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Designing experimental fishing trials to explore the effects of leader material on catch and mortality of sharks: A review of best practice, principles and criteria.

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Acknowledgement of Country

We acknowledge the Traditional Custodians of Australia and their continuing connection to land and sea, waters, environment and community. We pay our respects to the Traditional Custodians of the lands we live and work on, their culture, and their Elders past and present.

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Executive Summary

This paper presents a review of, and recommendations relating to, best practice principles and criteria for designing and conducting scientific fishing trials that aim to assess the relative effects of wire and nylon monofilament leader materials on the catch and mortality of sharks. More specifically, the papers recommendations are a response to the requirement specified in Paragraph 17 of IOTC Resolution 25-08 (*On the conservation of sharks caught in association with fisheries managed by IOTC*), which states that any such scientific trial "*will be conducted using an appropriate experimental design and analysed using appropriate statistical methods, the criteria and principles of which will be developed and agreed by the IOTC Scientific Committee at the annual Session in 2025"*.

In developing recommendations in line with paragraph 17, the authors have reviewed both a) core principles of scientific best practice for experimental design (see, e.g. Fisher, 1935; Montgomery, 2013; McAllister & Peterman, 1992), and b) the methodologies of previous scientific fishing trials that have examined leader material effects on shark catch and mortality (see, e.g. Ward et al., 2008; Afonso et al 2012; Scott et al 2022; Santos et al. 2017; Santos et al. 2024).

Experimental fishing trials to compare the effects of different pelagic longline leader material (nylon monofilament vs. wire) on pelagic shark catch and mortality, have previously been conducted in the Pacific, Atlantic, and Indian Oceans. These studies have examined key metrics such as catch-per-unit-effort (CPUE), mortality at haulback, and the number of bite-offs (see, e.g. Ward et al., 2008; Afonso et al., 2012; Santos et al., 2017). The outcomes of these experimental fishing trials have been previously reported in IOTC-2024-WPEB2-(DP)-11. This review has identified that these trials generally sought to adhere to many, or all of the following core scientific principles on experimental design, including: (i) setting clear objectives and hypotheses, (ii) controlling for known sources of variation, (iii) randomisation of treatments; (iv) ensuring adequate replication and statistical power, (v) standardised data collection and training; (vi) appropriate statistical analysis and, (vii) effective engagement with stakeholders to foster legitimacy and support for the results.

Based on this review, the authors suggest that the **WPEB recommend to the SC that they should endorse the following criteria and principles for conducting an** experimental fishing trial to investigate the effect of leader material on shark catch rates, bite-offs and haulback mortality**:**

1. That the trial is conducted in areas and seasons with known high shark abundance (including of vulnerable shark species), using existing data from Indian Ocean Regional Observer Programme (ROP) data or surveys to identify suitable hotspots.

2. Before the trial, conduct a power analysis (following Watson et al. 2005) informed by historical bycatch data from the Indian Ocean to determine the number of sets required to detect a true effect, thereby avoiding a Type II error.

3. That the trial employs a "paired comparison" approach by alternating control (nylon monofilament) and experimental (wire) leaders along each longline section. Also, alternate the leader type on the first branch line for every subsequent fishing set to ensure a balanced design.

4 That the trial standardises all gear and operational practices, including, *inter alia*, soak time, setting/hauling times, bait/hook types and branch line/leader lengths and other gear characteristics (e.g. use of lightsticks) to assist the trial in isolating the effect of leader material.

5 Use at least one, and preferably two, independent observers or scientific researchers who are trained in longline operations and species identification to minimise human error and observational bias.

6 Establish a standardised protocol for collecting data. Key metrics to record are species ID, leader material, fate (retained/discarded), condition at haulback, and the occurrence of bite-offs.

7 Ensure the trial vessel skipper and crew are briefed on the trial's objectives and design, and that they support the experimental protocols.

8. Develop the statistical analysis plan in collaboration with biostatisticians. Appropriate statistical approaches may include hierarchical or mixed-effect models (e.g., GLMMs) to analyse key response variables, including: CPUE, bite-off rate, and haulback mortality rate.

Undertaking an experimental fishing trial to investigate the effect of leader type on observed catch and fishing mortality of vulnerable shark species (including oceanic whitetip shark, silky shark, shortfin mako and thresher sharks) and blue sharks using these recommended criteria and principles, will allow the SC to have confidence in the outcomes of any trial presented to it for review, and for its development of advice to the Commission.

1 Purpose

The purpose of this report is to provide a comprehensive review of, and recommendations relating to, best practice principles and criteria for designing and conducting experimental fishing trials aimed at exploring the relative effects of wire and nylon monofilament leader materials on catch and mortality of sharks. It aims to directly address the requirement specified in Paragraph 17 of IOTC Resolution 25-08 *On the conservation of sharks caught in association with fisheries managed by IOTC*, relating to at sea scientific fishing trials (investigating such leader effects). Paragraph 17 states: *The trials will be conducted using an appropriate experimental design and analysed using appropriate statistical methods, the criteria and principles of which will be developed and agreed by the IOTC Scientific Committee at the annual Session in 2025*.

