when foraging from above. Underwater setting chutes and side setting may limit bird access to the hooks because they are protected from the birds (by the chute and the vessel hull, respectively) until they are underwater and out of diving reach of some seabirds. Underwater setting chutes, tori lines and side setting effect on seabird catch rates may be affected in part by the diving capabilities of the seabirds interacting with the vessel (Gilman et al., 2005; Gilman, 2011). Thawed bait may also reduce bird access as it increases baited hook sink rates relative to frozen bait. Tuna RFMO guidance materials on blue-dyed bait state that the bait must be thawed when being dyed, but do not require the bait to be thawed when set (e.g., WCPFC, 2012). In practice, however, vessels choosing this option likely dye the bait immediately prior to use and thus blue-dyed bait is likely also at least partially thawed. This is because operators do not want to take the time to thaw, pre-dye and then re-freeze the bait, and pre-dyed bait is not commercially available (Gilman et al., 2005).

To mitigate seabird bycatch, some fisheries are prohibited from discharging offal from processed catch, spent bait and dead discards during fishing operations, while others are required to "strategically" discharge these materials from the opposite side of the vessel from where gear is being set or hauled in an attempt to attract scavenging birds away from baited hooks (Gilman et al., 2005; Gilman, 2011; Clarke et al., 2014; Gilman et al., 2014a,b). Throwing offal and other discards on the opposite side of the vessel from the setting or hauling stations might draw scavenging seabirds' attention away from where baited hooks are available and reduce interactions rates (Cherel et al., 1996). However, this might be a short-term effect, where vessels that routinely discharge offal and other discards might be preferentially followed by seabirds and other scavengers (Brothers et al., 1999). Vessels that routinely retain offal and other discards during setting and hauling might reduce the abundance of seabirds and other organisms attending the vessel, reducing catch rates relative to vessels that routinely discharge offal and other discards (Brothers et al., 1999; Gilman, 2011; Gilman et al., 2014a). Retention during setting and hauling might also reduce competitive seabird scavenging behavior and foraging intensity, and reduce the risk of capture relative to vessels that discharge offal and other organic materials during setting and hauling (Brothers et al., 1999).

c. Indicators measurable by human and/or electronic observers

During each set, was a single tori pole and line, paired tori pole and line, side setting, bird curtain, blue-dyed bait, thawed bait, or underwater setting chute employed? During each set, was offal, spent bait or dead discards discharged away from the area where gear was entering the water? During each set, was all offal, spent bait and dead discards retained? During each haul, was all offal, spent bait and dead discards discharged on the opposite side of the vessel from the hauling station? During each haul, was all offal, spent bait and dead discards retained?

Electronic monitoring systems can determine the employment of these seabird bycatch mitigation methods through office-based 'dry' observer analysis of video (SPC, 2014).

d. Brief summary of tuna RFMO's current observer data collection protocol

- **CCSBT**: Observers record whether a tori pole was used (CCSBT, No Date).

- **IATTC**: For each record of a seabird interaction event, record mitigation measures in place to avoid capture of birds, including: bird scaring lines, side setting, blue dyed bait, underwater setting, and offal and discard discharge management (IATTC, 2012).
- **ICCAT**: National observer programmes of ICCAT members do not collect information on tori pole use, side setting, blue-dyed bait, thawed bait, underwater setting chute, and management of offal, spent bait and dead discards during setting and hauling (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: For each set, observers are to record whether bait was dyed, which species was used, the ratio of dyed to untreated baits, color or colors that the different baits are dyed, the dye color related to the species of bait, how long the bait was soaked in the dye (IOTC, 2010). Observers also record for each set whether a tori streamer line was used, the number of tori lines used, and whether it was used for the entire set (IOTC, 2010). Observers record for whether offal and used bait are retained for batch disposal or are disposed of ad hoc as they accumulate, and the position where offal and used bait were disposed of (IOTC, 2010).
- **WCPFC and SPC/FFA**: On each set, observers are to record whether bait was dyed blue (SPC and FFA, 2014). Did the vessel throw any fish offal (any dead fish or parts of dead fish) overboard at any stage during the setting or hauling, and where was offal disposed from (SPC and FFA, 2014). During each set, describe the disposal method for offal management; for example, did the vessel just throw it over the side as they process the fish, accumulate offal in baskets and throw it over in one go, or use a machine that blends the offal and sprays it over the side (WCPFC, 2015). During each set, was a tori pole, bird curtain or underwater setting chute used? (SPC and FFA, 2014; WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum and best**: During each set, record whether a single or paired tori pole and line, side setting, bird curtain, blue-dyed bait, thawed bait, or underwater setting chute were employed. During each set, record whether offal, spent bait or dead discards were discharged away from the area where gear was entering the water. During each set, record whether no offal, spent bait and dead discards were discharged. During each haul, record whether all offal, spent bait and dead discards were discharged on the opposite side of the vessel from the hauling station. During each haul, record whether no offal, spent bait and dead discards were discharged. Easy to collect, adequate data quality.

3.3. Catch

3.3.1. Hook number (between floats and shark line)

a. Evidence of significant effect on catch and mortality

Taxa	Effects
Teleosts	Higher catch rates of epi-pelagic species, including some billfishes, have been observed on shallower vs. deeper hooks between floats (Galeana-Villasenor et al., 2008; Beverly et al., 2009).
Sharks	Higher catch rates of some shark species have been observed on shallower vs. deeper hooks between floats (Hazin et al., 1994; Galeana-Villasenor et al., 2008; Bromhead et al., 2012; Caneco et al., 2014). Significant differences between catch rates of male vs. female blue sharks by hook number have also been observed (Hazin et al., 1994). Catch rates of some shark species on shark lines have been found to be significantly higher and haulback survival rates significantly lower than on hooks between floats (Bromhead et al., 2012, 2013; Caneco et al., 2014).
Sea turtles	Sea turtle catch rates have been observed to be higher on branchlines located closest to floats than on deeper branchlines (Kleiber and Boggs, 2000; Watson et al., 2002; Gilman et al., 2006b).

b. Mechanism for significant effect

See Section 3.2.4 for a review of how soak depth effects catch and survival rates, and Section 3.2.6 for additional information on shark lines.

