Abandoned, Lost or Otherwise Discarded Fishing Gear (ALDFG) in Tuna Pole-and-Line Fisheries

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Abstract

The fishing industry is recognized as one of the primary sources of at-sea marine litter, largely through its contributions via abandoned, lost or otherwise discarded fishing gear (ALDFG). Individual fleet's contributions to ALDFG vary significantly across this global industry. While much information is available for some fisheries, the rate of ALDFG remains poorly known for many techniques. In this study, we used data collected by fisheries observers onboard pole-and-line fishing vessels in the Azores (Atlantic Ocean) and the Maldives (Indian Ocean) to provide an accurate and representative estimate of ALDFG for this gear. Our analysis of 993 fishing events demonstrated ALDFG contributions much lower than have been recorded for any other commercial tuna fishing gear. Overall, we found that an angler loses some monofilament line in 1.4% (± 0.2) of fishing events. This informs that for every thousand tonnes of tuna harvested using this fishing technique, 0.3 kg of nylon is entering the marine environment. Globally, we estimate that all pole-and-line fisheries together contribute to 96 kg $\pm$ 42.6 kg of ALDFG per year. These results further evidence the low environmental impact of this traditional fishing practice, as well as the need for other methods to convert to less damaging gears.

Introduction

Fisheries are considered to be a principal source of sea-based litter globally, with 640,000 mt of fishing gear estimated to be lost or abandoned in the oceans annually¹. Abandoned, lost or otherwise discarded fishing gear (ALDFG¹) are therefore an important component of the debris floating at the ocean surface², stranded on coastlines³ and accumulating on the seafloor⁴. Over recent decades, fishing effort intensification and ongoing increases in the use of synthetic materials to construct fishing gears have been the main factors responsible for increasing amounts of ALDFG in our oceans worldwide¹.

Some of the greatest ecosystem impacts caused by ALDFG result from their continuous capture and entanglement of target and non-target species, sometimes for several years after loss, through a phenomenon known as "ghost fishing" ^{5,6}. This impact is unsurprising when passive fishing gears (e.g., nets, traps, longlines) have been purposely designed to withstand long periods in harsh marine environments (minimizing repair or replacement costs) while continuing to capture fish without requiring real time fisher oversight.

Charismatic megafauna such as marine mammals, seabirds, sharks and sea turtles, are regular victims of ghost fishing, which is recognized as a major source of mortality in some populations^{7,8,9}. These animals typically become entangled by ALDFG when pursuing prey species that associate with lost fishing gear such as drifting fish aggregating devices (FADs) ^{7,9,10,11}, when interacting with ALDFG out of curiosity, when seeking shelter amongst ALDFG, or when using ALDFG items as nesting material¹². Beyond direct entanglements of megafauna, ALDFG can also cause significant direct damage to marine habitats, including sensitive habitats such coral reefs, sea-grass meadows and mangroves that serve as nurseries for many marine species. As an example from the western central Pacific, tuna purse seine

fleets deploy between 44,700 and 64,900 drifting FADs annually with about 86% of these being lost or abandoned. Most of those devices (92%) are found on reefs, impacting multiple sensitive habitats during stranding and causing long term or permanent damages¹³. With the majority of these abandoned devices eventually sinking to the seafloor, their damage to deeper benthic marine ecosystems remains yet to be assessed and effectively quantified. In addition, ALDFG can represent navigational hazards or other threats to safety at sea, with the capacity to cause significant socio-economic costs when they damage boats and/or other still in use fishing equipment^{14,15}. As a result, there have been growing calls for large and increasingly common ALDFG components, such as drifting FADs, to have radar reflectors and navigational lights attached¹⁶.

Fisheries are operating across different environmental settings, from shallow waters to the open and deep ocean, using a wide variety of techniques to catch their target species. Fishermen lose, abandon or discard their fishing gears for various intentional and unintentional reasons¹⁷, and the rates of such losses are highly variable between gear types and regions¹⁸. Preventing the loss of fishing gear has become a global concern over the past decades¹⁴.