Based on a review of methodologies of relevant experimental fishing trials (globally) and general best practice experimental design principles, this paper recommends a set of best-practice design principles and criteria for conducting at-sea experimental fishing trials (for leader effects on shark catch and mortality) for discussion by WPEB and development of recommendations to the SC.

2 Introduction

In May 2025, the IOTC Commission adopted a new combined and strengthened conservation measure for sharks, *Resolution 25-08 On the conservation of sharks caught in association with fisheries managed by the IOTC*.

The adoption of the new measure was driven by concerns regarding the impacts of IOTC fisheries on a range of vulnerable shark species. These concerns reflected the global conservation status of these species (see, Patterson et al., 2024, which outlined stock status, ERA vulnerability rankings and conservation status (IUCN Red List)), findings of scientific research by IOTC CPC scientists (including ecological risk assessments, stock assessments, mitigation studies), and the scientific advice from the WPEB and IOTC Scientific Committee (IOTC 2023, IOTC 2024a, b; Murua et al. 2018).

Resolution 25-08 combines elements of a range of older (and now superseded) Resolutions (Resolutions 18-02, 17-05, 13-05, 13-06 and 12-09) and adds new or revised and strengthened conditions. These include:

- **A prohibition on shark finning** (and mandating of full utilisation of retained sharks), albeit with provisions for freezer vessels to store tagged fins separately or to attach fins to their carcasses with wire/ropes.

- **A requirement to develop a management procedure (MP) for blue shark** (to determine Total Allowable Catch (TAC)) and determine catch limits for CPCs.

- **Re-affirming existing retention bans** for oceanic whitetip (*Carcharhinus longimanus*), thresher (*Alopias spp*.), and whale sharks (*Rhincodon typus*) and encouraging the release of other live sharks, especially juveniles and pregnant individuals.

- **Strengthening a range of reporting requirements**.

- **Prohibiting the use of "shark lines"** - branch lines that run directly off the longline floats or drop lines—starting January 1, 2026.

The Commission also considered a proposal to include a **prohibition on the use of wire leaders** by longline vessels. The proposal was based on significant evidence from past experimental fishing trials, conducted in Atlantic, Pacific and Indian Oceans, which indicated that such a measure (as already adopted in WCPFC) would likely be effective in reducing shark catches and mortality (see: IOTC-2024-WPEB2-(DP)-11 for review of evidence). This has been recognised in advice from the WPEB and Scientific Committee (see: IOTC-2024-WPEB20(DP)-R[E] and IOTC-2024-SC27-RE).

However, the Commission did not reach consensus on including a provision to prohibit the use of wire leaders. Instead, the Commission included a range of provisions in Resolution 25-08 aimed at acquiring additional research and information, to inform future SC advice on the likely effectiveness of such a measure. Included in these provisions, Resolution 25-08 states:

- Paragraph 15 - *In order for any CPCs to continue to use wire trace north of 20S at least one CPCs will undertake scientific fishing trials to assess the effects of leader materials on the mortality of vulnerable shark species (including oceanic whitetip shark, silky shark, shortfin mako and thresher sharks) and blue sharks. Such trials must be conducted, concluded, presented to the IOTC Scientific Committee by SC30 subject to the possible extension in paragraph 8* [*i.e. of one year*]

- Paragraph 16 - *The trials objective will be to determine if, for the CPCs fleet, the use of wire leaders has a higher catch and mortality for the vulnerable and target shark species (both in total and by species) than does use of nylon monofilament leaders*.

- Paragraph 17 - *The trials will be conducted using an appropriate experimental design and analysed using appropriate statistical methods, the criteria and principles of which will be developed and agreed by the IOTC Scientific Committee at the annual Session in 2025*.

The purpose of this paper is to directly address the requirement of Paragraph 17, by:

1. reviewing the methodologies of past experimental fishing trials (globally) which have examined wire and nylon monofilament leader effects on pelagic shark catch and mortality;

2. reviewing general best practice experimental design principles, including as they relate to conducting fisheries field trials; and

3. based on 1. and 2., recommending best-practice design principles and criteria for conducting at-sea experimental fishing trials (for leader effects on shark catch and mortality) for WPEB review and recommendation to the SC (as meeting the requirements of Paragraph 17).

3 Review of experimental designs used in leader material trials

Experimental fishing trials have been conducted in the Pacific, Atlantic, and Indian Oceans to compare the effects of different leader materials (wire vs. nylon monofilament). These studies have examined key metrics such as catch-per-unit-effort (CPUE), mortality at haulback, and the number of bite-offs (see, e.g. Ward et al., 2008; Afonso et al., 2012; Santos et al., 2017). The experimental designs within these trials have informed the principles and criteria outlined in Section 4. For more information on the outcomes of these leader trials for non-shark species, including target species, please refer to IOTC-2024-WPEB20(DP)-11. To ensure the studies considered here are directly relevant to the objectives of the SC, this review only includes scientifically designed trials that specifically test wire and nylon monofilament leader materials and which are conducted on pelagic longline fishing vessels fishing for tuna or swordfish.

