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Review article

Ghost Fishing Gear: An Overlooked Threat in Marine Debris Management

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ABSTRACT
Abandoned, lost, and discarded fishing gear (ALDFG) presents significant ecological and socioeconomic challenges. One of the most critical impacts of ALDFG is its capacity to "ghost fish," which is influenced by the type of gear (abandoned, discarded, or lost) and the local environment, particularly regarding currents, depth, and location. This phenomenon jeopardises fishers' sustainability and economic viability, as a portion of their catch is effectively lost. The use of synthetic materials in ghost gear exacerbates issues such as marine life entanglement, mortality, habitat degradation, and microplastic pollution. Ghost gear threatens vital marine ecosystems, including coral reefs, seagrass beds, and benthic algae. This issue has been recognised and discussed by the International Maritime Organization (IMO), the United Nations Environment Programme (UNEP), the Food and Agriculture Organization (FAO), and other international bodies, all of which consider marine debris, including ALDFG, to be a pressing concern. Various mitigation and prevention strategies have been proposed, such as gear marking, biodegradable net materials, financial incentives, enhanced port facilities, and advanced technologies. However, existing measures have proven insufficient to address the challenges ghost gear poses fully. There is a pressing need for comprehensive policies, standards, and management strategies to mitigate the harmful effects of ALDFG. In light of this, it is essential to tackle the problem of abandoned and lost fishing gear collectively and urgently at national, regional, and local levels to ensure the productivity of our oceans and seas for current and future generations.

Key words: ALDFG, Pollution, Marine litter, Sustainability

INTRODUCTION

For centuries, fishing gear has been lost, abandoned, or discarded in our seas and oceans. Recently, with fishing activities expanding offshore and into deep-sea environments, the impact of abandoned, lost, or discarded fishing gear (ALDFG) has garnered increased attention (Anonymous 2021). Nearly 6.4 million tonnes of fishing gear end up in the oceans annually (Anonymous 2005). According to a UNEP publication, ALDFG constitutes 70% of all ocean macro-plastic marine litter by volume (Anonymous 2016). This type of litter, also known as ghost gear, is particularly harmful to marine animals and ecosystems (Wilcox et al. 2016). Understanding the effects of this debris on marine fauna and ocean health has become a critical environmental priority, especially for threatened and endangered species (Drinkwin 2022). The issue of ALDFG has been raised multiple times at the United Nations General Assembly (UNGA) because it is a part of the broader problem of marine pollution, which falls under the jurisdiction of the International Maritime Organization (IMO). The International Convention for the Prevention of Pollution from Ships (MARPOL) is included in the IMO's mandate (Anonymous 2006). The United Nations Environment Programme (UNEP) addresses ALDFG as part of its larger Global Initiative on Marine Litter (Anonymous 2005). The Food and Agriculture

Organization's Committee of Fisheries (FAO COFI) has also discussed the issue, recognising marine debris and ALDFG as major concerns. The FAO Code of Conduct for Responsible Fisheries (CCRF) was established to promote responsible fishing practices and encourage states to address the impact of fishing on the marine environment. MARPOL requirements are specifically outlined in Article 8.7 of the CCRF. The European Commission (EC) Communication on Promoting More Environmentally Friendly Fishing Methods (Anonymous 2004) acknowledges the need to address ghost fishing as part of a larger effort to combat unwanted catches. Macfadyen et al. (2009) specify requirements for marking passive gear and beam trawls in EC waters. Various studies have shown that ghost fishing poses significant ecological threats to marine species, exacerbating the impacts of anthropogenic debris. Additionally, it can hinder safe navigation, cause damage to beaches and reefs, and lead to economic losses for fisheries and other marine-dependent industries worldwide. As this problem persists globally, the FAO has developed Voluntary Guidelines for the Marking of Fishing Gear (VGMFG), which defines ALDFG as (Anonymous 2019): *Abandoned fishing gear*: Gear that the operator/owner has control over, which could be retrieved but is intentionally left at sea due to unforeseen circumstances; *Lost fishing gear*: Gear the owner/operator has inadvertently lost control of and cannot locate or retrieve; *Discarded fishing gear*: Gear that has been released into the sea without any attempt by the owner/operator to control or recover it (Drinkwin 2022). Several countries estimate the annual loss of fishing gear, including 38,535 tonnes of gear lost in the Republic of Korea, 10,000 gillnets lost in the Baltic Sea, and over 12,000 crab pots lost in the Salish Sea in the United States (Szulc et al. 2015). This loss contributes to the increasing amount of plastic entering our oceans yearly. Two recent studies have attempted to estimate the global rate of fishing gear loss. Richardson et al. (2019) reported that globally, 5.7% of fishing nets, 8.6% of traps and pots, and 29% of fishing lines are lost, abandoned, or discarded into the environment. Annual losses were estimated at 3-7 net panels per boat, equating to 38,535 tonnes of nets per region and 7-50% of traps and pots (Lively and Good 2018).