'Hook number' refers to the position of a hook between two floats, where 'hook one' is the first hook to be hauled following retrieval of a float, and hook n is the last hook to be hauled before retrieving the next float. Because the mainline of a pelagic longline soaks in a catenary curve (see Beverly et al. [2003] for a description of pelagic longline fishing gear and methods), branchlines attached to the mainline between two adjacent floats soak at different depths, and therefore hook number is an indicator of the soak depth of that hook (Hazin et al., 1994; Bigelow et al., 2002). However, actual depth of hooks will be variable depending on numerous gear design, fishing method and environmental variables (Section 3.2.4) (Boggs, 1992; Beverly and Robinson, 2004; Ward and Myers, 2005, 2007; Bigelow et al., 2002, 2006; Vega and Licandero, 2009). And, some species may tend to be captured as the gear is sinking to its final soak depth, or during retrieval, as the gear passes through the water column, where capture by hook number does not reflect differences in soak depth, primarily an issue in deeper-set longline fisheries, where terminal tackle passes through a relatively large section of water column, for a relatively large time period, during setting and hauling operations (Boggs, 1992; Kerstetter and Graves, 2006).

c. Indicators measurable by human and/or electronic observers

During the haul, observers can record the hook number or otherwise a shark line on which each organism was caught (SPC, 2014). This information can be collected by electronic monitoring systems through review of the video (SPC, 2014).

d. Brief summary of tuna RFMO's current observer data collection protocol

- **CCSBT**: Observers are not tasked with recording the hook number on which organisms are caught, or to record when organisms are caught on a shark line (CCSBT, No Date).

- **IATTC**: Observers are not tasked with recording the hook number on which organisms are caught, or to record when organisms are caught on a shark line (IATTC, 2012).
- **ICCAT**: Observers of national observer programmes of member parties are not tasked with recording the hook number on which organisms are caught, or recording when organisms are caught on a shark line (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Observers are not tasked with recording the hook number on which organisms are caught, or recording when organisms are caught on a shark line (IOTC, 2010).
- **WCPFC and SPC/FFA**: During the haul, record the hook number between floats or otherwise a shark line (branchlines attached to floats) on which each organism was caught, where hooks are counted from the last float hauled onboard to the next float hauled onboard (SPC, 2014; WCPFC, 2015). When there are more than 8 hooks in a basket (between floats), or when fishing is very busy, an estimate of hook number is acceptable (SPC, 2014).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: During the haul, record whether an organism was caught on a hook next to a float, hook not next to a float, or on a shark line. East to collect, minimum data quality.
- **Better**: During the haul, record the hook number between floats on which each organism was caught or if the organism was caught on a shark line (branchline attached to a float). More time consuming to collect, highest data quality.

3.3.2. Species, length, sex

a. Evidence of significant effect on catch and mortality

Documenting the catch composition by species, and length distributions and sex ratio by species, and their temporal and spatial trends, is some of the fundamental information needed for stock assessments and for assessing population-level effects of fishing mortality (e.g., Heppell et al., 1999; Dulvy et al., 2004; Chaloupka and Balazs, 2007; Maunder and Punt, 2013). The number of caught organisms by species or less specific taxonomic rank is a typical response or dependent variable in statistical analyses.

Pelagic longlining selectively removes older age classes of a subset of species of pelagic ecosystem apex to middle trophic levels (Cox et al., 2002; Kitchell et al., 2002; Hinke et al., 2004; Ward and Myers, 2005; Polovina et al., 2009; Gilman et al., 2012). There is evidence of species-specific variability in survival rates of species susceptible to catch in pelagic longline gear (e.g., review of post-release mortality of billfishes, Musyl et al., 2015; review of at-vessel and post-release mortality of elasmobranchs, Musyl et al., 2011; Gilman et al., In Review). There is also evidence of an effect of length on survivability: smaller individuals of species of teleosts and sharks have been observed to have a lower probability of at-vessel and post-release survival (Neilson et al., 1989; Milliken et al., 1999; Diaz and Serafy 2005, Campana et al., 2009, Coelho et al. 2012b; Epperly et al., 2012; Gallagher et al., 2014). Different pelagic longline gear designs and fishing methods have also been observed to result in size selectivity. For instance, Ferrari and Kotas (2013) found significantly larger pelagic stingrays mean lengths caught on a narrower J hook than on a wider circle hook. Amorim et al. (2014) observed significantly larger bigeye tuna and significantly smaller yellowfin tuna were caught on narrower J hooks vs. wider circle hooks. For some species, sex-skewed catch and mortality rates have been observed. For instance, sex-skewed longline catch rates have been observed for some seabird (Bugoni et al., 2010), billfish (Shimose et al., 2012) and shark species (Beerkircher et al., 2002; Vandeperre et al., 2014). And, for instance, Coelho et al. (2012b) observed a significantly higher proportion of male blue and crocodile sharks were dead upon haulback than females.

b. Mechanism for significant effect

Susceptibility to capture, by species, size and sex, is variable by individual longline fishery, and by individual vessels within a fishery. This is due to differences in the temporal and spatial distribution of effort, fishing gear designs and fishing methods, which causes individual pelagic longline fisheries, and individual vessels within a fishery, to have different catch compositions by species, age class and sex ratios. See Section 3.2.9 for a discussion of the effect of spatial and temporal distribution of effort on catch composition, including by species, length and sex, and see Section 3.1.1 for a discussion of unique vessel effects. Species-specific differences in survival are due to morphological and behavioral differences between species, e.g., where species that depend heavily on ram ventilation for breathing are more vulnerable to mortality from asphyxiation the longer the soak time and the shorter the branchlines, and e.g., species that are typically foul-hooked or species that tend to get hooked in the mouth, such as those with relatively small mouths, have a higher probability of survival than species that tend to swallow hooks, such as larger-mouthed species (e.g., Epperly et al. 2012; Swimmer and Gilman 2012). Some species exhibit temporal and spatial segregation by sex, resulting in differences in relative abundance and concomitant catch rates by sex (e.g., pelagic sharks, Strasburg, 1958; Beerkircher et al., 2002; Litvinov, 2006; Nakano and Stevens, 2008; Carvalho et al., 2011; Vandeperre et al., 2014; seabirds Bugoni et al., 2010; billfishes Shimose et al., 2012). Species with sexual size dimorphism (differences in size by sex of the same age class, i.e., differential growth by sex) might have sex-skewed longline catch rates due to the larger sex having a competitive advantage at scavenging baits and/or if the gear is size selective, however, this has not been documented to occur in pelagic longline fisheries. Smaller organisms, in general, are weaker and more sensitive to capture and handling stress (Broadhurst et al., 2006). For species with sexual size dimorphism (of all teleosts this is understood to be most extreme in istiophorids, Prince and Brown, 1991), this might explain an observed effect of sex on survival rates.

c. Indicators measurable by human and/or electronic observers

Species, length and sex of caught organisms, including those removed from the gear in the water and those that are brought on deck and either retained, released alive or discarded dead.