In order to appropriately inform fisheries management on the need to reduce ALDFG, and additional stock mortalities caused by ghost fishing, data on the contribution of gear loss by different fishing techniques is increasingly needed. A recent meta-analysis of ALDFG highlighted the significant knowledge gaps on the rate of gear loss for many fishing gear types¹⁸. Also a recent legal analysis of the 'loss' and 'abandonment' of FADs shows how complex the issues are and suggests some instances where the use of these devices constitutes illegal, unreported and unregulated (IUU) fishing among international legislations¹⁹. The use of drifting FADs is also coming under increasing scrutiny for potentially contravening international marine pollution legislations including MARPOL V and the London Convention²⁰.

Tunas are among the most valuable fishes on the planet, being exploited across the globe with a variety of fishing techniques. Today, purse seine net fisheries using drifting FADs are landing the majority of tuna harvests worldwide, followed by pelagic longlines, which together with gillnets represent important contributors to ALDFG²¹. In the 1950s, pole-and-line fishing was responsible for the highest proportion of tuna landings globally, but nowadays it represents less than 10% of global tuna catches²². Pole-and-line is a fishing technique used to harvest various species of tunas, which has recently been popularised as a one-by-one fishing method together with handline, troll and rod-and-line fishing gears. One-by-one fishing methods are recognized as being more environmentally friendly than other fishing gears used to commercially harvest tunas, predominantly because they are active fishing techniques that catch one fish at a time, yielding low bycatch and discard rates²³ while also reducing the likelihood of overfishing, habitat damage or gear loss. Especially when compared to "passive gears" that are deployed and left at sea for later retrieval. Pole-and-line is essentially an artisanal fishing technique mainly performed in Maldives, Japan and Indonesia with landings from each of these nations varying between 76,000 and 100,000 tons per year²². Other pole-and-line fleets in Brazil, Senegal and Lakshadweep (India) typically

catch between 13,500 and 25,000 tons of tuna per year, while those in the Canary Islands (Spain), West coast of USA, Azores (Portugal), Basque country and Cantabria (Spain), Ghana, South Africa, Namibia, Madeira (Portugal), Salomon Islands and Venezuela with catches between 1,000 and 8,000 tons per year. The lowest pole-and-line catches, being up to 1,000 tons per year, are typically reported from places such as Baja California (Mexico), Ecuador, Hawaii (USA), Palau, St Helena (UK Overseas Territory), Basque country (France) and Cape Verde²².

Although pole-and-line fisheries elicit many positive social and environmental attributes when compared to purse seining, gillnetting and longlining, the proportion of the tuna catch taken by pole-and-line has been decreasing for many years^{22,24}. As a result, there has been substantial effort to demonstrate the assets of pole-and-line tuna fishing by different NGOs (e.g. International Pole & Line Foundation (IPNLF), WWF, Greenpeace) but also by government fisheries agencies, and private companies. While there have been different quantitative assessments on the environmental ecological footprint of pole-and-line (including bycatch rates²³, discards²³ and on the use of baitfish²⁵, there is little detailed information on gear loss rate and ALDFG in pole-and-line fisheries. Based on an old earlier account of gear loss in pole-and-line fisheries²⁶, Richardson et al. (2019) predicted a rate of line loss of 65% for these fisheries, which would represent the highest for all line fisheries worldwide. However, this outcome stood in stark contrast to previous qualitative observations which suggested that gear loss from pole-and-line fishing to be an extremely rare occurrence²³.

Considering the absence of publicly available data and publications assessing gear loss among pole-and-line fisheries, the objective of this study was therefore to use observer data across 2019 to provide a detailed and robust assessment of the quantities of gear loss associated with this fishing technique. This study utilises data collected by trained fisheries observers in two case study pole-and-line fleets, the Azores and Maldives, to quantify the frequency and amount of lost fishing gear (ALDFG) resulting from both of these fisheries, operating under different circumstances, and to ultimately provide an accurate estimate of gear loss by pole-and-line fisheries at the global level.

