# Large-scale experiment shows that banning wire leaders helps pelagic sharks and longline fishers

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**Abstract:** We assess the performance of wire leaders, which some jurisdictions have banned to reduce shark mortality from pelagic longline fishing. Experiments were conducted on commercial vessels that deployed equal numbers of wire and nylon monofilament leaders randomly along their longlines. Catch rates of several species, including sharks, were significantly lower on nylon than on wire leaders, probably because those animals often escape by severing the nylon leaders. High bite-off rates indicate that as many animals escape from nylon leaders as are caught on nylon leaders. The fate of escaped animals is not known, although large sharks are more likely to survive than are small animals. By contrast, catch rates of valuable bigeye tuna (*Thunnus obesus*) were higher on nylon than on wire leaders. Bigeye tuna are probably able to see wire leaders and avoid those hooks. The financial benefits of increased bigeye tuna catches outweigh the costs associated with banning wire leaders, such as increased rates of gear loss. Thus, banning wire leaders is an effective way of reducing shark catches that fishers should be keen to adopt.

**Keywords:** Bycatch mitigation, sharks, tuna, billfish, pelagic longline, open-ocean, catchability

**Running head:** Longline bycatch mitigation experiment

## Introduction

There is considerable concern over the ecological effects of pelagic longline fishing, which extends throughout tropical and temperate regions of the world's oceans (Lewison et al. 2004; Werner et al. 2006). The longlines are deployed in a daily operation to catch large tuna (*Thunnus* spp.) and billfish (Istiophoridae and Xiiphidae). They consist of a series of baited hooks attached to a mainline that is suspended from floating buoys. The hooks range from near the surface to depths of several hundred meters. Up to 4000 hooks are deployed each day on branchlines attached to mainlines that may span 100 km of the sea surface (Ward and Hindmarsh 2007).

Several management agencies have mandated bycatch mitigation measures, such as bird-scaring "tori" lines, to reduce the mortality of seabirds that dive for longline bait, e.g., threatened wandering albatross (*Diomedea exulans* ) (Brothers et al. 1999). Sea turtles, such as the leatherback (*Dermochelys coriacea*), are also threatened by pelagic longlining. Measures to reduce sea turtle interactions and mortality include large circle hooks and nighttime deployment of longlines (Watson et al. 2004; Watson et al. 2005).

Sharks (Elasmobranchii) are another group of vulnerable animals that interact with longlines. Concern over shark mortality has led to restrictions on landing sharks

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and bans on “finning”, where sharks are brought on board the fishing vessel, dispatched, and the fins removed. The fins are sold at lucrative markets, while the carcass is often discarded. Unfortunately, bans on finning and landing often result in the discarding of sharks at sea, which reduces the effectiveness of those measures in reducing shark mortality (Rose and McLoughlin 2001). Finning is estimated to result in the mortality of 30–52 million sharks per year worldwide, much of which is attributed to longlining (Clarke et al. 2006).

A more effective way to reduce shark bycatch may be to ban wire leaders or “steel traces”. Pelagic longliners have used wire leaders since the 1920s to reduce the loss of fishing gear and hooked animals that are able to sever leaders constructed from natural or synthetic fibers. Many longliners began using nylon monofilament leaders in the 1980s, although several fleets have continued to use wire leaders or use wire for a proportion of their branchlines (Gilman et al. 2007; Ward and Hindmarsh 2007). To reduce shark bycatch, Australia banned the use of wire leaders in its eastern tuna longline fishery in 2005. However, there are few published studies of the effects of wire leaders on catches, and most results are ambiguous because of small sample sizes or inappropriate experimental design. Berkeley and Campos (1988), for example, monitored one longliner fishing for broadbill swordfish (*Xiphias gladius)* with about 25% wire leaders and 75% nylon leaders in 13 longline operations. They reported fewer sharks on wire leaders than on nylon, but the difference was not statistically significant. Branstetter and Musick (1993) placed 50 branchlines with nylon leaders on the end of survey longlines that comprised 100 branchlines with wire leaders. Overall, catch rates of sharks were higher on the nylon leaders. However, shark catch rates in offshore waters showed the opposite pattern, with higher catch rates on wire.

Many studies of bycatch mitigation have focused on the ability of particular measures to reduce mortality of the species of concern. A more holistic approach is emerging with the broadening of studies to include the effects of mitigation on catches of other species and financial aspects of commercial fishing operations (Werner et al. 2006). This article presents results of a large-scale experiment that compares the performance of nylon and wire leaders for various target and bycatch species. It includes analyses of the financial costs and benefits of banning wire leaders. The results are also relevant to measuring the relative abundance of pelagic animals from catch and fishing effort data. For pelagic longline fisheries, abundance indices are often based on commercial catch rates or the “catch-per-unit-effort” (CPUE) that is reported as the number of animals caught per 1000 hooks. An understanding of catchability—the efficiency of the fishing gear—is critical to deriving estimates of abundance from catch rates (Bishop 2006). It is affected by the distribution of animals and their behavior in relation to the fishing practices and gear.

## Methods

We compared catches on nylon and wire leaders deployed by five commercial longliners during September 2005 – December 2006 off northeastern Australia (Fig. 1). They targeted bigeye (*Thunnus obesus*) and yellowfin tuna (*T. albacares*) for sashimi markets.