Species can be determined through the review of video collected by electronic monitoring systems. Lengths might be determined from video images of fish that are laid on a measuring mat. For species where evidence of sex is externally visible such as with shark species, sex may be able to be determined from a review of video. For species where evidence of sex is not externally visible, video would need to show the fish processing in order to provide a possibility of review of the video to determine sex (SPC, 2014).

d. Brief summary of tuna RFMO's current observer data collection protocol

Species

- **CCSBT**: For each caught organisms, record the FAO species code, or use National codes and provide a translation table to FAO species codes, and record the number of each species caught (CCSBT, No Date).
- **IATTC**: For each set, for organisms brought aboard the vessel, record the species name. If the animal is lost from a hook, escapes or falls back into the sea, do not record it as part of the catch (IATTC, 2012). Record the scientific name whenever possible, the common name, or the alpha code assigned to this species (IATTC, 2012).
- **ICCAT**: Normally for each set or trip at least the FAO species code and weight or number of each species per haul is recorded (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: For all retained and non-retained (discarded and released) catch, record the species of fish using the IOTC three figure alpha codes (IOTC, 2010). Use the FAO code for seabird species. If a species cannot be positively identified or an FAO code is unavailable, then the observer records the species scientific or common name. If the observer cannot identify the species, then the observer records the species as "unknown" and assigns a unique reference number to that individual species. The same reference number should be used throughout the trip for that species. Where possible the observer should retain a sample and/or take a photograph of the unidentified organism. This is especially important when organisms are cut off in the water. The observer records the number and estimated weight of each species (IOTC, 2010).
- **WCPFC and SPC/FFA**: FAO species code for all caught organisms (WCPFC, 2015).

Length

- **CCSBT**: Optional for species other than southern bluefin tuna. Identify the measurement method used. Round to the nearest cm (CCSBT, No Date). .
- **IATTC**: For organisms brought aboard the vessel only, record the length in cm as follows:
  - Sharks: (i) total length (TL**,** from the tip of the snout to the tip of the tail), but if a shark's tail is damaged or missing, then leave TL blank; (ii) precaudal length (PCL, from the tip of the snout to the anterior insertion of the caudal fin), (iii) interdorsal space (IDS, from the posterior insertion of the first dorsal fin to the anterior insertion of the second dorsal fin), and (iv) for male sharks measure the clasper length (CL).

- Rays: (i) total length (TL, from the tip of the disc to the tip of the tail), (ii) disc length (DL), and (iii) disc width (DW).
- Turtles: (i) curved carapace length, and (ii) curved carapace width (IATTC, 2012).

- **ICCAT**: Most national observer programmes of member parties collect information on the length of catch (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: A range of length measurements can be recorded for different fish species. Note clearly the measurement method and units employed. Record the lengths of turtles and marine mammals where this is possible. For turtles record shell length, head width and tail length. Note if measured in straight line or over the curve. For marine mammals measure the total length (IOTC, 2010).
- **WCPFC and SPC/FFA**: Measure length of species using the recommended measurement and record the code for the type of measurement used (WCPFC, 2015). The preferred measurement method for non-billfish teleosts and sharks and for marine mammals is upper jaw/snout to the fork in the tail (UF), for billfishes is lower jaw to fork in the tail (LF), for rays is total width (TW), and for seas turtles is carapace length (CL) (SPC and FFA, 2014). For tunas, if UF cannot be measured, then measure upper jaw to second dorsal fin (US) or pectoral fin to second dorsal fin (PS). For billfishes, if LF cannot be measured, then measure pectoral fin to fork in tail (PF) or PS. For sharks, if UF cannot be measured, then measure total length (TL). Measure the pectoral and second dorsal fins at the most forward points that they attach to the body (SPC and FFA, 2014).

Sex

- **CCSBT**: Determine the sex. If not possible to determine, then record "indeterminate". If not examined, then record "not examined" (CCSBT, No Date).
- **IATTC**: For organisms brought aboard the vessel only, record the sex if it is possible to determine (IATTC, 2012).
- **ICCAT**: Some national observer programmes of member parties collect information on the sex of caught species of special interest (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Record the sex when this can be determined (IOTC, 2010).
- **WCPFC and SPC/FFA**: Sex the caught fish if possible. If too difficult to determine, then record "indeterminate". If not seen i.e. on a whole fish, record "unknown" (WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

Species

- **Minimum and best**: For each set, record the FAO species code for all caught organisms and the number caught for each species, including those removed from the gear in the water and those that are brought on deck. If an observer observes an organism freeing itself from the gear and is not handled by crew (e.g., throws the hook, breaks the line, becomes untangled from line), then constitutes a pre-catch escapement event and not a released catch event. If a species lacks an FAO species code, then record a scientific name from an authoritative list agreed by the tuna RFMOs. For species that an observer cannot identify to the species level, attempt to retain a sample (if not a live species of conservation concern) or take a photograph so that the species might later be identified by experts. Time consuming to collect, adequate data quality.

Length

- **Minimum and best**: For rare-event species, attempt to measure lengths for all catch. For common species, measure a sample of the catch employing a sampling method that ensures within-strata randomness. Measure to nearest cm. Use large calipers (1.5m length) or a measuring board to measure small to medium-sized organisms. Use a flexible measuring tape to measure the length of large organisms and for all sea turtles. Record the measurement method employed. Time consuming to collect, adequate data quality.

Sex

- **Minimum and best**: For rare-event species, attempt to determine sex (male, female, could not determine, did not examine) for all catch. For common species, measure a sample of the catch employing a sampling method that ensures within-strata randomness (e.g., every third caught organism of a common species). Time consuming to collect, adequate data quality.

3.3.3. At-vessel life status (condition when caught) and depredation

a. Evidence of significant effect on catch and mortality

The at-vessel or haulback life status (the disposition or condition of a caught organism when brought to the vessel during gear hauling before being handled by crew) provides information on one component of fishing mortality (ICES, 1995; FAO, 2011; Gilman et al., 2013b). Haulback condition is a typical response or dependent variable. Haulback condition, including whether catch was depredated, has been observed to affect the quality of marketable pelagic longline catch (Nobrega et al*.* 2014).

b. Mechanism for significant effect

Information on haulback condition enables assessments of the effects of explanatory variables on mortality rates, and might be an indicator of pre-catch and post-release probability of mortality (Gilman et al., 2013b, In Review). Information on depredation of catch provides an indication of the cause of catch observed to be dead upon haulback, a reason for discarding catch of marketable species, and an indication of the indirect, collateral effect of fishing on the diet of species that depredate catch from pelagic longline fisheries. Depredation, the removal and damage of caught fish and bait from fishing gear, typically is conducted by odontocetes, sharks and squid in pelagic longline fisheries (e.g., Secchi and Vaske, 1998; Gilman et al., 2006a, 2008b; Hamer et al., 2012; Clarke et al., 2014). Fish damaged by cetaceans is usually distinguishable from shark-damaged fish with the latter typically being bitten in half with clean bites or several small bites. Some cetacean species leave only the fish head up to the gills, or just the lips and upper jaw (Secchi and Vaske, 1998).