Materials And Methods

Study areas and pole-and-line fisheries

We focused our assessment on two distinct pole-and-line fleets for which all operational aspects are well described^{23,27}. Both fleets have well-established observer programs^{23,27} which are using comparable data collection methods and simultaneously offering two distinct ecological and social settings.

The Azores

The Azores is an oceanic archipelago located in the NE Atlantic (Figure 1). These nine Portuguese islands are inhabited by a relatively small population of 242,846 people in 2019. The economy is mainly supported by agriculture (dairy farming), tourism and fisheries. Tuna fishing, using exclusively pole-and-

line (Figure 2) and hand-line techniques with livebait, is the second most important fishery in the region. In some years it represents more than half of the total seafood landed in the EEZ (~1 million km²)²⁸. The Azorean pole-and-line fleet is classified as an artisanal fishery using small to medium sized vessels (up to 30 m long) and catching mostly skipjack (*Katsuwonus pelamis*) and bigeye (*Thunnus obesus*) tunas; with albacore (*Thunnus alalunga*) and yellowfin (*Thunnus albacares*) tunas being caught in much smaller quantities. The occurrence of tuna in the Azores is highly seasonal, with bigeye tuna being more abundant from May to July, and skipjack tuna from July onwards. As a result, tuna fisheries operate mainly from May to November.

The Maldives

As an archipelagic nation located in the central Indian Ocean and an exclusive economic zone (EEZ) covering an area of over 900 000 km² (3 000 times its land mass), the Maldives has a long and ongoing history of being heavily dependent on its marine resources²⁹. The pole-and-line tuna fishery is both the oldest and still the largest and primary fishery in the Maldives, and has been a mainstay in the country for centuries^{30,31,32}. As a result, the tuna sector is one of the most important sectors of the national economy, and it provides about 85 percent of the total protein consumed by Maldivians³³. The target species of this pole-and-line fishery is skipjack tuna (*Katsuwonus pelamis*), with yellowfin tuna (*Thunnus albacares*) caught as a secondary species due to their conspecific schooling behaviour. The Maldives is the third largest producer of pole-and-line tuna in the world, behind Japan and Indonesia. This fishery can land over 68 100 tonnes of skipjack per year, representing over one-fifth of the total global supply of pole-and-line caught tuna, and 18–20 percent of the total catch of skipjack from the Indian Ocean^{34,25}. Finally, and crucially for the domestic market, the pole-and-line fishery also currently accounts for 56–76 percent of all the tuna caught in the Maldives³⁵.

Data collection

Data on gear loss in both locations were collected by trained fisheries observers onboard pole-and-line vessels. In the Azores, the fisheries observers are managed under the Azores Fisheries Observer Program (POPA, Programa de Observação para as Pescas dos Açores²⁷) while in the Maldives observers under the national observer program supported and managed by the International Pole and Line Foundation (IPNLF). In the Azores, we used data collected between May and September 2019, while in the Maldives we used data from May to November 2019 along with eight fishing events in February 2020.

Observers at both locations followed a similar and comparable protocol to record the loss of fishing gear components, and to record other relevant operational and catch data for both baitfish and tuna fishing events. For each baitfish fishing event, the observers recorded the number of net deployments for livebait and any losses of gear components, while also recording total weight of the baitfish catch and its species composition. Out of the 172 observed events targeting baitfish, only a single scoop net was lost. Therefore, ALDFG production in baitfish catch was considered as insignificant and not included in the results.

For each pole-and-line tuna fishing event (defined as periods of active fishing separated by at least 10 minutes), observers recorded the geographic position of the event, its duration, number of active fishers, type of poles (carbon vs. bamboo), total tuna catch (number of individuals, species and average size/weight). School association was also recorded in the following six categories: anchored FAD (aFAD), drifting FAD (dFAD), floating debris, underneath the fishing vessel, seamount, or free school. Schools were defined as associated to a FAD when the start of the fishing event was located within 1 nautical mile of the FAD (or other floating object); while for seamounts, the schools were defined as being associated when fishing initiated within 5 nautical miles from the seamount²³.