The wire leaders used in the study were 30 cm, stainless steel, 6-strand wire cable (Fig. 2). A 38 g swivel was attached to the branchline 5 m above the hook. The nylon leaders did not have a weighted swivel. They were 2 mm diameter (250–300 kg breaking strain) nylon. One longliner used 30 cm double nylon leaders. The nylon monofilament is a copolymer, with a core of flexible nylon and an outer skin of tougher nylon. Both the nylon and wire leaders were attached to 16 m nylon monofilament branchlines constructed of the same material as the nylon leaders. All longliners used 4 mm diameter nylon monofilament mainlines and Japanese tuna hooks (55 mm total length, 28 mm bite, 27 mm gape, 10° offset). They used frozen pilchard (*Sardinops* spp.) or squid as bait. On about 9% of branchlines, crewmembers attached luminescent lightsticks 2 m above the hook.

Observers monitored experimental protocols and collected data on the longliners. Roughly, equal numbers of nylon and wire leaders were deployed on each longline. Crewmembers were instructed to attach the different types of leader, bait species, and lightsticks randomly along the longline. Observers regularly monitored the sequence of lightsticks, bait, and leader types during deployment. The total number of each type of leader deployed and retrieved, the number of lost hooks, and the number of each leader type repaired after each longline operation were counted. For retained, discarded, and released animals, observers recorded the type of leader that each animal was caught on, the species, its length, time of landing, and the sequential hook number. Operational constraints, such as adverse weather and high catch rates, sometimes prevented observers collecting all the requisite data on longline operations and catches.

Conditional logistic regression (Hosmer and Lemeshow 1988) was used to determine whether there were statistically significant differences in catch rates between the two leader types. Conditional logistic regression allows the simplification of the linear predictor so that covariates that are constant within the experiment can be ignored. This simplifies the interpretation of results and avoids the model selection process. The advantage of using a conditional likelihood in this analysis is that covariates that are common to hooks (e.g., season, location) within a longlining operation do not appear in the conditional probabilities. It overcomes the problem of not having detailed information about all the characteristics associated with each operation.

Separate models were estimated for each species and species group. The data were analyzed at the hook-level with the catch of the species being “1” if the particular leader caught the species and “0” otherwise. Hooks that caught another species and hooks without bait are treated as a zero catch for the species under consideration. Given a catch of species $i$, $p_{i,nylon}$ is the probability that the catch was on nylon and $p_{i,wire}$ is the probability that it was on wire. The odds of catching the species on wire is $p_{i,wire}(1-p_{i,wire})^{-1}$ and the odds of catching it on nylon is $p_{i,nylon}(1-p_{i,nylon})^{-1}$.The odds ratio $OR_i$ is then:

$$OR_i = \frac{p_{i,nylon}\left(1-p_{i,nylon}\right)^{-1}}{p_{i,wire}\left(1-p_{i,wire}\right)^{-1}}$$

The odds ratio is referred to as “relative catchability”. A relative catchability of 1.25, for example, indicates that the odds of catching the species on nylon are 25% higher than that on wire. Conversely, a value of 0.75 indicates that the odds of catching it on nylon are 25% less than that on wire. For species that were too rare to model, we present the mean catch rate on nylon divided by that on wire as the measure of relative catchability. This is roughly equivalent to the odds ratio because the odds ratio is approximated by $p_{i,nylon}/p_{i,wire}$ when there is a very small probability of catching the species on any given hook (which is the case here).

We implemented the models in the *R* statistical language (*R* Development Core Team 2006) using *clogit* from library *survival*. A Wald test was used to determine the significance of the leader type variable. We explored the sensitivity of estimates to double nylon leaders by fitting the model to a dataset that excluded the double nylon data.

The value of catches on the two leader types was estimated by multiplying the market price of each species (Vieira 2007) by its weight and catch rate. The weights of measured animals were estimated from length-weight relationships (Froese and Pauly 2003). Estimates of value were limited to those animals that were retained by the vessel and to species where catch rates on nylon were significantly higher than those on wire leaders.

We used a generalized additive mixed model with a Poisson error distribution to identify variables influencing the loss rates of hooks ("bite-offs") from nylon leaders. The model included a random vessel effect to allow for correlations among the operations of each vessel.

## Results

Observers monitored 177 longline operations consisting of 77 011 hooks (37 679 nylon leaders and 37 422 wire leaders). The longliners concentrated on a relatively small area of the western Coral Sea outside the Great Barrier Reef (Fig. 1). Longline activity was uniformly distributed throughout the 15-month study period. The longliners deployed 9 or 10 branchlines between buoys, with the maximum depth of hooks probably ranging down to about 170 m (Campbell et al. 1997). They usually deployed 500 longline hooks at dawn or dusk each day. Deployment lasted about two hours on average, and then the longline was allowed to drift for about seven hours. Hauling usually commenced in the mid-afternoon or early morning and lasted about three hours.

A runs test (Zar 1984) at the 0.05 level of statistical significance indicated that the sequence of nylon and wire leaders was random for 80 of the 86 longline operations where observers recorded data on the sequence. However, some of the samples were heavily weighted towards one leader type, suggesting that a larger number of non-random operations may have been detected if observers had monitored the entire sequence. Regardless, data from all monitored longline operations were included in the analyses presented in this article.