Extent of Marine Litter and ALDFG

Marine litter can be found at sea and on land, with fishing being just one potential source (Table 1). Currently, no comprehensive figure is estimating ALDFG's contribution to marine litter. Several estimates suggest that land-based sources are the primary contributors to marine debris in coastal areas, while merchant shipping is the primary sea-based source of litter (Macfadyen et al. 2009).

Impacts of ALDFG

(I) Continued Capture of Target and Non-Target Species

The condition of fishing gear at the time of failure is crucial. For example, lost nets may continue to operate at maximum fishing efficiency, leading to significant ghost fishing catches. If they are well anchored, these nets can take a long time to collapse. Conversely, some abandoned or lost gear may collapse immediately unless snagged on rocks, coral, or wrecks, resulting in lower initial fishing efficiency.

Table 1. Source of marine litter

Sea based	Land-based
Merchant shipping, ferries and cruise ships	Waste from municipal landfills
Fishing vessels and fish farming	A wider context of waste management
Naval vessels, research ships & pleasure craft	Discharge of untreated municipal sewerage & storm water
Offshore oil and gas platforms	River transport
	Tourism and beach users' debris
	Industrial facilities
	Deforestation

Source: Anonymous (2005)

Discarded gear or its parts typically have reduced fishing efficiency. Fish that die in these nets can attract scavengers, which can become entangled, leading to a cyclical catch pattern by the fishing gear.

(II) Interactions with Threatened/Endangered Species

Abandoned, lost, or discarded fishing gear (ALDFG), especially when made from persistent synthetic materials, can pose serious risks to marine fauna, including seabirds, turtles, seals, and cetaceans, primarily through entanglement or ingestion. Entanglement is generally considered a more significant cause of death than ingestion. The world's smallest porpoise, the Vaquita, is nearing extinction due to entanglements with lost gill nets (Crosta et al. 2018).

(III) Physical Impacts on the Benthic Environment

Gillnets may have minimal impact on benthic fauna and bottom substrates. However, strong currents and winds can drag them along the seabed during retrieval, potentially harming delicate organisms such as sponges and corals. Some localised impacts may occur in deeper water areas (Grabowski et al. 2014). The potential physical impacts of ALDF traps vary depending on the habitat type and its occurrence. Crab and lobster traps affect sandy and muddy bottom habitats less than sensitive environments like seagrass beds or areas with emergent fauna such as corals and sponges. ALD hook-and-line fishing, a standard commercial and recreational method, has low capture efficiency but can potentially entangle marine animals and habitats, particularly in complex inshore environments like reef structures (Macfadyen et al. 2009).

(IV) Distribution of Marine and Terrestrial Litter

According to the UNEP Global Programme of Action, up to 70% of all marine litter entering the world's oceans sinks to the bottom, accumulating on the seabed in shallow coastal areas and much more profound parts of the ocean. This accumulation of litter can suffocate benthic communities on soft and hard seabed substrates (Nama and Prusty 2021).

(V) Introduction of Synthetic Material into the Marine Food Web

Modern plastics can persist in the marine environment for up to 600 years (Butterworth 2016), depending on water conditions, ultraviolet light exposure, and physical abrasion. The effects of microscopic plastic fragments and fibres generated from the degradation of larger items remain largely unknown. Studies have shown that microplastics are particularly abundant in beaches, estuarine, and subtidal sediments, and their accumulation may contribute to toxic chemicals in the marine environment (Thompson et al. 2004).