At the end of each fishing event, the observers recorded the number of all gear components that were lost during that particular fishing event. The gear components included poles (bamboo or carbon), gaffs, lures and lines. We did not include the loss of hooks due to their small sizes and limited environmental implications. When monofilament nylon leaders were lost, the observers estimated the length (meters) of each fragment that was lost. Total length of lost leaders were converted into mass using nylon runnage metrics for the 1.2 mm fishing line (<http://www.fao.org/3/ah827e/AH827E03.htm>) which is typically used by Azorean and Maldivian fishermen.

Data analysis

We computed three metrics of gear loss rates: (a) the number (and weight) of line losses recorded per tonne of tuna (line loss: tuna catch ratio); (b) the percentage of gear lost (proportion of lost gear in relation to the total number of gear units used per fishing event) and (c) the number (and weight in the case of lines) of units of gear lost per event (count). Considering that a varying number of anglers are fishing during each event, the rate of gear loss per event was normalized per number of anglers actively fishing per event. To investigate whether the amount of gear loss was influenced by the species composition of the catch, each pole-and-line event was classified depending upon its catch composition; being “single species” when the catch was composed by a unique species and “mixed species” when more than one species was caught during the event. The rationale behind such grouping is that it is expected that when fishers are gearing up for a particular species, the probability of gear loss is higher if another larger species joins the feeding school during the same fishing event.

We used general additive models (GAM) to determine the influence of four different predictor variables on the probability of gear loss per event: (1) average length of the tuna caught; (2) the type of school association; (3) the species composition; (4) the fleet (Azores vs. Maldives) and (5) the total tuna catch (kg). Both the length of tuna and total catch were included in the model as a smooth term. School association was included as a factor and grouped into; (1) free schools, (2) associated (i.e. anchored FAD (aFAD), seamounts; drifting FAD (dFAD), or when tuna have aggregated around the boat). The inclusion of association variables followed the assumption that schools that are associated with floating objects are more frequently composed of different species compared to free schools that are generally composed of a single species²³. Similarly, the model also included a factor variable which distinguished the fishing event from being composed by single species or mixed. Finally, a case study approach was included as a

factor to evaluate potential differences between the assessed fleets (Maldives and Azores). Finally, the number of anglers was included as an offset in the model in order to account for differences in fishing effort. The model was fitted using a negative binomial distribution due to the large amount of zeros. Model assumptions were evaluated through the inspection of diagnostic plots. All analyses were performed using R statistical software³⁶ and GAM models were developed using the mgcv library³⁷.

Based on the observed average gear loss to tuna catch ratio, we estimated total line loss for both fleets using total landed catch for year 2019 (3,301 t for the Azores, 105,640 t in Maldives). Based on an estimated global tuna catch by pole-and-line fishing of 291.2 thousand tons in 2018²⁴, we further extrapolated line loss for this fishing technique at the global level.

Table 1

Overview of the data collected by the fisheries observers onboard pole-and-line fishing vessels in the Azores and Maldives.

		Azores	Maldives	Total
	Period covered	May-Sept 2019	May 2019-Feb 2020	
	Total number of observers	5	2	7
	Total number of unique vessels covered	15	13	28
Pole and line	Total number of fishing events observed	837	156	993
	Total number of lines deployed	6344	1904	8248
	Average number of anglers per event ($\pm$ SD)	8 ± 3	12 ± 3	8 ± 4
	Total observed catch (t)	875	146	1021
	<i>Katsuwonus pelamis</i>	495	119	615
	<i>Thunnus alalunga</i>	213	-	213
	<i>Thunnus albacares</i>	1	27	28
	<i>Thunnus obesus</i>	165	-	165
	Average catch (t) per event ($\pm$ SD)	1.0 ± 2.5	0.9 ± 1.3	1.0 ± 2.3
	Lost gear			
	Total number of lost monofilament segments	58	40	98
	Total length of lost monofilament segments	47.7	53.5	101.2
	Total number of lost bamboo poles	7	0	7
	Total number of lost carbon poles	1	0	1
	Total number of lost lures	2	0	0
	Total number of lost gaffs	3	0	3
Baitfish	Total number of events observed	85	87	172
	Total observed catch (t)	29	22	51
	Average catch (t) per event ($\pm$ SD)	0.3 ± 0.3	0.3 ± 0.2	0.3 ± 0.3