The longliners caught 4051 animals, consisting of 32 species or species groups (Table 1). Catch rates of all species combined were 13% higher on wire leaders than on nylon ($p < 0.001$). The catch rate of all bycatch species combined on nylon was almost half that on wire. For many species, including blue marlin (*Makaira nigricans*), snake mackerel (*Gempylus serpens*), and sharks, wire leader catch rates were significantly higher than nylon catch rates. They were higher on wire for eight of the ten shark species and significantly higher for all shark species combined ($p < 0.001$). Combined catch rates for other teleosts were also significantly higher on wire ($p < 0.001$). Catch rates of two species (bigeye tuna and black marlin, *M. indica*) showed the opposite trend; their catch rates were significantly higher on nylon ($p < 0.02$). For 12 species there was no significant difference between nylon and wire catch rates ($p > 0.10$), and a further nine species were too rare to model.

Exclusion of data for double nylon leaders resulted in variations within ±5% in the estimate of relative catchability for most species. The double nylon data were included in the analyses presented here because they did not introduce any consistent bias into parameter estimates.

There was considerable variation in bite-off rates from nylon leaders. They ranged up to 53.3% per longline operation (mean = 5.1±7.0% SD). By comparison, observers reported few bite-offs for wire (mean = 0.2±0.6% SD). Season and catch rates of yellowfin tuna, snake mackerel, and sharks were significant predictors of nylon bite-offs (Table 2). Deployment time and soak time were not significant, perhaps because those variables had low contrast in the data.

Observers counted repairs for 19 longline operations. Repairs included bite-offs as well as damaged or abraded leaders and branchlines. Nylon repair rates averaged 24.5±15.3% SD per operation, compared to 14.3±8.8% SD for wire leaders.

## Discussion

We consider the underlying mechanisms that are responsible for the differences in catchability among species, the fate of animals that escape from nylon leaders, compare the financial costs and benefits of the two leader types, and identify improvements to the study's design. The analyses show that the relative catchability of leader types varies among species. Catch rates of bigeye tuna on nylon, for example, were 26% higher than those on wire (Fig. 3). Catch rates of many species, including sharks, snake mackerel, lancetfish, and wahoo (*Acanthocybium solandri*), show the opposite tendency; they were higher on wire. Before the study commenced, fishers indicated that those latter species were responsible for severing nylon leaders. The mixed model showed that bite-off rates rose with the increased local abundance of sharks and snake mackerel (Table 2). We conclude that the catch rates of species with sharp teeth, such as sharks and snake mackerel, are lower on nylon because the animals are able to sever the leader and escape.

Table 1 includes combined results for sharks because several species were too rare to model. However, relative catchability probably varies among shark species. The heavily serrated teeth of tiger shark (*Galeocerdo cuvier*), for example, are more likely to sever nylon than the smooth, needle-like teeth of species like bigeye thresher shark (*Alopias superciliosus*). The position of hooking will also be important. Circle hooks almost always embed in the corner of the jaw (Prince et al. 2002; Skomal et al. 2002). Consequently, the leader will be less exposed to abrasion. Nylon catch rates are likely to be more similar to wire catch rates when circle hooks are used. By contrast, J-shaped hooks, like those used in the present study, often embed in the throat or gut (Kerstetter and Graves 2006). The leader will be exposed to abrasion against the teeth. J-shaped hooks on nylon leaders are therefore expected to have higher bite-off rates than circle hooks on nylon leaders.

In contrast to sharks, tuna have small conical teeth (Collette and Nauen 1983) that are less likely to sever nylon leaders. Mesopelagic species, like bigeye tuna, have excellent vision (Brill et al. 2005). We hypothesize that catch rates of bigeye are lower on wire leaders because the animals are often able to see the wire and avoid baited hooks attached to those leaders.

The results suggest that banning wire leaders will reduce catches of blue marlin, but increase black marlin catches for longline operations with similar attributes to those analyzed in this study. The differences in catchability might be due to behavioral differences between the two species. Recreational anglers report that blue marlin have a violent reaction to hooking, which might result in the abrasion and severing of leaders. Black marlin tend to be more docile when hooked. Fishery managers considering the banning of wire leaders will need to balance its beneficial effects on blue marlin and adverse effects on black marlin, as both species are important to anglers. Swordfish also respond violently to hooking. Although the differences with leader type were not statistically significant in the present study, wire catch rates might be higher than nylon catch rates, especially at higher latitudes where large swordfish are more frequently encountered.

The similar catch rates of yellowfin tuna on the two leader types might indicate that this species is unable to detect wire leaders and unable to sever nylon leaders. However, catches on nylon leaders are the product of two independent processes: elevated catchability of nylon due to its low visibility; and increased loss rates due to animals severing leaders. Hooking rates of yellowfin tuna might actually be higher on nylon, but landings may be reduced by losses, resulting in similar catch rates between the two leader types.