3.1 Ward et al 2008

In the Australian tuna and billfish fishery off eastern Australia, Ward et al. (2008) conducted an experimental fishing trial involving five commercial vessels (18–24 m in length). Each vessel deployed wire and monofilament leaders in roughly equal numbers, randomly distributed along the longlines. Wire leaders were fitted with a 38 g weighted swivel, while monofilament leaders were unweighted, with some constructed using two nylon strands instead of one. Two bait types (fish and squid) were used, and approximately 9% of branchlines included luminescent light sticks. All vessels used the same mainline and J-hook configuration. Observers recorded detailed gear data, including: (i) type of leader deployed and retrieved; (ii) number of branchlines retrieved with severed leaders; and (iii) number of leaders repaired after each operation. They also documented species caught, their length, time of landing, hook number, and whether the catch was retained or discarded, along with the leader type on which it was caught. A total of 177 longline sets were observed, with 75,101 hooks deployed—37,679 with nylon leaders and 37,422 with wire. Conditional logistic regression was used to determine whether there were statistically significant differences in catch rates between the two leader types with separate models developed for each species and species group. Catch-per-unit-effort (CPUE) for all shark species combined, and for eight out of ten individual species, was higher on wire leaders. Additionally, significantly less bite-offs occurred on wire leaders compared to nylon. The study acknowledged potential limitations affecting leader performance and catch rates, including variability in nylon strand composition across vessels and the exclusive use of weighted swivels on wire leaders.

3.2 Afonso et al 2012

In a pelagic longline fishery targeting swordfish and tunas (*Thunnus* spp.) in the southwest Atlantic Ocean, Afonso et al. (2012) investigated the effects of hook type (J and circle) and leader material (nylon and wire) across 17 longline sets. Each set included 1,200 hooks, with 1,000 hooks allocated to four treatment combinations of hook and leader types—250 hooks each of circle hook with nylon (CNYL), circle hook with wire (CSTE), J-hook with nylon (JNYL), and J-hook with wire (JSTE). These treatments were randomly distributed along the longline. Squid was used as standardised bait, and all hooks were equipped with an 80g weighted swivel. Catch was identified to the lowest possible taxonomic level, and bite-offs were recorded. Two-way factorial ANOVA was used to analyse differences in both CPUE and mortality per unit effort (MPUE) between hook and leader types. A post hoc power analysis was also performed. Normality and homoscedasticity were assessed with Shapiro–Wilk and Levene's tests, respectively. When data were not normal, data was transformed to fulfill parametric assumptions (Afonso et al. 2012). Results showed higher catch-per-unit-effort (CPUE) for sharks when using wire leaders, while nylon leaders experienced significantly more bite-offs. However, when bite-offs were considered as undetected shark captures, no significant difference in CPUE was found between leader types (Afonso et al. 2012).

3.3 Santos et al 2017

In the southwest Indian Ocean pelagic longline fishery targeting swordfish, Santos et al. (2017) conducted experimental trials involving 82 longline sets over two fishing trips aboard a Portuguese longline vessel between November 2013 and March 2014. Each branch line was composed of four sections, with the fourth containing either the control gear (2.5 mm nylon monofilament leader) or the treatment gear (1.2 mm stainless steel multifilament leader). All other aspects of the gear and fishing practices—including branch line configuration, setting time, light colour, bait type (squid), and hook style (J-hook)—were standardised throughout the study. Each set deployed a fixed number of hooks: 504 per leader type (84 hooks per section), ensuring equal effort for both gear types. The leader material used in the first section was alternated in a fixed sequence across sets (mono:wire:mono:wire). Power tests, based on Watson et al. (2005), were conducted to determine the number of sets required to detect a 25% or 50% change in blue shark catch rates relative to the control. A trained observer recorded data on species identification, gear details, bite-offs, fate, and condition at haulback. The impact of transitioning between the two leader types was analysed using a generalised linear model (GLM) employing a binomial error distribution and a logit link function. Parameter interpretation was conducted by examining the calculated odds ratios and their corresponding 95% confidence intervals (CIs). Because of a lack of normality and homogeneity of variances, randomisation tests (Monte Carlo approach) were used to randomise and resample the data to build the expected distribution of the differences under a random distribution and the result was then compared and used to determine the significance of the differences observed in the sample (Santos et al. 2017). Results showed that shark catch rates were 30% higher on wire leaders. While bite-offs were significantly more frequent on monofilament leaders, there was no statistically significant difference in haulback mortality between gear types (Santos et al. 2017).