Results

Across both national fleets, fisheries observers monitored a total of 993 pole-and-line fishing events, corresponding to a total catch of 1,021 tonnes of tunas, mostly skipjack tuna (60.2% of total), across both regions. In the Azores, skipjack tuna represented 56.6% of the total observed catch by weight, while the remaining catch was composed of albacore (24.3%) and bigeye tuna (18.9%). In the Maldives skipjack tuna composed 81.5% of the observed catch, while the rest was yellowfin tuna (18.5%).

Across both fleets, gear loss was registered in 83 pole-and-line fishing events, indicating that gear loss occurred in 8.4% of the total number of pole-and-line events monitored. A total of 111 gear components were lost during those 83 events, the majority being leaders, representing 90% of the total number of items lost (Table 1). Considering that an average of 8 anglers (± 4) was operating per fishing event, the average rate of gear loss was estimated at 1.4% (± 0.2) per angler. The average loss of gear components was 0.1 items (± 0.02) per fishing event. The average length of lost line per event was estimated to be 0.1 meters (± 0.02), with a corresponding mass of 0.13 g (± 0.02).

Results from the GAM suggested a significantly higher probability of gear loss for Maldives fleets compared to the Azores (Figure 3). Furthermore, the model revealed that the probability of gear loss was higher for fishing events involving multiple species compared to fishing events composed of single species (Figure 3). Increasing tuna size and total catch also resulted in an increase in gear loss (Figure 3). The GAM also highlighted that the gear loss for fishing events associated with drifting or fixed features was significantly higher than that of free schools (Figure 3).

Overall, we found that for every 1000 tonnes of tuna caught with pole-and-line, 333 g (± 146) of nylon are being lost in the oceans. This metric was slightly different between the two fleets; 309 g (± 174) for the Azores and 454 g (± 99) for Maldives. Based on total tuna catches for 2019 of both fleets (3,301 and 105,640 t, respectively), the entire pole-and-line fleets in the Azores and Maldives lost 1.01 kg (± 0.57) and 48.01 kg (± 10.46) of monofilament lines respectively. This corresponds to lengths of 0.76 ± 0.43 and 36.01 ± 7.85 km of lost monofilament line during 2019. The resultant global estimate that pole-and-line fleets produce is 96 kg (± 42.6) of plastic ALDFG per year, mainly as monofilament lines.

Discussion

The results of this study suggest very low gear loss frequency and volumes resulting from pole-and-line fishing for tunas. On average, 1.4% (± 0.2) of the lines used are lost during pole-and-lines fishing events, relating to 0.1 meters (± 0.02) of monofilament line. The ecological and economic impacts of ALDFG stemming from this gear type are limited, especially when compared to other types of fishing techniques (such as gillnets or pot gears) for which loss events generally represent losing the entire gear. Overall, we estimate that pole-and-line fisheries across the globe are losing a total of 96 kg of monofilament lines per year, consisting of small lengths of lost line that pose a negligible risk of causing entanglement mortalities and other ghost fishing. While the extrapolation of our data to the world's pole-and-line fleet