Bite-offs may also mask the increased catchability of nylon for other species. Subtracting nylon catch rates from wire catch rates for species where wire catch rates were higher gives an overall loss rate of 11.6 animals per 1000 hooks. By contrast, observers reported bite-offs at a rate of 5.14% or 51.4 per 1000 hooks. The discrepancy between loss rates and bite-off rates is due to nylon leaders elevating catchability for many species, but many animals subsequently escape by severing the leader. The high bite-off rate indicates that as many animals escape from nylon leaders as are caught on nylon leaders.

The species composition of animals that are lost through bite-offs might be obtained by multiplying the bite-off rate by the difference between catch rates on the two leader types. For example, the difference between wire and nylon catch rates is 1.9 per 1000 hooks for longnosed lancetfish (*Alepisaurus ferox*). This is 16% of the wire-nylon differential for all animals (11.6 per 1000 hooks). Multiplying 16% by the bite-off rate (51.4 per 1000 hooks) gives a loss rate of 8.5 longnosed lancetfish per 1000 hooks. The same method can be use to estimate the loss rates of other species where wire catch rates exceeded nylon catch rates. However, this method of estimation does not take into account animals that might bite-off more than one hook during a longline operation. Furthermore, the loss rate of each species is likely to be overestimated because the method omits the seven species where nylon catch rates exceeded wire catch rates. At least some of those omitted species are likely to be lost, but their elevated catchability on nylon leaders probably masked those losses. Regardless, it is clear that large numbers of snake mackerel, lancetfish, great barracuda (*Sphyraena barracuda*), and blue marlin must escape from nylon leaders. The development of leader materials that combine the advantages of nylon (low visibility) and wire (resistance to abrasion) would significantly increase catches of target species and financial returns, but it would also increase bycatch levels.

Banning wire leaders is an effective way of reducing the number of sharks landed, but its benefits in reducing mortality are unclear because the fate of animals that sever the leader and escape is unknown. Several shark species seem to be robust to the stresses associated with being hooked, e.g., 83% of the 163 sharks that observers monitored during the study were alive, with most classified at the top of the scale (“alive and vigorous”). Furthermore, fishers and observers often report catching sharks with several longline hooks embedded in their jaws. In contrast to sharks, we did not find any reports of fishers catching small species like lancetfish embedded with hooks from past encounters with longlines. Mortality rates may be high for small, fragile species that escape.

High bite-off rates, like those observed in this study, are common in pelagic longline fisheries. Each year, hundreds of thousands of hooks are lost from the nylon leaders deployed by Australian longliners and, based on estimates of global longlining effort (Lewison et al. 2004), many millions must be lost worldwide. There is a need to quantify this cryptic mortality and introduce measures to mitigate it.

In contrast to the uncertain survival rates of animals lost from nylon leaders, there is information on survival rates of animals caught on wire leaders. Observers reported that 80% of the snake mackerel were dead. Few animals are released alive. Fishers often dispatch sharks caught on wire leaders so that they can safely retrieve hooks or they may cut the branchline leaving the hook embedded in the shark with a trailing leader. On the other hand, some fishers believe that wire leaders provide better control over live sharks, allowing them to bring the animal alongside the vessel where they can remove the hook.

The estimated value of the catch taken on the two leader types shows a financial incentive for fishers to use nylon leaders. The increased value resulting from the elevated catchability of bigeye tuna outweighs losses associated with the reduced catchability of sharks. The annual value of the bigeye tuna and shark catch landed by a typical longliner deploying only nylon leaders is about USD20 000 higher than that of a typical longliner using all wire leaders (

Table 3). Nylon leaders cost about USD12 000 more to replace or repair each year (

Table 4), which reduces the financial benefit of using nylon to about USD8000. Variations in retention practices will influence these conclusions. Fishers involved in this study chose not to land commercially valuable striped marlin (*Tetrapturus audax*), and landed less than half of their shark catch because of regulations and operational considerations, e.g., some sharks were too large or dangerous to bring on board. Furthermore, the analyses do not include safety issues or the cost of the labor involved in repairing branchlines and replacing hooks or subsequent reductions in time available for fishing.

Three improvements could be made to the study so that conclusions are applicable to longline fisheries in other regions. First, future work should compare leaders with the same weighting regime. In our study, fishers attached 38 g weighted swivels to the wire leaders, but not to the nylon leaders. An experiment by G. Robertson (pers. comm.) showed that branchlines with a 100 g swivel reach a depth of 10 m in 38 seconds on average compared to 44 seconds for branchlines with a 60 g swivel. The difference in sinking rates increased with depth over the experiment’s depth range (1–15 m). This suggests that for the shallowest leaders in our study, the nylon leaders would take about 15 seconds longer than the wire leaders to reach their maximum depth (~30 m). The deepest nylon leaders might take about two minutes longer to reach their maximum (~170 m). However, this is likely to have a small effect on catchability because of the long soak time of baited hooks (about nine hours on average). The two leader types might also reach different maximum depths, although currents and the weight of adjacent branchlines will also affect the maximum depth.

A second improvement to the study is the construction of leaders. The nylon leaders consisted of a single strand of nylon, like those used by many other fleets (Ward and Hindmarsh 2007). One of the longliners in the study used two strands of nylon, although this was found not to significantly change results. Historically, several longline fleets have used braided “multifilament” nylon leaders that have been shown to have lower catchability than nylon, presumably because of their higher visibility (Stone and Dixon 2001). The results of the experiment may be confounded by the effects of leader visibility on catchability and the effects of leader durability on loss rates. A better approach to estimating relative catchability would be to deploy leaders constructed from the same nylon of varying visibility determined by dyes mixed with the nylon. Separate experiments might then compare the performance of opaque nylon and wire leaders.