c. Indicators measurable by human and/or electronic observers

During hauling, when a caught organism is brought to the vessel but before being handled by crew, observers can record whether the organism was alive or dead, degree of injury for live catch, and a description of any depredation. Office-based ‘dry’ observer can analyze electronic monitoring video of the hauling station to determine the condition of each caught organism when hauled to the vessel (SPC, 2014). Dry observers could also identify depredation for catch brought on deck.

d. Brief summary of tuna RFMO’s current observer data collection protocol

- **CCSBT**: Condition only of southern bluefin tuna is recorded (CCSBT, No Date).
- **IATTC**: The condition when captured of sea turtles and seabirds is recorded (IATTC, 2012).
- **ICCAT**: Noting that there is there is great variability in information required between national observer programmes of ICCAT members, national observer programmes collect information on the condition of observed catch (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: At-vessel condition is not recorded by longline observers (IOTC, 2010). The reason for discarding fish is recorded, including if the reason was due to damage from depredation (IOTC, 2010). Record if caught fish have been depredated, and record the species directly observed or deemed responsible for the depredation (IOTC, 2010). Number of sets with observed depredation, percent of sets with observed depredation, and percent of catch per species damaged by depredation is recorded (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]). Whether depredation occurred and the species that conducted the depredation is optional information (IOTC interim, unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).

- **WCPFC and SPC/FFA**: The condition of organisms when caught is recorded (WCPFC, 2015). Depredation is not recorded (SPC and FFA, 2014; WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: Record the condition (alive, dead or not known) of all caught organism when brought to the vessel during gear hauling before being handled by crew, and record any evidence of depredation of the caught organism. Easy to collect, adequate data quality.
- **Better**: Record the condition (alive, dead or not known) of all caught organism when brought to the vessel during gear hauling before being handled by crew, the degree of damage from depredation to the organism (none, minor, moderate, high), and what species likely caused the depredation. Easy to collect, higher data quality.

3.3.4. Hooked/entangled, position of hook, and gear remaining attached to released organisms

a. Evidence of significant effect on catch and mortality

Externally hooked organisms have been observed to have a lower haulback and post-release mortality rate relative to those that are deeply hooked (Borucinska et al. 2002; Cooke and Suski 2004; Horodysky and Graves 2005; Ryder et al. 2006; Prince et al. 2007; Reeves and Bruesewitz 2007; Campana et al. 2009; Bansemer and Bennett 2010; Pacheco et al. 2011; Epperly et al. 2012; Swimmer and Gilman 2012; Gilman et al. 2013b).

b. Mechanism for significant effect

Whether an organism was captured via entanglement in line only, or via hooking with or without also being entangled, the hooking location, and the type, amount and location of gear remaining attached to organisms that are released alive, provides an indicator of the degree of injury and concomitant probability of pre-catch, haulback and post-release survival (Chaloupka et al., 2004; Ryder et al., 2006; IATTC and OFCF, 2011; Parga, 2012; Swimmer and Gilman 2012; Gilman et al., 2013b, In Review).

Removal of hooks from lightly hooked organisms (hooks are in the body or in the mouth, but not deeply ingested) and removal of fishing line are hypothesized to improve the probability of post-release survival (Gilman et al., 2013b). Leaving deeply-hooked hooks in place is hypothesized to result in less injury than would result from their removal (Ryder et al., 2006; Parga, 2012). The length of trailing line that remains attached to a released organism is hypothesized to affect the probability of post-release mortality, and organisms that are released entangled in line may have a lower probability of survival relative to those not entangled but with line trailing (Ryder et al., 2006). The ingestion of line, the length of line swallowed relative to the organism's size, and whether the line was attached to a hook are additional factors hypothesized to have significant effects on the probability of post-release survival (Bjorndal et al., 1994; Oros et al., 2004; Casale et al., 2008).

c. Indicators measurable by human and/or electronic observers

During hauling, record whether each captured organism was entangled in line, hooked, and if hooked where in the body the hook was located. For organisms released alive, record whether it was released entangled in line, with trailing line, with a hook, and if hooked, where in the body the hook was located. This protocol could realistically be instituted by onboard human observers and by electronic monitoring systems for low catch rate taxonomic groups of species of conservation concern of sea turtles, marine mammals and seabirds, but is likely not practical to collect for sharks and rays which can make up over half of the total catch primarily in some shallow-set pelagic longline tuna and billfish fisheries (Gilman et al. 2008b; Clarke et al., 2014). This information may be able to be determined through office-based 'dry' observer analysis of electronic monitoring video showing organisms when retrieved to the vessel, and showing organisms being released in the water or from the deck (SPC, 2014).

d. Brief summary of tuna RFMO's current observer data collection protocol

- **CCSBT**: Observers on longline vessels are not tasked with collecting information on whether individual caught organisms were entangled, hooked, and where the hook was lodged, or information on gear remaining attached to live released organisms (CCSBT, No Date).
- **IATTC**: Hooking location is recorded for all caught species, hooking location and information on entanglement is recorded for caught sea turtles, and whether or not seabirds were caught by being hooked and/or entangled is recorded. For fish, hooking location codes are: other, swallowed, jaw, external, and not hooked, and for sea turtles, hooking location codes are: other, swallowed, jaw, external, not hooked, head, upper jaw, lower jaw, neck, right

front flipper, right rear flipper, left front flipper, left rear flipper, armpit, tongue, tail, shell and epiglottis. For turtles, observers are to note which part of the gear entangled them, and which appendage of the turtle became entangled, and they are to record an entanglement code. Entanglement codes for turtles are: other, alongside float, gangion, mainline, gangion and mainline, floatline and gangion, and mainline and float (IATTC, 2012). For sea turtles and seabirds, observers are to record when they are released alive with a hook still present (IATTC, 2012).

- **ICCAT**: Noting that there is there is great variability in information required between national observer programmes of ICCAT members, national observer programmes do not collect information on whether individual caught organisms were entangled, hooked, and where the hook was lodged, or information on gear remaining attached to live released organisms (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Observers on longline vessels are not tasked with collecting information on whether individual caught organisms were entangled, hooked, and where the hook was lodged, or information on gear remaining attached to live released organisms (IOTC, 2010).
- **WCPFC and SPC/FFA**: For 'species of special interest' (all seabirds, sea turtles, marine mammals, silky sharks, oceanic whitetip sharks, and whale sharks) that are landed on deck, for both organisms that are alive and dead, observers are to record if they were entangled, hooked externally, hooked internally, or hooked with location not detected (SPC and FFA, 2014).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: For sea turtles, seabirds and marine mammals, during hauling, record whether each captured organism was entangled in line, hooked, and if hooked whether it was externally hooked, hooked in the mouth (when the bend of the hook was not posterior to the esophageal sphincter), or deeply hooked (hook was swallowed posterior to the esophageal sphincter or deeper). For organisms of these species groups that were released alive, record whether it was released entangled in line, with trailing line, with a hook, and if hooked, whether it was externally hooked, hooked in the mouth, or deeply hooked. Easy to collect, high data quality for these three species groups but poor data quality for elasmobranchs.
- **Better**: Same as minimum but also record for sharks and rays. Time consuming to collect, high data quality.