3.4 Scott et al 2022

In the U.S. Pacific longline fishery, Scott et al. (2022) conducted paired gear trials across four fishing trips, deploying 15–20 sets per trip. To minimize spatial bias in catch rates, wire and monofilament leaders were alternated every 10–30 segments of the longline. Each segment included 24 hooks, each equipped with either a wire or monofilament leader, a 45 g weighted swivel, and time-depth recorders on the first 10 hooks. An onboard observer recorded data on leader type, bite-offs, catch gear type, species caught, and the condition and fate of each animal. The vessel used both forged and unforged

14/0 and 15/0 offset circle hooks. Due to the hierarchical structure of the longline data, generalised linear mixed models (GLMMs) were used to investigate the effect of leader material on catch. A negative binomial error distribution with a log-link was ultimately selected to account for the non-normal and over dispersed nature of the count data with model selection based on the corrected Akaike Information Criterion (AIC) (Scott et al. 2022). Shark catch-per-unit-effort (CPUE) was 41% higher on wire leaders, and bite-offs occurred significantly more often on nylon leaders. However, when bite-offs were treated as undetected shark captures, CPUE differences between leader types were no longer significant. Blue shark and shortfin mako catch rates were notably higher on wire leaders—by 35.3% and 64.5%, respectively. Mortality was generally higher with wire leaders, though this trend did not hold for blue sharks (Scott et al. 2022).

3.5 Santos et al 2024

In the Portuguese Atlantic longline fishery targeting swordfish, Santos et al. (2024) conducted paired gear trials over 105 longline sets during three experimental fishing trips between June 2013 and October 2014. The study aimed to test the effects of bait type (fish vs. squid) and branch line material (monofilament vs. wire). Each branch line measured approximately 12.5 meters and included a 9.85-meter section of 2.5 mm monofilament connected via an 80 g weighted swivel to a second segment. For the control setup, this second segment consisted of a 2.65-meter nylon monofilament leader with a hook. In the wire treatment, the second segment was a 1.9-meter nylon monofilament gangion connected by a 60 g swivel to a third segment—a 0.75-meter, 1.4 mm stainless steel multifilament wire leader (3 strands) with a hook (Santos et al. 2024). To reduce confounding factors related to environmental conditions (e.g., location, water temperature, fish density), branch line types were alternated along the longline. The gear type at the start of each set was also rotated systematically (mono:wire:mono:wire). Bait type (either squid or mackerel) varied with each set, while all other gear features and fishing practices—including gear placement, setting time, flashlight colour, bait size, and hook type—were standardised throughout the three trips (Santos et al. 2024). Like Santos (2017), power analyses were conducted to estimate the sampling effort needed to detect 25% and 50% changes in catch rates of the two most common species—swordfish and blue shark and the same statistical methods were employed. Results showed that combined catch rates for elasmobranchs were higher when using wire leaders, which also resulted in increased haulback mortality for these species. A significant difference in bite-off rates were observed between the two leader types, with most bite-offs occurring on nylon leaders. Wire leaders reduced bite-off rates by 78% compared to nylon (confidence interval: 74–82%) (Santos et al. 2024).

4 Review of scientific best practice for experimental field trials

4.1 General criteria and principles

There are some core principles of scientific best practices that should be adhered to when designing at-sea scientific trials comparing different fishing gears or strategies, to ensure the findings are robust and can inform management decision-making. These include:

- **Clear objectives and hypotheses:** It is important to set explicit, testable hypotheses and objectives for the experimental fishing trial (Fisher, 1935). These should clearly define the research question, what is being measured, and the expected outcome, to ensure that the trial addresses a clearly articulated management or conservation objective (Salafsky et al. 2001).

- **Accounting for known variation and factor screening:** It is usually important to understand which factors (other than the parameters being tested) have the most influence on the response variable (Montgomery, 2013; McAllister & Peterman, 1992). The design of an experimental fishing trial must explicitly control and/or account for these factors or known sources of variation, such as vessel effects, crew behaviour, spatial heterogeneity, and temporal factors (e.g., season, moon phase). This is crucial for isolating the effect of the response variable being tested. This can be achieved through a variety of methods:
    - *Stratified sampling:* Dividing the study area into strata (e.g., different seasons or regions) and conducting random sampling within each.
    - *Paired comparisons:* Using paired treatments within the same fishing set or day to control for external factors.
    - *Statistical adjustments:* Incorporating fixed or random effects into the statistical models to account for the influence of these variables during analysis.

- **Treatment randomisation:** To minimise bias and ensure that the effects of unmeasured variables (covariates) are evenly distributed, treatments must be randomly assigned to experimental units (e.g., in this context, hooks, branchlines and/or sets) (Fisher, 1935; Hurlbert, 1984; McAllister & Peterman, 1992). This is critical to prevent environmental or operational variability from systematically favouring one treatment over another, thereby strengthening the internal validity of the trial (Hurlbert, 1984). Computer software programs are widely used to assist researchers in selecting and constructing experimental designs. These programs often present the runs in the experimental design in a random order using a random number generator (Montgomery, 2013).