Recreational anglers who fish for sharks often use wire leaders that are encased in plastic because they believe that the electrical field emitted by the wire may deter sharks attacking their bait. Coated wire leaders, if they were to be used by longliners, might increase shark catchability above the levels estimated in the present analyses and elevate shark mortality.

A third improvement to the study is the exploration of the effects of light and soak time on relative catchability. Higher nylon loss rates are likely for longer operations than those in this study, as there will be more time for leaders to be abraded. This effect could be investigated with time–depth recorders that provide the actual time when each animal is hooked. We also hypothesized that catch rates of bigeye tuna were lower on wire leaders because these animals are sometimes able to see the wire and consequently avoid those baited hooks. According to this hypothesis, relative catchability should decline to unity at night when vision is less important for locating baited hooks. To test this prediction, we separately modeled longline operations that occurred entirely during the day and those that occurred entirely at night. The analyses contradicted our predictions; relative catchability was not significant for the day operations ($p > 0.620$), but nylon catch rates were significantly higher at night ($p < 0.034$). These results warrant further investigation although they might be affected by the reduced number of observations available for analysis.

Regardless of these suggested improvements to the study, the comparison of the performance of nylon and wire leaders is valid for this particular fishery because this is the gear deployed by commercial longliners involved in the fishery.

## Conclusions

The analyses show the benefits of banning wire leaders. It significantly reduces catches of sharks and other bycatch species. At least some sharks that sever the nylon escape and survive, although the fate of other bycatch species is unknown. By increasing the catchability of bigeye tuna, nylon increases financial returns. The increased returns outweigh the costs of replacing and repairing damaged gear.

The results also have important implications for assessments of target and non-target species. Global declines in shark populations may not be as severe as suggested by Baum et al. (2003) if the switch to nylon by many longliners during the 1980s resulted in large declines in shark catchability and if the mortality rates of escaped sharks are not significant. Conversely, declines in bigeye tuna will be larger than currently estimated if the switch to nylon leaders by many longliners in the 1980s resulted in the increased catchability indicated by the analyses.

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Table 1. Summary of catches of each species on nylon and wire leaders, and estimates of relative catchability, its standard error (SE), and statistical significance.

| Scientific name | Common name | Fate[a] | Number caught |  | Catch rate[b] |  | Relative catchability[c] |  |  |  |
|---|---|---|---|---|---|---|---|---|---|---|
|  |  |  | nylon | wire | nylon | wire | estimate | SE | *p*-value[d] |  |
| Tunas and tuna–like species |  |  |  |  |  |  |  |  |  |  |
| *Acanthocybium solandri* | Wahoo | B | 32 | 40 | 0.85 | 1.07 | 0.78 | 0.24 | 0.31 |  |
| *Katsuwonus pelamis* | Skipjack tuna | D | 4 | 2 | 0.11 | 0.05 | 2.71 | 0.87 | 0.25 |  |
| *Thunnus alalunga* | Albacore tuna | B | 150 | 132 | 3.98 | 3.53 | 1.14 | 0.12 | 0.28 |  |
| *Thunnus albacares* | Yellowfin tuna | T | 838 | 848 | 22.24 | 22.66 | 0.93 | 0.05 | 0.16 |  |
| *Thunnus obesus* | Bigeye tuna | T | 255 | 186 | 6.77 | 4.97 | 1.26 | 0.10 | 0.02 | * |
|  | Tunas subtotal |  | 1 279 | 1 208 | 33.94 | 32.28 | 1.00 | 0.04 | 0.95 |  |
| Billfishes |  |  |  |  |  |  |  |  |  |  |
| Istiophoridaed | Unid. marlin | D | 10 | 3 | 0.27 | 0.08 | 1.85 | 1.23 | 0.62 |  |
| *Istiophorus platypterus* | Sailfish[e] | D | 1 | 0 | 0.03 | 0.00 | >1.00 | – | – |  |
| *Makaira indica* | Black marlin | D | 102 | 66 | 2.71 | 1.76 | 1.45 | 0.16 | 0.02 | * |
| *Makaira nigricans* | Blue marlin | D | 8 | 29 | 0.21 | 0.77 | 0.27 | 0.40 | 0.00 | ** |
| *Tetrapturus audax* | Striped marlin | D | 11 | 19 | 0.29 | 0.51 | 0.55 | 0.38 | 0.12 |  |
| *Xiphias gladius* | Broadbill swordfish | B | 16 | 23 | 0.42 | 0.61 | 0.70 | 0.33 | 0.27 |  |
|  | Billfishes subtotal |  | 148 | 140 | 3.93 | 3.74 | 0.97 | 0.12 | 0.79 |  |
| Other teleosts |  |  |  |  |  |  |  |  |  |  |
| *Alepisaurus brevirostris* | Shortnosed lancetfish | D | 23 | 43 | 0.61 | 1.15 | 0.61 | 0.26 | 0.06 | . |
| *Alepisaurus ferox* | Longnosed lancetfish | D | 52 | 123 | 1.38 | 3.29 | 0.41 | 0.17 | 0.00 | *** |