(VI) Impact on Major Marine Habitats

Ghost gear adversely affects sensitive habitats, including seagrass beds, coral reefs, macroalgae, and mangroves, which serve as nurseries for many commercially important species. It can disrupt fishing operations, damage boats, and contaminate beaches and commercial harbors. Additionally, ghost gear detracts from the natural beauty of aquatic habitats and can significantly impact the tourism industry. Lead pollution is also associated with sink lines used in gillnets (Nama and Prusty 2021).

(VII) Socioeconomic Impacts

ALDFG entails significant economic and social costs. The navigational risks ALDFG poses create substantial socioeconomic challenges for marine users (Gallagher et al. 2023). Due to a lack of literature on this topic and the inherent difficulty in quantifying and comparing social costs, it is challenging to assess or compare the extent of various socioeconomic impacts. Efforts to estimate the costs of ALDFG compliance, rescue operations, and research have not yet been adequately undertaken (Baske and Adam 2019).

Causes of Ghost Fishing

It is important to acknowledge that some degree of ALDFG is unavoidable due to the environment in which fishing occurs and the technology used. The causes of ALDFG can vary between different fisheries and within the same fishery. Fishing gear can be a) abandoned, b) lost, or c) discarded, indicating that some ALDFG is intentional while others are unintentional. Consequently, the methods used to reduce ALDFG may need to be diverse (Smith 2001). Direct causes of ALDFG stem from various pressures on fishers. For instance, enforcement pressure may lead illegal fishers to abandon gear to hide their activities, contributing significantly to ALDFG in the sea. Operational pressures and inclement weather conditions can make it more likely for gear to be left behind or discarded.

Additionally, spatial pressures can lead to the loss or damage of gear due to conflicts with other fishing operations. Economic pressures also play a role, often forcing fishers to dispose of unwanted gear at sea rather than onshore. The lack of onshore waste disposal facilities, along with issues of accessibility and cost, are contributing factors. Other causes of ALDFG include snagging on reefs, rocks, and other underwater obstructions, interactions with marine animals, long soak times, fishing in deep habitats, and deploying more gear than can be regularly retrieved. The type of fishing gear used is closely related to the risk of gear loss. Gear that makes contact with the bottom and gear not actively managed by fishers is more likely to be lost. Trawl gear, traps and pots, and gillnets have all been identified as having a high risk of being lost (Gilardi et al. 2020, Gilman et al. 2021).

Impacts of ghost fishing on Indian fisheries

Research indicates that gear loss in gillnet fisheries in India is significant, leading to considerable financial losses for fishers (Thomas et al. 2020). Marine debris assessments along the coast of Kerala reveal that fishing-related items make up 39.8% of the debris found, with these items being four times more common in areas with higher fishing activity (Daniel et al. 2019). Experimental trawl and net fishing conducted along the Kerala coast further identified large quantities of abandoned, lost, or discarded fishing gear (ALDFG) (Kripa et al. 2016). Between 2018 and 2019, volunteer divers from the Olive Ridley Project removed nets from Indian waters (Anonymous 2017). Diver surveys in the Gulf of Mannar showed that ALDFG constituted 43% of marine debris, contributing to coral damage (Edward et al. 2020). A study of 17 beaches in the Hooghly Estuary found that fishing-related litter accounted for 17% of the total weight of marine debris discovered (Mugilarasan et al. 2021). Additionally, a WWF India project that surveyed hundreds of coastal fishermen revealed that some reported losing as many as ten pieces of netting each year due to various factors contributing to ALDFG (Anonymous 2020b). Stelfox (2019) modelled the sources of abandoned nets impacting sea turtles in the Maldives, concluding that some of these nets originate from near the Indian and Sri Lankan shorelines, suggesting that coastal and artisanal fishing could be a contributing factor. Indian fisheries were also highlighted as a potential source of ALDFG found off the coast of northern Australia's Gulf of Carpentaria (Gunn et al. 2010).

Methods to Mitigate Ghost Fishing

Strategies for reducing the incidence of abandoned, lost, and discarded fishing gear (ALDFG) can be categorised into preventative measures and remedial actions. Preventative methods are typically more cost-effective than remedial measures. Many of these techniques also serve broader fisheries management goals, such as regulating fishing mortality rates of target species and reducing bycatch of vulnerable species in active gear. Their implementation plays an essential role in mitigating ALDFG and ghost fishing (Table 2).