3.3.5. Hook, bait, leader material and length, branchline weight amount, and light attractor for capture of species of conservation concern

a. Evidence of significant effect on catch and mortality

The effects of hook type (shape, minimum width, offset), bait type, leader material, leader length, branchline weight amount and light attractor use on pelagic longline catch and survival rates were reviewed in Sections 3.2.1, 3.2.2, 3.2.3, 3.2.5 and 3.2.8, respectively.

b. Mechanism for significant effect

The mechanisms for the observed effects of hook type (shape, minimum width, offset), bait type, leader material, leader length, branchline weight amount and light attractor use on pelagic longline catch and survival rates were reviewed in Sections 3.2.1, 3.2.2, 3.2.3, 3.2.5 and 3.2.8, respectively.

If a mix of gear designs are used in an observed fishing trip, instead of assuming that an individual catch event was on a branchline with the predominant gear design, or the average of a random sample, as has been the method in studies where information on gear designs of branchlines of individual catch events was not available (e.g., Bromhead et al., 2012; Gilman et al., 2012), it would improve the rigor of analyses of the effects of individual gear factors on catch and survival rates given information on gear designs for specific catch events. For example, a sea turtle caught in a set containing 90% 15/0 10^{o} offset circle hooks and 10% 3.8 non-offset tuna hooks might have been caught on a tuna hook, but if the observer programme dataset associates the capture with the predominant circle hook, then use of the dataset to assess the effect of hook type on sea turtle catch and survival rates will reduce certainty in findings (Gilman et al., 2012).

c. Indicators measurable by human and/or electronic observers

Record the gear factors hook shape, hook minimum width, hook offset, bait type, leader material, leader length, branchline weight amount and light attractor presence for the branchline on which the individual organism was captured. This protocol could realistically be instituted by onboard human observers and by electronic monitoring systems for low catch rate taxonomic groups of species of conservation concern of sea turtles, marine mammals and seabirds, but is likely not practical to collect for sharks and rays which can make up over half of the total catch primarily in some shallow-set pelagic longline tuna and billfish fisheries (Gilman et al. 2008b; Clarke et al., 2014). Individual branchline gear designs may be able to be determined through office-based ‘dry’ observer analysis of electronic monitoring video, discussed in Sections 3.2.1, 3.2.2, 3.2.3, 3.2.5 and 3.2.8 (SPC, 2014).

d. Brief summary of tuna RFMO’s current observer data collection protocol

- **CCSBT**: Information on gear designs for individual catch events are not recorded by pelagic longline observers (CCSBT, No Date).
- **IATTC**: Information on hook type (for up to three hook types) is recorded for individual catch events for all caught organisms that are brought on deck (IATTC, 2012).
- **ICCAT**: National observer programmes of ICCAT members do not task observers with collecting information on individual branchline gear designs for individual catch events (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: It is optional for observers to record the hook, bait and leader type for individual catch events (IOTC interim protocols, unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).

- **WCPFC and SPC/FFA**: Information on gear designs for individual catch events of 'species of special interest' (all seabirds, sea turtles, marine mammals, silky sharks, oceanic whitetip sharks, and whale sharks) are not intended to be recorded by pelagic longline observers (SPC and FFA, 2014; WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: For each caught sea turtle, seabird and marine mammal, record the hook shape, hook minimum width, hook offset, bait type, leader material, leader length, branchline weight amount and light attractor presence of the branchline on which the organism was caught, following the data collection protocols for these gear elements described in Sections 3.2.1, 3.2.2, 3.2.3, 3.2.5 and 3.2.8. If an organism is released by cutting the line then it may not be possible to identify some terminal tackle components. Easy to collect, high data quality for these three species groups but poor data quality for elasmobranchs.
- **Better method**: Same as minimum method but also applied to elasmobranchs. Time consuming to collect, high data quality.

3.3.6. Fate and final condition: Released alive, discarded dead, retained, retained shark fins and carcass, retained shark fins discarded carcass

a. Evidence of significant effect on catch and mortality

Information on whether caught organisms were released alive and the degree of injury, discarded dead or retained is fundamental information needed to estimate some of the components of fishing mortality rates and levels (Gilman et al., 2013b), and to assess compliance with measures banning or requiring full retention of certain species, and banning the retention of shark fins without also retaining the carcass. Retained catch includes catch that is landed, transshipped and landed, consumed by the crew, used for bait, and rejected at port and not landed (Gilman et al., 2013b).

b. Mechanism for significant effect

A proportion of organisms that are released alive will survive the interaction, where soak duration, depth of capture, ambient conditions, length, sex, hooking location, handling and release methods employed, duration out of the water, physical conditions onboard such as air temperature, and tackle remaining attached to the organisms upon release can all have significant effects on the probability of post-release survival (Davis 2002; Ryder et al*.* 2006; Suuronen 2005; Benoit et al*.*2013; Neilson et al*.* 2012; Gilman et al*.* 2013b). Organisms that are released dead and that are retained represent two additional fishing mortality sources. Other fishing mortality sources not accounted for by observations of the fate of the catch include: pre-catch loss, ghost fishing mortality, collateral mortality indirectly caused by effects of fishing such as mortalities resulting from fisheries that reduce optimal species- and habitat-specific school sizes (Pitcher, 2001), cumulative stress and injury caused by repeated sub-lethal interactions, and synergistic effects of interacting fishery sources of stress and injury (Gilman et al., 2013b).

c. Indicators measurable by human and/or electronic observers

For all caught organisms, observers can record whether the organism was released alive and degree of injury, discarded dead or retained. For retained sharks, observers can record if the fins and carcass were retained or just the fins were retained. If crew release a caught organism from the gear in the water and do not bring it on deck, the observer can attempt to observe whether the organism was alive or dead. If an observer observes an organism freeing itself from the gear and is not handled by crew (e.g., throws the hook, breaks the line, becomes untangled from line), this constitutes a pre-catch escapement event and not a released catch event.