| Scientific name | Common name | Fate[a] | Number caught | | Catch rate[b] | | Relative catchability[c] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | nylon | wire | nylon | wire | estimate | SE | *p*-value[d] | |
| *Centrolophus niger* | Rudderfish[e] | B | 1 | 2 | 0.03 | 0.05 | 0.50 | – | – | |
| *Coryphaena hippurus* | Mahi mahi (dolphinfish) | B | 151 | 139 | 4.01 | 3.71 | 1.03 | 0.12 | 0.83 | |
| *Gemphylus serpens* | Snake mackerel | D | 135 | 322 | 3.58 | 8.60 | 0.46 | 0.10 | 0.00 | *** |
| *Lampris guttatus* | Opah (moonfish)[e] | B | 1 | 0 | 0.03 | 0.00 | >1.00 | – | – | |
| *Lepidocybium flavobrunneum* | Black oilfish (escolar) | B | 42 | 38 | 1.11 | 1.02 | 1.17 | 0.23 | 0.48 | |
| *Mola* sp. | Sunfish[e] | D | 0 | 1 | 0.00 | 0.03 | 0.00 | – | – | |
| *Ruvettus pretiosus* | Oilfish[e] | D | 0 | 1 | 0.00 | 0.03 | 0.00 | – | – | |
| *Sphyraena barracuda* | Great barracuda | D | 12 | 35 | 0.32 | 0.94 | 0.46 | 0.39 | 0.05 | * |
| *Sphyraena jello* | Pickhandle barracuda[e] | D | 0 | 1 | 0.00 | 0.03 | 0.00 | – | – | |
| *Thyrsites atun* | Barracouta[e] | D | 1 | 6 | 0.03 | 0.16 | 0.17 | – | – | |
| | Other teleosts subtotal | | 418 | 711 | 11.09 | 19.00 | 0.61 | 0.06 | 0.00 | *** |
| Sharks | | | | | | | | | | |
| *Alopias pelagicus* | Pelagic thresher shark | D | 1 | 13 | 0.03 | 0.35 | 0.08 | 1.04 | 0.01 | * |
| *Alopias superciliosus* | Bigeye thresher shark | D | 6 | 5 | 0.16 | 0.13 | 1.07 | 0.63 | 0.91 | |
| *Carcharhinus* spp. | Unid. whaler sharks[f] | B | 6 | 27 | 0.16 | 0.72 | 0.21 | 0.45 | 0.00 | *** |
| *Carcharhinus falciformis* | Silky shark | B | 12 | 20 | 0.32 | 0.53 | 0.61 | 0.37 | 0.18 | |
| *Carcharhinus longimanus* | Oceanic whitetip shark | B | 3 | 11 | 0.08 | 0.29 | 0.31 | 0.65 | 0.07 | . |
| *Carcharhinus tilstoni* | Australian blacktip shark[e] | D | 1 | 0 | 0.03 | 0.00 | >1.00 | – | – | |
| *Galeocerdo cuvier* | Tiger shark | D | 14 | 24 | 0.37 | 0.64 | 0.54 | 0.34 | 0.07 | . |
| *Isurus oxyrinchus* | Shortfin mako shark[e] | D | 0 | 3 | 0.00 | 0.08 | 0.00 | – | – | |

| Scientific name | Common name | Fate[a] | Number caught | | Catch rate[b] | | Relative catchability[c] | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | | nylon | wire | nylon | wire | estimate | SE | *p*-value[d] | |
| *Sphyrna sp.* | Hammerhead shark[e] | D | 1 | 0 | 0.03 | 0.00 | >1.00 | – | – | |
| | Sharks subtotal | | 44 | 103 | 1.17 | 2.75 | 0.42 | 0.19 | 0.00 | *** |
| | Grand total | | 1 889 | 2 162 | 50.13 | 57.77 | 0.87 | 0.03 | 0.00 | *** |

[a] "D" indicates bycatch species that were discarded; "T" indicates target species, and "B" indicates byproduct species that were retained.

[b] Number of animals per 1000 hooks of that leader type deployed.

[c] The estimated parameter of the leader type variable from the conditional logistic regression.

[d] Statistical significance of leader type from the conditional logistic regression, indicating whether nylon and wire leader catch rates were statistically different:

| | |
|---|---|
| *** | $0 \le p < 0.001$ |
| ** | $0.001 \le p < 0.01$ |
| * | $0.01 \le p < 0.05$ |
| . | $0.05 \le p < 0.1$ |
| – | insufficient numbers for modelling |

[e] For species where insufficient numbers were available for modelling, relative catchability is estimated as the observed catch rate on nylon leaders divided by that on wire leaders.

[f] Observers reported 23 bronze whaler shark (*Carcharhinus brachyurus*). These have been included with unidentified whaler sharks because bronze whaler are not known from the study area. They are likely to be another species, probably silky shark.