- **Appropriate replication to improve statistical power:** The experimental fishing trial must include enough replicates for each treatment to enable rigorous statistical analysis and ensure there is sufficient statistical power to detect any effect that exists. (Montgomery, 2013; Hurlbert, 1984; McAllister & Peterman, 1992). This means replication across different stochastic factors encountered during the trial (spatial, environmental, and temporal scales - e.g., fishing grounds, sea surface temperature, seasons) is essential. Replication has two important properties. First, it allows the experimenter to obtain an estimate of the experimental error. This estimate of error becomes a basic unit of measurement for determining whether observed differences in the data are statistically different. Second, if the sample mean is used to estimate the true mean response for one of the factor levels in the experiment, replication permits the experimenter to obtain a more precise estimate of this parameter (Montgomery, 2013). A statistical power analysis should ideally be used (see, e.g. Watson et al. 2005) to determine the minimum sample size needed for the study to ensure there is a high chance of detecting a genuine result.

- **Standardised data collection:** All data collection protocols, forms (including specific data fields), and tools must be clearly defined and standardised in advance. Detailed instructions must be provided to independent observers and scientific researchers on how to record experimental data consistently (these often take the form of standards within RFMO observer or electronic monitoring programs – see Wolfaardt, 2016). This ensures data integrity and comparability across all replicates and treatments.

- **Observer and researcher training:** All independent observers and scientific researchers must possess prior experience and skills, particularly in species identification, and receive comprehensive training. This training should cover the experimental design and standardised data collection protocols. This minimises human error, reduces observational bias, and significantly improves the reliability and quality of the collected data (Tillett et al, 2012).

- **Appropriate statistical analysis:** The experimental design must be tailored to the statistical methods that will be used to analyse the data once its collected (Montgomery, 2013). This ensures that the collected data can be appropriately analysed to test the initial hypotheses. The use of appropriate statistical models, such as Generalised Linear (or Mixed) Models (GLMs or GLMMs), that can account for repeated measures and random effects (e.g., set or vessel) is vital for robust analysis. Residual analysis and model adequacy checking are also important analysis techniques (Montgomery, 2013).

- **Stakeholder participation and support:** Engaging key stakeholders, particularly the fishers and industry representatives in the design and implementation process of the experimental fishing trial is highly beneficial (Johnson & van Densen, 2007; Stanley et al 2015; McAllister & Peterman, 1992). Fishers can contribute their knowledge of gear/vessel operations and gear-habitat interactions, as well as of spatial and temporal fish behaviour (Johnson & van Densen, 2007). This collaboration with researchers can improve the legitimacy, support, and practical feasibility of the trial, ensuring that the design is not only scientifically sound but also operationally realistic on the fishing vessel(s) involved.

4.2 Specific criteria and principles for conducting leader material experimental trials

Drawing from the core scientific principles outlined above, the following considerations are essential for designing an experimental fishing trial to assess the effect of leader material on shark catch rates, bite-offs, and haulback mortality. These include:

- **Shark abundance:** To maximise the probability of capturing the target species, experimental fishing trials should be conducted in areas and seasons known to have sufficiently high abundance of the vulnerable species of interest (see Resolution 25/08) and blue shark. Suitable locations can be identified using existing data from a range of sources, including the IOTC ROP data and abundance and species richness surveys within the Indian Ocean. Global ocean mapping of the distribution of all shark species has shown that species richness peaks at mid-latitudes like patterns observed for tuna and billfish (Lucifora, García and Worm, 2011). Regarding abundance rather than species richness per se, pelagic sharks are known to congregate at the boundaries of thermal fronts (Bigelow, Boggs and He, 1999) and in areas of upwelling above seamounts (Gilman et al., 2012). For example, the Kenya and Somalia basin has been identified as a hotspot for oceanic whitetip sharks during the summer monsoon (June to September) when cold-water upwelling occurs (Lopetegui-Eguren et al., 2022). Similarly, the central Mozambique Channel is a regional density hotspot for pelagic megafauna, including sharks (Laran et al., 2017). Furthermore, the WPEB has noted fishing grounds around Reunion Island and Madagascar show a high incidence of sharks (IOTC WPEB 2024 - see Figure 1). These observations can help inform the selection of trial locations to ensure a sufficient sample size of relevant shark species.