Electronic monitoring systems can produce information on whether a caught organism was retained or not if a camera is positioned to show the area next to the vessel hull where crew would strike off catch before landing, a camera is positioned to show where catch is processed, and a camera is positioned to show where organisms brought aboard are released and discarded overboard (SPC, 2014).

d. Brief summary of tuna RFMO's current observer data collection protocol

- **CCSBT**: Number retained or discarded by species, and life status (dead and damaged; dead and undamaged; alive and vigorous; and unknown) of discarded catch (CCSBT, No Date).
- **IATTC**: Observers are to record the fate (disposition) of caught fish (other, returned to sea dead, commercial sale, consumed by crew, used for bait, returned to sea alive, retained as laboratory specimen), and the fate of caught sea turtles and birds (the 7 for fish plus 3 additional: released with minor injuries, released with grave injuries, released with hook still present). Observers also are required to record the condition of turtles and birds (other, entangled alive, entangled dead, hooked alive, hooked dead, sighted) (IATTC, 2012). For sea turtle fate, generally, a 'light injury' is one that the turtle will most likely survive, and a

‘grave injury’ is one that will likely kill the turtle. If the encounter is simply a turtle sighting, record the disposition code for ‘other fate’ (IATTC, 2012).

- **ICCAT**: Normally for each trip or set, observers in national observer programmes of member parties collect information on the fate (landed, released live or discarded dead) and condition (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Observers are to record the number and weight of catch by species that was retained, discarded dead and released alive. For non-retained catch record the reason for not retaining, including damage caused by depredation from marine mammals or sharks, size, etc. (IOTC, 2010). For seabirds, sea turtles and marine mammals, observers are to record the fate (dead, alive swam away condition not determined, alive and in good health, alive minor injuries and stress with high probability of survival, alive with life threatening injuries and severe stress where the organism is unlikely to survive, and condition not observed and unknown) (IOTC, 2010).
- **WCPFC and SPC/FFA**: Record a fate code to document what happens to an organism after it is caught, where fate codes denote various iterations of having: retained, discarded, retained shark trunk and fins, retained shark fins discarded trunk, and escaped (WCPFC, 2015). And record one of the following condition codes to record the condition of organisms that are returned to the sea after being brought onto the vessel: alive but unable to describe condition, alive and healthy, alive but injured or distressed, alive but unlikely to live, entangled okay, entangled injured, hooked externally injured, hooked internally injured, hooked unknown injured, dead, entangled dead, hooked externally dead, hooked internally dead, hooked position unknown and dead, condition unknown, entangled unknown condition, hooked externally condition unknown, hooked internally condition unknown, and hooked position unknown and condition unknown (SPC and FFA, 2014; WCPFC, 2015). Write a description of the condition of the ‘species of special interest’ (all seabirds, sea turtles, marine mammals, silky sharks, oceanic whitetip sharks, and whale sharks) when it was landed and returned to the sea (SPC and FFA, 2014).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum and best**: For each caught organism, record the fate and condition as either: retained, discarded dead, released alive, or released unknown condition. For retained sharks, record whether fins and trunk were retained, or whether fins were retained and the trunk was discarded. Released and discarded organisms include both those that crew remove from the gear in the water without bringing the organism onto the vessel, and organisms that are brought onto the vessel and then returned to the water. ‘Retained’ catch includes catch that is landed, transshipped and landed, consumed by the crew, used for bait, and rejected at port and not landed. ‘Discarded’ catch refers to returning dead caught organisms back to the sea. “Released’ catch refers to returning live caught organisms back to the sea. If an organism frees itself from the gear and is not handled by crew (e.g., throws the hook, breaks the line, becomes untangled from line), this constitutes a pre-catch escapement event should not be recorded as a released catch event (however a field for escapement events may be included where this would then be recorded). Time consuming to collect, adequate data quality.

3.4. Environmental Parameters and Seabird Local Abundance

3.4.1. Beaufort scale (sea state) and wind velocity

a. Evidence of significant effect on catch and mortality

Taxa	Effects
Teleosts	Bigelow et al. (1999) observed a significant but weak effect of wind velocity on standardized catch rates for swordfish, with an increase in wind velocity reducing swordfish catch rates.
Sharks	Bigelow et al. (1999) observed a significant but weak effect of wind velocity on standardized catch rates for blue shark, with an increase in wind velocity increasing blue shark catch rates.
Seabirds	Beaufort scale and wind strength have been observed to significantly explain seabird bycatch rates in longline fisheries (Brothers et al., 1999; Gilman et al., 2014b).

b. Mechanism for significant effect

Beaufort wind force scale, which uses visual observations of sea state, has been used as an index for wind speed. Wind velocity can significantly affect seabird susceptibility to longline capture (Brothers et al., 1999; Gilman et al., 2014b; Wolfaardt, 2015). This is because wind velocity may provide an index of seabird relative abundance, and because seabirds are more agile while flying and have higher efficacy scavenging from longline gear during setting and hauling, with higher wind strength, and thus have higher capture risk with higher wind strength (Gilman et al., 2014b).

Furthermore, especially for shallow-set longline gear, wind velocity along with other oceanographic variables such as wave height and current strength, can affect the shape and depth of the gear, and bait retention rates, significantly affecting catch rates (Section 3.2.4) (e.g., Bigelow et al., 1999; Vega and Licandeo, 2009).

c. Indicators measurable by human and/or electronic observers

The Beaufort wind force scale uses visual observations of the appearance of the sea surface (i.e., sea state) as an index for wind speed. Observers assign a numerical value, from force 0, when there are calm conditions when there is almost no wind movement and the sea surface is flat, to force 12, when there are hurricane conditions with >64 knot wind speed and > 15 m wave height (NMFS, 2010; IOTC, 2010; Gilman et al., 2014b). Beaufort scale observations might be feasible via review of electronic monitoring system video.

Apparent wind velocity can be measured using an anemometer, or the vessel might have apparent and true wind speed measuring equipment. Wind speed observations might be feasible via electronic monitoring systems if tied into a vessel wind speed sensor.

d. Brief summary of tuna RFMO's current observer data collection protocol

Beaufort scale

- **CCSBT**: CCSBT does not require observers to record Beaufort scale or other measurement of sea state (CCSBT, No Date).
- **IATTC**: Observers are not tasked with recording Beaufort scale or other measurement of sea state (IATTC, 2012).
- **ICCAT**: National observer programmes of member parties do not call upon observers to record Beaufort scale or other measurement of sea state (unpublished tables compiled for

the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).

- **IOTC**: Observers must record the weather at the start of setting and hauling operations. And a summary must be provided in the observer trip report on the average weather conditions experienced during the trip. Observers are to record sea height and direction, and swell height and direction (IOTC, 2010). For wind force, observers are to use the Beaufort scale (IOTC, 2010).
- **WCPFC and SPC/FFA**: Observers are not tasked with recording Beaufort scale or other measure of sea state (SPC and FFA, 2014; WCPFC, 2015). Observers are to record comments on unusual wind/sea state that affect setting strategies or cause problems (SPC and FFA, 2014).