has quite an associated level of uncertainty, we acknowledge that regional variation exists, it nonetheless provides a research informed preliminary measure of the magnitude of gear loss resulting from this gear type globally, which can be refined in the future. Regardless of uncertainty related to this metric, the potential ALDFG contribution of pole & line fishing is clearly not comparable to losses by other tuna fishing gears that contribute many tons of plastic ALDFG to the oceans each year. As such, it is fair to assume that the contribution of gear loss by pole-and-line fishing is at the lowest end of the spectrum when compared to other fisheries, including longlining which have a higher gear loss rate (19-22%) and are also known to lose longer fragments of monofilament when partial losses occur¹⁸. While lost monofilament lines can be responsible for entanglement of marine organisms³⁸, the average length of lost gear in pole-and-line fishing gear was 0.1 meters, which represent a very limited potential for causing entanglements and ghost fishing.

Our results contrast significantly with the meta-analysis by Richardson et al. (2019), which predicted that proportions of gear losses for pole-and-line was between 62 and 69%, the highest among “hooks and lines” fisheries. While their calculations were based on a general study from the early 1990s²⁶, our assessment is centred on a dataset covering 993 pole-and-line events monitored by trained fisheries observers across two pole-and-line fleets within distinct environmental settings. Therefore, we are confident that our results are trustworthy, reliable and representative of this fishing technique. Detailed collection of ALDFG data by fisheries observers is the most reliable method to quantify gear loss, a method that should be applied and more transparently reported across all future fishing activities.

The importance of gear loss is challenging to compare between fishing techniques. The most common metric used to report gear loss is expressed as a proportion of deployed gear¹⁸. While this can be a valuable metric, it often does not provide a useful comparison of the contributions of ALDFG between different gear types, because it fails to appropriately account for the actual size of the lost equipment, and therefore the volumetric contribution that each loss event actually represents. We suggest that reporting the ALDFG quantity (in weight and number) as totals, and as a proportion of achieved total fish catch. This approach will offer more suitable metrics of gear loss that are also more directly comparable between different fishing gears and fleets. We believe the ultimate aim of such comparisons should be to help inform the minimisation of total and relative (per tonne of catch) ALDFG contributions by fisheries both between and within gear type categories.

Our data also provide relevant information on the causes of gear loss in pole-and-line fisheries. The most important factors influencing gear loss rate were the type of tuna school being fished (associated with floating objects or not), and its species composition. We found that free schools were typically monospecific composed of single species, and resulted in a lower gear loss compared to mixed schools, where smaller species (e.g. skipjack tuna) are mixed with larger species (bigeye tunas in the Azores or yellowfin tunas in the Maldives). Accordingly, the probability of gear loss also unsurprisingly increased with increasing fish size.

This study further demonstrates the sustainability benefits of pole-and-line fisheries. Along with being a selective fishing technique with minimal bycatch and limited impacts to the broader marine ecosystem, the overall contribution of pole-and-line fisheries towards ALDFG is also a minor fraction of that seen from its counterpart tuna fleets using more damaging gears. Similar studies should be rigorously performed across all different fishing techniques and regions, using trained observers and comparable techniques, to suitably quantify the environmental footprint of various fisheries and their gear types.

Declarations

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Author Contributions Statement

CKP, MM, ZE, SA designed the study. IS, IN, collected the data, CKP, SA, YR, JP, IS, IN analysed the data. CKP, MM, ZE, SA, ZE, RB wrote the manuscript. All authors revised the manuscript and gave final approval for publication.

Competing interests

We have no competing interests.

Ethics

The present work did not involve any contact or experimentation with the animals.

Data Availability

The authors confirm that all data underlying the findings will be fully available without restriction. Data from the beach surveys are being uploaded in the public repository Pangaea.

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Figures

Figure 1

Location of both case study areas where observers onboard pole-and-line tuna vessels collected data on gear loss.

Figure 2

Schematic representation of pole-and-line fishing (©Les Gallagher).

Figure 3

Generalized additive model (GAM) derived effects of the investigated parameters (average length of tunas, total catch, school type, catch composition and location) on the probability of gear loss during

pole-and-line fishing events in the Azores and Maldives. Dashed lines indicate 95% confidence intervals.