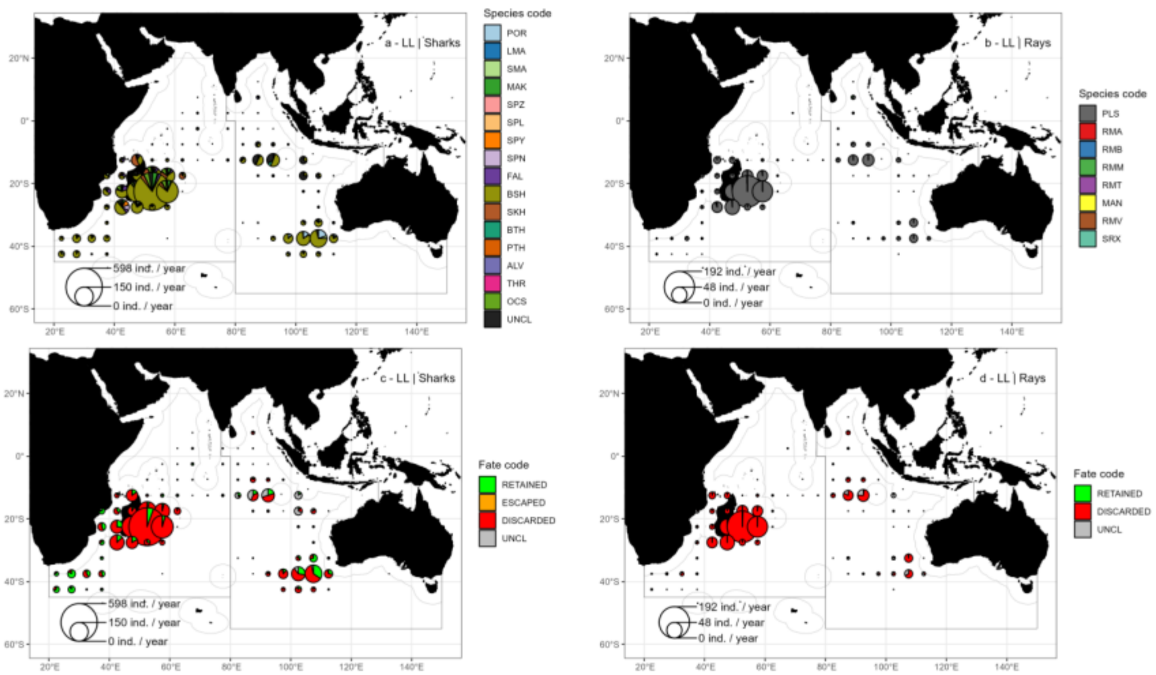

Figure 1: Mean annual number of shark and ray interactions (numbers of individuals per year) with deep-freezing longline fisheries by species (a & b) and fate (c & d) as reported to the Secretariat during the period 2005-2022 (Source: IOTC 2024a).

- **Power analysis:** A power analysis to estimate the amount of experimental fishing (no. of shots) required to detect a fishing method (nylon monofilament leaders) that has different degrees of effectiveness (50% and 25%) in reducing bycatch of sharks should be undertaken as designed by Watson et al. (2005) and used by Read (2007) and Santos et al. (2017; 2024). This analysis should be informed by historical observer data from the areas of the Indian Ocean selected for the study to provide realistic bycatch rates. The results will be used to set the number of shots for the experimental fishing trial, ensuring sufficient data are collected to detect a true effect if one exists, thereby minimising the risk of a Type II error (McAllister & Peterman, 1992).

- **Deployment Strategy:** To minimise confounding effects from variables such as location, water temperature, or spatial variation in fish density, control and experimental branch lines should be alternated along each longline section (e.g., between floats). This "paired comparison" deployment strategy is critical because the difference in catch between two leader materials can be much smaller than the natural variation in catch between different times and places (Brewer et al., 1998; Read et al., 2007). Following the methodology used by Santos et al. (2017; 2024), the control (monofilament leaders) and experimental (wire leaders) treatments should be deployed in an alternating pattern within each section (e.g., mono:wire:mono:wire). Furthermore, the branch line type used on the first section of the longline should be alternated for every subsequent fishing set to ensure a balanced experimental design as similarly undertaken by Santos et al. (2017; 2024).

- **Controlled comparisons:** To ensure the integrity of the experimental trial, it is crucial to standardise as many factors as possible across trial vessel(s). Differences in gear configuration and fishing practices can introduce confounding variables that can obscure the effects of the treatment being tested (Montgomery, 2013). Therefore, the characteristics of the longline fishing gear and operational practices on board the trial vessel(s) should be standardised and maintained constant throughout the experimental trial. These include, but are not limited to:
    - *Soak Time:* The duration the longline gear with each leader treatment remains in the water.
    - *Setting and Hauling Time and Speed:* The time of day and speed at which the gear is deployed and retrieved.
    - *Terminal branch line set up – e.g. Baits, Hooks, lightsticks etc*: The type, size, and rigging of both the bait and the hooks.
    - *Branchline and Leader Length*: The dimensions of the terminal tackle.

  By controlling these variables, the interpretation of results from the experimental fishing trial can more reliably attribute any observed differences in outcomes directly to the leader material being tested, rather than to extraneous factors.

- **Trained independent observers and researchers:** The vessel(s) participating in the experimental trial should carry at a minimum one (preferably two) independent observer(s) or scientific researchers who are trained in the operation of pelagic longline fishing vessels and have prior experience and skills in shark identification, bycatch safe handling and release, collection of biological data, tagging of animals, etc. Experience specifically within the IOTC Convention Area is highly desirable to ensure familiarity with regional species and fishing practices. Having experienced and well-trained observers or researchers is critical for minimising human error and reducing observational bias, thereby ensuring data reliability.