Wind Velocity

- **CCSBT**: For each set record wind speed (with unit) and direction (CCSBT, No Date).
- **IATTC**: Observers are not tasked with recording wind speed (IATTC, 2012).
- **ICCAT**: National observer programmes of member parties do not call upon observers to record wind speed (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: Observers must record the weather at the start of setting and hauling operations. And a summary must be provided in the observer trip report on the average weather conditions experienced during the trip. Observers are to record wind force and direction, but for wind force, observers are to use the Beaufort scale and do not measure and record wind speed (IOTC, 2010).
- **WCPFC and SPC/FFA**: Observers are not tasked with recording wind speed (SPC and FFA, 2014; WCPFC, 2015). Observers are to record comments on unusual wind/sea state that affect setting strategies or cause problems (SPC and FFA, 2014).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

Beaufort scale (sea state)

- **Minimum**: Observe the sea state and record a Beaufort wind force scale number once during the set and once during the haul. Easy to collect, variable data quality.
- **Best**: Observe the sea state and record a Beaufort wind force scale number at the beginning and end of the set and haul. Easy to collect, better data quality.

Wind velocity

- **Minimum:** Use an anemometer and record apparent wind speed (does not account for effect of vessel speed on the measurement of wind speed) once during the set and once during the haul, in knots or m/s. Easy to collect, variable data quality.
- **Best:** Observe vessel wind speed measuring equipment and record true wind speed at least once during the set and at least once during the haul, in knots or m/s. Easy to collect, adequate data quality.

3.4.2. Number of seabirds attending the vessel during setting and hauling

a. Evidence of significant effect on catch and mortality
The number of seabirds susceptible to capture in pelagic longline fisheries present in the area around the fishing vessel (i.e., seabird local abundance) during setting and hauling operations has been documented to have a significant effect on nominal seabird catch rates during setting and hauling (Reid and Sullivan, 2004; Gilman et al., 2003, 2005, 2008a, 2014b; Wolfaardt 2015). Seabirds can be hooked or entangled primarily while pelagic longline gear is being set, but also during gear retrieval (Gilman, 2011; Gilman et al., 2014b). In addition, information on the presence/absence of species of seabirds that are susceptible to capture during setting and hauling has been used in selecting study samples: records with no seabirds present during setting and hauling and no seabirds captured were excluded from studies assessing the effect of potentially significant explanatory factors and covariates on standardized seabird catch rates (Gilman et al., 2008a, 2014b).

b. Mechanism for significant effect
Seabird local abundance during setting and hauling affects catch rates due to the effect of animal density on catchability (Gilman et al., 2003, 2005). The local abundance of seabirds also can affect their scavenging behavior, where the larger the local seabird abundance, up to some threshold level, the more intense competitive scavenging behavior and risk of capture will be. The distribution of local abundance by seabird species can also affect capture susceptibility, where, e.g., the presence and local abundance of relatively small deep-diving seabirds that retrieve submerged baited hooks and bring them to the surface where they become available to larger seabird species with poor diving capabilities can affect nominal catch rates (Gilman et al., 2005). In some fisheries, the effect of hierarchical competitiveness between seabird species and individual birds on catch rates may be a larger effect and potentially override the effect of seabird relative abundance on catch rates (Melvin et al., 2014).

c. Indicators measurable by human and/or electronic observers
Human onboard observers can record the number of each species of seabird, or of each higher taxonomic rank such as family, within a standardized area around the fishing vessel during setting and hauling operations, when there is sufficient daylight (e.g., the Hawaii longline observer programme, NMFS, 2010). In some fisheries, the onboard observer will observe each haulback in full and sleep and eat during the set, however, it may be feasible for observers to conduct seabird scan counts during the first and last hour of each set (Gilman et a., 2008a). It is not likely that electronic monitoring systems could be used to estimate local abundance of seabirds during setting and hauling (SPC, 2014), but should be able to document species-specific presence/absence during daylight.

d. Brief summary of tuna RFMO's current observer data collection protocol
- **CCSBT**: Information on seabird local abundance is not collected by observers on longline vessels (CCSBT, no date; unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IATTC**: Information on seabird local abundance is not collected by observers on longline vessels (IATTC, 2012; unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **ICCAT**: Some national observer programmes of ICCAT members record observations of seabirds present during fishing operations (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).

- **IOTC**: Information on seabird interactions that do not entail interaction with the fishing gear, including seabird local abundance, is not collected by observers on longline vessels (IOTC, 2010; unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **WCPFC and SPC/FFA**: Observers record interactions with seabirds that were not landed on deck, including the vessel activity when the siting occurred, and number of animals sighted (SPC and FFA, 2014; WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: Record each species of seabird or otherwise each higher taxonomic rank of seabird (e.g., families of Diomedeidae or albatrosses, Procellariidae or petrels and shearwaters, Laridae or gulls and terns, Sulidae or gannets and boobies, Phalacrocoracidae or cormorants, Anderson et al., 2011) present during setting and hauling. Easy to collect, variable data quality.
- **Better**: During daylight, at least once during each set, count and record the number of individuals of each seabird species or higher taxonomic rank (such as family) within 100m of the vessel. Time consuming to collect, variable data quality.
- **Even better**: During daylight, at 30 minutes into the set, at the end of the set, 30 minutes into the haul and at the end of the haul, count and record the number of individuals of each seabird species or higher taxonomic rank within 100m of the vessel. Time consuming to collect, higher data quality.
- **Best**: During daylight, at 30 minutes into the set, at the end of the set, and every other hour during the haul, count and record the number of individuals of each seabird species or higher taxonomic rank within 100m of the vessel. Time consuming to collect, even higher data quality.

3.4.3. Sea surface temperature

a. Evidence of significant effect on catch and mortality

Sea surface temperature (SST), one of several dynamic environmental variables frequently used to standardize longline catch rates (Section 3.2.9), has been observed to significantly explain species- and sex-specific catch rates and haulback condition of pelagic species susceptible to capture in pelagic longline fisheries (Nakano and Nagasawa, 1996; Simpfendorfer et al., 2002; Watson et al., 2005; Yokota et al., 2009; Vega and Licandeo, 2009; Carvalho et al., 2011; Bromhead et al., 2012; Foster et al., 2012; Brodziak and Walsh, 2013; Clarke et al., 2014; Mitchell et al., 2014; Vandeperre et al., 2014).

b. Mechanism for significant effect

SST, which tends to be negatively correlated with latitude, is an indicator for species-specific habitat suitability, as pelagic predators caught in pelagic longline fisheries have disparate temperature preferences (Brodziak and Walsh, 2013). Warmer seawater typically contains lower dissolved oxygen concentrations, and therefore fish caught in warmer waters might have higher stress due to increased metabolic rates (e.g., Skomal and Bernal, 2010).