Table 2. Results of a generalized additive mixed model of bite-off rates for nylon leaders. Variables that did not have a statistically significant effect on bite-offs included soak time, deployment time, bigeye tuna catch rates, and lancetfish (*Alepisaurus* spp.) catch rates.

| Term | Estimate | Standard error | *p*–value |
|---|---|---|---|
| Intercept | –4.0265 | 0.1395 | 0.0000 |
| Season: spring | –0.3737 | 0.1620 | 0.0226 |
| Season: summer | –0.1602 | 0.1736 | 0.3577 |
| Season: winter | –1.1259 | 0.2796 | 0.0001 |
| Yellowfin tuna | 0.0114 | 0.0023 | 0.0000 |
| Sharks | 0.0748 | 0.0130 | 0.0000 |
| Snake mackerel | 0.0206 | 0.0026 | 0.0000 |

Table 3. Summary of the weight and value of retained species that had significantly different catch rates on the two leader types.

| Product | Mean dressed weight (kg)[a] | Annual catch (kg)[b] |  | Unit price (USD/kg)[c] | Annual value (USD)[d] |  |
|---|---|---|---|---|---|---|
|  |  | nylon | wire |  | nylon | wire |
| Bigeye tuna | 20.7 | 14 005 | 10 285 | $6.69 | $93,710 | $68,823 |
| Shark carcass | 29.5 | 838 | 1 918 | $1.54 | $1,291 | $2,954 |
| Shark fins | 1.4 | 41 | 94 | $57.75 | $2,372 | $5,429 |
| Total | – | 14 884 | 12 298 | – | $97,373 | $77,206 |

[a] Whole weight derived from observer length measurements and length-weight relationships (Froese and Pauly 2003) then converted to dressed weight by dividing by 1.2077 for bigeye tuna and 1.320 for shark carcass. Weight of shark fins estimated as 4.9% of shark dressed weight (Cortes and Neer 2006).

[b] Product of the mean number of hooks reported in logbooks by the longliners in 2006 (91 700 hooks), dressed weight, catch rate on that leader type, and the proportion of the species retained.

[c] Bigeye tuna and shark carcass price (Vieira 2007) and shark fin prices (G. Heilman, pers. comm.) converted from Australian dollars (AUD) to US dollars (USD) using a 1.00AUD:0.77 USD exchange rate.

[d] Estimated value of the catch of bigeye tuna and sharks landed by a typical longliner in 2006 derived by multiplying the unit price by the annual catch on each leader type.

Table 4. Estimated costs (US dollars) of replacing lost hooks and repairing damaged branchlines for the two leader types on a typical longliner.

| Component | Nylon | Wire |
|---|---|---|
| Hooks and leaders | | |
| bite-off rate | 5.1% | 0.2% |
| unit cost | \$0.62 | \$0.85 |
| annual cost[a] | \$2 929 | \$ 125 |
| Branchlines | | |
| repair rate | 19.8% | 14.4% |
| unit cost | \$1.93 | \$1.93 |
| annual cost[a] | \$34 982 | \$25 472 |
| Total annual cost | \$37 911 | \$25 597 |

[a] Unit cost and bite-off rate (or repair rate) multiplied by the mean number of hooks reported in logbooks by the longliners in 2006 (91 700 hooks).

## Figure Captions

Fig. 1. Map of the study area showing the distribution and intensity of longline fishing activity.

Fig. 2. The two types of leader used in the study.

Fig. 3. Comparison of the effects of leader type on the relative catchability of the 18 most frequently caught species. Relative catchability is the estimated parameter of the leader type variable in conditional logistic regressions (circles) and 90% confidence intervals for the estimate (horizontal lines).