- **Standardised data collection protocols:** Whenever a species is caught on the longline, the independent scientific observer or researcher should record the following data fields at a minimum:

- *Species id.*
- *Leader line material*. (e.g., control vs. experimental)
- *Fate.* Whether the animal was retained or discarded.
- *Condition at Haulback.* Classified as alive or dead.
- *Condition upon Discard/Release.* Classified as alive or dead.
- *Occurrence of Bite-Off.* Record if the leader was bitten through.

Recording bite-offs is crucial because they can potentially mask differences in catchability between leader materials (as shown by Ward et al., 2008; Santos et al., 2017). While bite-offs may not significantly alter overall catchability, the condition of sharks (dead or alive) is likely to vary between leader types, especially with long soak times. Therefore, it is essential that both catchability and mortality data are collected and analysed to fully understand the effects of different leader materials.

- **Vessel support:** The skipper and the crew of the vessel(s) should be appropriately briefed prior to commencing fishing operations on the aim of the trial and experimental design. This ensures their understanding and cooperation, which are critical for execution of the trial protocols. The selection of trial vessel(s) should, in part, be based on their demonstrated support for the trial.

- **Statistical analysis and validation:** The statistical analysis should be developed in collaboration with experienced biostatisticians at the trial design stage. The experimental trial should be designed to detect differences in the following key response variables:
  - *Catch-per-unit-effort (CPUE):* typically measured as the number of sharks caught per 1,000 hooks, for both total shark (grouped) catches and species-specific catch.
  - *Bite-off rate:* the proportion of hooks where the bait or leader was severed and the terminal gear lost, likely due to shark bites, which is a proxy for undetected shark interactions.
  - *Haulback mortality rate*: the proportion of sharks that are dead upon retrieval to the side of the vessel, which is a critical indicator of gear impact on shark survival.

These metrics should be reported at both the species level for all vulnerable sharks identified in IOTC Resolution 25-08 (i.e. oceanic whitetip, silky, shortfin mako, and thresher sharks, as well as blue sharks) and at a broader taxonomic group level (e.g., all pelagic sharks). Given the hierarchical nature of fishing data (e.g. multiple hooks per set and sets per trip), the use of hierarchical or mixed-effect models is essential. These models correctly account for the non-independence of observations within sets or vessels, thereby avoiding pseudo-replication. For instance, GLMs or GLMMs could be used to test for the effects of leader type (e.g., wire vs. monofilament) and other experimental variables. Model selection should be guided by established criteria such as the AIC or the Bayesian Information Criterion (BIC). The validity of model assumptions should be confirmed through residual plots and tests for overdispersion and multicollinearity. To further assess model robustness, cross-validation or bootstrapping techniques should be employed where appropriate.

Table 1: Overview of the key features of an experimental fishing trial investigating leader material in the Indian Ocean and an assessment of whether this is a mandatory or optional requirement based on operational realities.

Feature	Design	Requirement and Realities
Shark abundance	When designing the trial, both the spatial and temporal elements should be aligned with areas and seasons of high shark abundance in the Indian Ocean. This will maximise the likelihood of a meaningful sample size and ensure the results are representative of the areas where shark bycatch is most prevalent.	***Optional*** Possible operational reasons will preclude this from eventuating but may mean a greater number of shots have to be undertaken if sharks are not caught.
Power analysis	A power analysis must be conducted to determine the necessary sample size for the trial. This analysis, which should follow the methodology of Watson et al. (2005), is critical for reducing the risk of a Type II error (i.e. false negative) and must be informed by historical observer data from the Indian Ocean fishery to provide realistic bycatch rates.	***Mandatory*** Will prevent over-sampling and wasting resources, while also ensuring that enough sets are undertaken to yield a real result.
Randomised paired comparison	To ensure a balanced experimental design, the two leader treatments—monofilament (control) and wire (experimental)—should be deployed in an alternating pattern on each longline section. Additionally, the leader type used on the first branch line of the longline should be alternated for every subsequent fishing set. This dual randomisation strategy mitigates potential bias related to gear position and order of deployment.	***Mandatory*** Critical to reduce potential bias caused by environmental variables.
Controlling factors	To ensure a robust and reliable experimental trial, all longline fishing gear and operational practices must be standardised and kept consistent. This includes: • Soak time • Setting and hauling times and speeds • Bait and hook type and size • Branch line and leader length • Any line weighting Maintaining these parameters constant across all trial vessels and fishing sets is critical to isolating the effect of the experimental variable.	***Mandatory*** By controlling these characteristics any observed differences in outcomes can be attributed to the leader material being tested, rather than to extraneous factors.