c. Indicators measurable by human and/or electronic observers

Observers can record the sea surface temperature during fishing operations. Electronic monitoring systems might be able to record SST if the vessel has a SST gauge and the electronic monitoring system is linked to the gauge. However, standardized catch rate models typically use public domain databases of satellite-derived estimates of SST (e.g., Bigelow et al., 1999), however some studies have used SST data collected by onboard observers (e.g., Pons et al., 2013).

d. Brief summary of tuna RFMO's current observer data collection protocol

- **CCSBT**: Record the SST in degrees Celsius, to 1 decimal place, at the start of each set (CCSBT, No Date).
- **IATTC**: Record the SST during each set (IATTC, 2012).
- **ICCAT**: National observer programmes of ICCAT members do not record SST (unpublished tables compiled for the 2015 meeting on *Harmonisation of Longline Bycatch Data Collected by Tuna RFMOs* [ISSF, 2015]).
- **IOTC**: At the start of setting and hauling, it is useful but not required to collect information on SST (IOTC, 2010).
- **WCPFC and SPC/FFA**: Observers are not tasked with recording SST (SPC and FFA, 2014; WCPFC, 2015).

e. Recommended data collection method and information that is recorded, with comments on ease of collection and data quality

- **Minimum**: Do not record SST (databases of satellite-derived estimates of SST are publically available).
- **Better**: At the beginning of each set, record SST in degrees Celsius to the nearest tenths place value, either using SST measuring equipment provided to observers or if the vessel has a SST gauge, then by reading the temperature shown on the gauge. Easy to collect, variable data quality.
- **Even better**: At the beginning of each set and haul, record SST in degrees Celsius to the nearest tenths place value, either using SST measuring equipment provided to observers or if the vessel has a SST gauge, then by reading the temperature shown on the gauge. Easy to collect, variable but higher data quality.

- **Best:** At the beginning and end of each set and haul, record SST in degrees Celsius to the nearest tenths place value, either using SST measuring equipment provided to observers or if the vessel has a SST gauge, then by reading the temperature shown on the gauge. Easy to collect, higher data quality.

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Appendix A. Longline Fishery Variables that Affect Catch and Survival Rates and Can be Collected in Observer Programmes

Variables considered for inclusion in this report, organized into six categories, are listed in this Appendix. Variables with an asterisk are those selected for inclusion.

1. Vessel characteristics and equipment

* Unique vessel identification
Vessel flag state
Vessel cruising speed
Vessel hold capacity
Refrigeration methods
Length
Tonnage
Engine power
Radar
Bird radar
Depth sounder
Global Positioning System
Track plotter
Weather facsimile
Sea Surface Temperature (SST) gauge
Sonar
Radio or satellite buoys
Doppler current meter
Expendable bathythermograph
Satellite Communications Services
Other technology aids for fish finding and gear deployment and retrieval that affect effective fishing power
Fishery information services
Vessel Monitoring System
*Mainline line shooter (setter)
Bait caster (automatic bait thrower, bait casting machine)
Mainline hauler
Branchline hauler (coiler)

2. Gear characteristics

* Hook shape
* Hook width
* Hook offset
Hook with a ring or not
Hook with a swivel or not
Hook material
J hook straight or curved shank
Hook gape
Hook maximum total width
Hook straight total length
Hook bite
Hook orientation of the point
Hook with an added appendage to increase the minimum width
*Bait species
Bait size (length, weight)
Bait live vs. dead
Method for threading bait onto hook
Mainline material
Mainline length on vessel
Mainline length of line
Mainline linear distance covered per set
Mainline diameter
Mainline color
Mainline weight amount and number per unit of length
Branchline material
*Branchline length
Branchline diameter
Branchline color
Floatline material
*Floatline length
Floatline diameter
Floatline color
Buoy material
Buoy color
Number of buoys per set
* Leader (trace) material
Leader length
Leader diameter
Leader color
*Number of hooks per basket
Distance between branchlines (spacing of hooks)
Branchline weight
Distance of branchline weight from the hook
Orientation of the bait on the hook
Orientation of the hook in the water
*Number of shark lines per set
* Hooks per set and proportion of total hooks observed during the haul
*Number of light attractors per set and per hook
Light attractor characteristics (wavelength, color, flicker rate, etc.)
Number of radio buoys per set
Number of dhan buoys per set
Shark repellents, including chemical, electrical current, electropositive rare-earth metal and magnetic repellents

3. Fishing methods

*Vessel position at start and end of set and haul
*Date and time at start and end of set and haul
Distance from land at start and end of set and haul
Distance from shallow submerged features at start and end of set and haul
Date and time of departure and return from port
Port of departure
Port of return
*Seabird bycatch mitigation methods: Tori pole and line, stern vs. side set, bird curtain, blue-dyed bait, thawed bait, underwater setting chute, discharge offal/bait during setting, discharge offal/bait during hauling
Tori line design, aerial coverage, length, location on deck
Towed buoy
Deck lighting when setting or hauling at night
*Mainline line shooter speed relative to vessel setting speed (mainline tension)
Declared target species
*Vessel speed during setting
Vessel speed during hauling
Gear (mainline and branchlines) enter the sea within or outside of the area affected by prop turbulence
Set direction
Gear retrieval direction
Branchline hauler (coiler) used during hauling

4. Catch

*Hook number (between floats and shark line)
*Species, length, sex
Weight of shark fins and weight of shark carcasses by species (if fins are not naturally attached)
* At-vessel life status (condition when caught) and depredation
*Hooked/entangled, position of hook, and gear remaining attached to released organisms
*Hook, bait, leader material and length, branchline weight amount, and light attractor for capture of species of conservation concern
Color and other characteristics of the nearest float or buoy of each caught sea turtle
Seabird observed caught during haul, came up from soak, or not observed
* Fate and final condition: Retained, shark retained fins and carcass, shark retained fins only, released in the water, landed on deck and released alive, landed deck and discarded dead
Handling and release methods for individual organisms caught and released alive (including whether sea turtles were comatose and resuscitated prior to release)
Biochemical indicators of mortality and morbidity
Tag data

5. Environmental parameters, seabird local abundance, seabird non-catch interactions

*Beaufort scale (sea state)
*Number of seabirds attending the vessel during setting and hauling
Seabird non-catch event interactions (e.g., distance astern birds dive for baited hooks during setting and hauling)
*Sea surface temperature
*Wind velocity
Wind direction in relation to vessel course
Current strength and direction
Cloud cover
Visibility
Sea surface concentration of chlorophyll-a
Thermocline depth
Sea surface height anomalies
Range of sea surface temperature occurring within the area around the fishing grounds
Lunation (moon phase)

6. Captain, crew, observer, owner, manager

Unique captain
Nationality of captain
Unique crew
Nationality of crew
Total number of crew
Vessel owner
Vessel manager
Unique observer
Nationality of observer