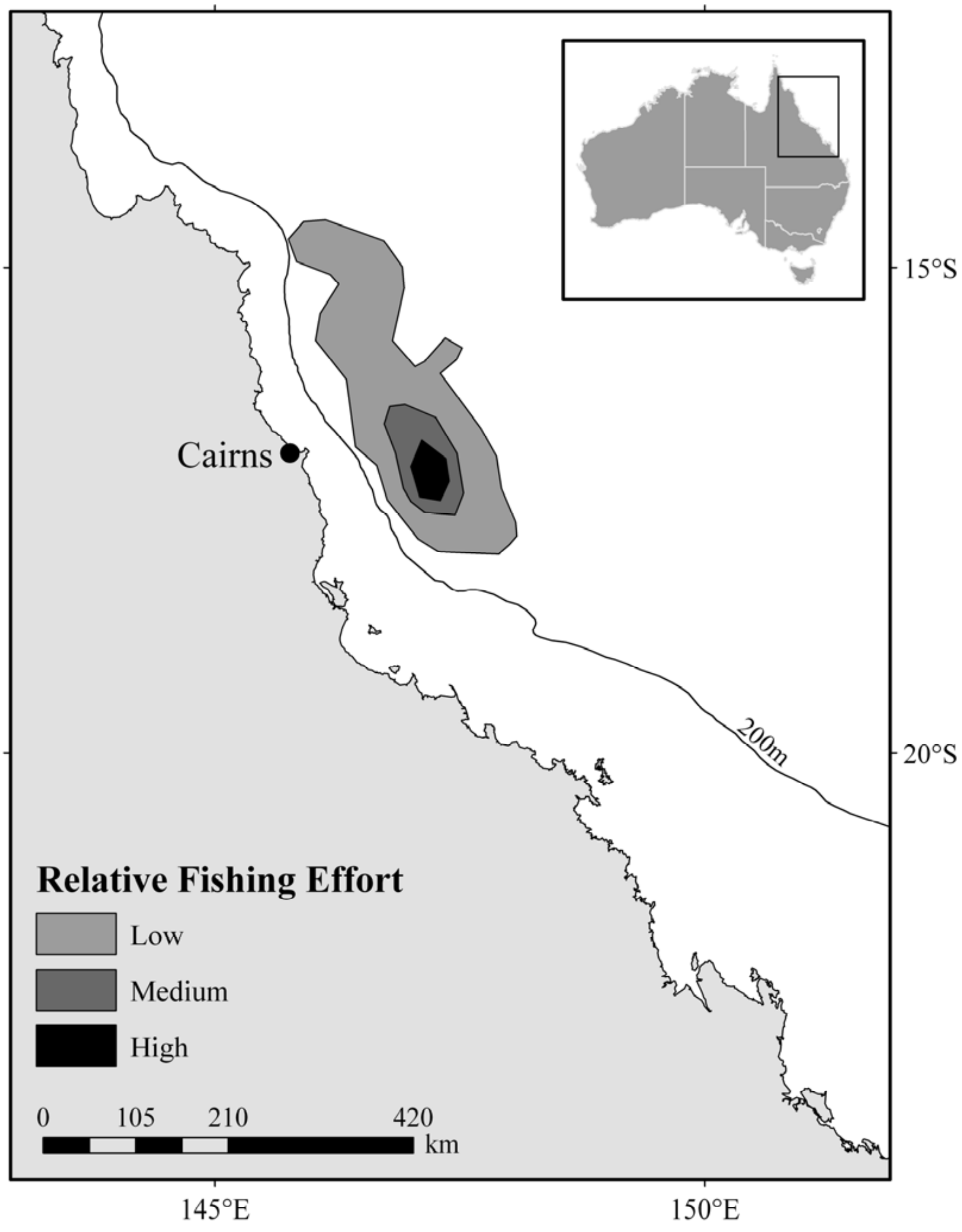
Cairns
200m
15°S
20°S
145°E
150°E
Relative Fishing Effort
Low
Medium
High
0
105
210
420
km

Fig. 1

Fig. 2

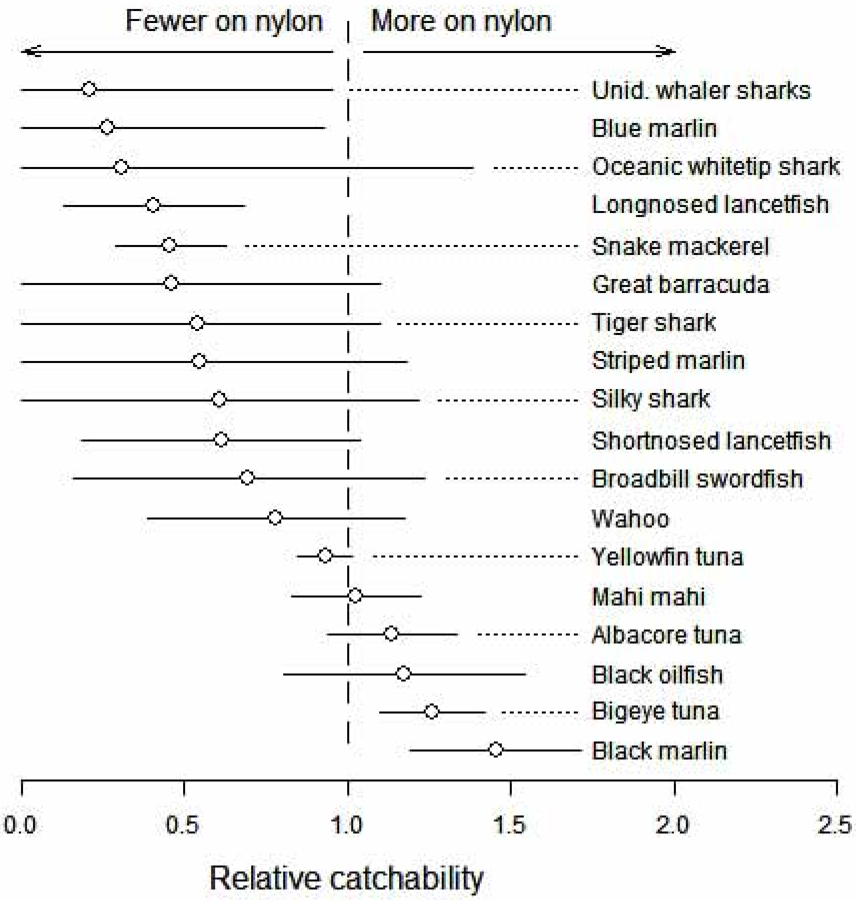
Fewer on nylon
More on nylon
Unid. whaler sharks
Blue marlin
Oceanic whitetip shark
Longnosed lancetfish
Snake mackerel
Great barracuda
Tiger shark
Striped marlin
Silky shark
Shortnosed lancetfish
Broadbill swordfish
Wahoo
Yellowfin tuna
Mahi mahi
Albacore tuna
Black oilfish
Bigeye tuna
Black marlin
0.0
0.5
1.0
1.5
2.0
2.5
Relative catchability

Fig.3