Independent observers or researchers	The vessel participating in the trial should carry at a minimum one (preferably two) independent observer(s) or scientific researcher(s) to record results from the trial at sea.	***Mandatory – minimum one observer or researchers with skills in species id, collection of biological data.*** ***Optional – ideally two observer or researchers; experience in IOTC convention area***
Trial vessel selection	Selection of trial vessel(s) should, in part, be based on a vessel owner or skippers demonstrated support for the trial and ability to meet mandatory requirements during fishing operations. Furthermore, they should be briefed prior to commencing fishing operations on the aim of the trial and experimental design.	***Mandatory***
Standardised data reporting	The following data fields should be collected as part of the leader trial: • *Set and Haul time* • *Latitude/Longitude* • *Species id.* • *Hook number* • *Leader line material* • *Fate.* • *Condition at Haulback.* • *Condition upon Discard/Release* • *Occurrence of Bite-Off* • *Bait type and size* • *Hook type and size*	***Mandatory***
	• *Amount of Trailing Gear* • *Hooking location (e.g. mouth or foul hooked)* • *Length and Sex of individual* • *Sea surface temperature* • *Depth* • *Wind speed, direction wave height*	***Optional*** Allows additional co-variates to be included in the statistical models.
Statistical analysis:	Statistical analysis (and resulting model validation outputs) should be developed by experienced biostatisticians at the trial design stage. The experimental trial should be designed to detect differences in the following key response variables: • Catch-per-unit-effort (CPUE):	***Mandatory***

	• Bite-off rate • Haulback mortality rate These metrics should be reported at both the species level for all vulnerable sharks identified in IOTC Resolution 25-08 and at a broader taxonomic group level (e.g., all pelagic sharks).	

5 Recommendations

This paper has provided a detailed review of best practice design principles and criteria for undertaking an experimental fishing trial to investigate the effect of leader material on shark catch rates, bite-offs and haulback mortality. These principles and criteria are based on both core principles of scientific best practices (see, e.g. Fisher, 1935; Montgomery, 2013; McAllister & Peterman, 1992) for experimental design, and the methodologies of previous scientific experiments examining leader material effects as described in peer-reviewed journals (see. e.g. Ward et al., 2008; Santos et al. 2017; 2024), the outcomes of which were previously reviewed in IOTC-2024-WPEB2- (DP)-11.

Based on this review, the authors suggest that the **WPEB recommend to the SC that they should endorse the following criteria and principles for conducting an** experimental fishing trial to investigate the effect of leader material on shark catch rates, bite-offs and haulback mortality**:**

1. That the trial is conducted in areas and seasons with known high shark abundance (including of vulnerable shark species), using existing data from Indian Ocean Regional Observer Programme (ROP) or independent surveys to identify suitable hotspots

2. Before the trial, conduct a power analysis (following Watson et al. 2005) informed by historical bycatch data from the Indian Ocean to determine the number of sets required to detect a true effect, thereby avoiding a Type II error.

3. That the trial employs a "paired comparison" approach by alternating control (monofilament) and experimental (wire) leaders along each longline section. Also, alternate the leader type on the first branch line for every subsequent fishing set to ensure a balanced design.

4. That the trial standardises all gear and operational practices across the trial, including, *inter alia*, soak time, setting/hauling times, bait/hook types and branch line/leader lengths and other gear characteristics (e.g. use of lightsticks) to assist the trial in isolating the effect of leader material.

5. Use at least one, and preferably two, independent observers or scientific researchers who are trained in longline operations and species identification to minimise human error and observational bias.

6. Establish a standardised protocol for collecting data. Key metrics to record are species ID, leader material, fate (retained/discarded), condition at haulback, and the occurrence of bite-offs.

7. Develop the statistical analysis plan in collaboration with biostatisticians. Appropriate statistical approaches include hierarchical or mixed-effect models (e.g., GLMMs) to analyse key response variables, including: CPUE, bite-off rate, and haulback mortality rate.

We understand that there are likely to be trade-offs and costs associated with the implementation of these recommendations, but the WPEB should consider them crucial for several reasons:

- Ensuring data is consistent and comparable across all trial replicates and treatments, which is a cornerstone of sound experimental design (McAllister & Peterman, 1992).

- Enabling a robust statistical analysis with sufficient power to detect a true effect, preventing a Type II error (Montgomery, 2013; Hurlbert, 1984; McAllister & Peterman, 1992).

- Minimising human error and observational bias, significantly improving the reliability and quality of the collected data (Tillett et al., 2012).

- Ensuring the trial's design is both scientifically sound and practically feasible for the fishing vessels involved (Johnson & van Densen, 2007).

Undertaking an experimental fishing trial to investigate the effect of leader type on observed catch and fishing mortality of vulnerable shark species (including oceanic whitetip shark, silky shark, shortfin mako and thresher sharks) and blue sharks using these recommended criteria and principles, will allow the WPEB and SC to have confidence in the outcomes of any trial, and support the development of appropriate advice from the SC to the Commission regarding the potential effectiveness of a prohibition on wire leaders in future.

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