Best Practices Framework for the Management of Fishing Gear

The Global Ghost Gear Initiative (GGGI) is a collaborative effort that unites seafood stakeholders in addressing ALDFG throughout the seafood supply chain. The GGGI has published a Best Practices Framework for the Management of Fishing Gear (BPF), which outlines management strategies to prevent harm caused by ALDFG (Anonymous 2020a).

Importance of reporting and retrieval of ghost gear

Fishers' actions play a crucial role in reducing the occurrence of lost fishing gear. The Best Practices Framework (BPF) and the Volunteer Gear Management Fishing Group (VGMFG) offer specific options and recommendations for fisheries management aimed at preventing and minimising the harm caused by abandoned, lost, or discarded fishing gear (ALDFG). Fisheries managers can also utilise many of these best practices for purposes beyond just preventing gear loss. There are 16 fisheries management strategies available that can help prevent and mitigate the adverse effects of ALDFG. While only six of these methods explicitly address ALDFG, others - such as spatiotemporal restrictions - serve various purposes and help reduce gear loss (Gilman 2015). Reporting lost gear is essential for

Table 2. Preventative methods to avoid and minimize fishing gear from becoming abandoned, lost and discarded and remedial methods

Methods	Description
Preventive methods	
Gear marking to identify ownership and increase visibility	In recent years, international agreements have been developed for marking fishing gear to enable identification of the owner or user, as well as an incentive to report abandoned and lost gear (Anonymous 2011). There is also a need to increase the visibility of passive fishing gear through gear marking to reduce navigational risk for vessel operators, which may help avoid accidental loss of gear when damaged by passing vessels or active fishing gear. Flags, reflectors, buoys, inscriptions, writing and tags are all examples of traditional gear marking. Newer types of marking, such as electronic buoys and electronic devices, are being evaluated in a variety of fisheries to determine their utility (He and Suuronen 2018).
Technology to avoid unwanted gear contact with seabed	GPS and seafloor mapping technologies help reduce the chance of losing gear by accidental contact with the seafloor, reducing the chance of accidentally losing gear (Anonymous 2010a)
Technology to track gear position	The use of radar reflectors and radio buoys on fishing gear reduces the risk of losing gear, avoids interactions with towed gear, and makes it easier to locate lost gear (MacMullen et al. 2003, Anonymous 2010a). Fishing gear is set up to mark the position of passive fishing gear below the surface, reducing the risk of damage from being cut by passing vessels (Macfadyen et al. 2009).
Gear technology to reduce gear loss	A change in the design or material of fishing gear might reduce the loss rate (Chaves and Silveira 2014)
Input controls, including limit on soak time	It is possible to reduce the quantity of ALDFG by limiting the amount of fishing effort or capacity. Gear loss can be reduced by limiting the gear soak time gear and retrieving gear during closed periods (Anonymous 2011).
Periodic or constant observation of passive gear	Observing passive gear periodically or continuously can increase the likelihood of sea turtles caught in it being released alive as well as reduce the likelihood of it being damaged (Gilman 2015).
Spatial and temporal restrictions on fishing	It is possible to reduce gear loss by separating passive and mobile gears temporally and spatially and by not using fishing methods which have high probability of gear loss on submerged features (Anonymous 2010a). It has been banned to use gillnets and trammel nets, in some cases specifically to avoid ghost fishing (Anonymous 2010b).
IUU deterrents	Illegal, unreported, and unregulated (IUU) fishing can be discouraged with effective deterrents.
Ban on intentional abandonment & discarding of fishing gear at sea	It can be possible if strong surveillance and enforcement systems are implemented (Anonymous 2014).

Methods	Description
Economic incentives	Economic incentives could encourage fishers to report lost gear or bring to port old and damaged gear, as well as any ghost nets they might recover accidentally while fishing (MacMullen et al. 2003).
Port reception facilities for unwanted gear	By providing accessible and affordable port reception facilities for discarded fishing gear, at-sea discarding is reduced (Anonymous 2010a).
Training for new entrants	In fisheries with high gear loss probabilities, providing training opportunities for new entrants can enhance skipper ability to use best practice gear designs and fishing methods to reduce gear loss and recover ALDFG (MacMullen et al. 2003).
Remedial methods	
ALDFG port reception and recycling facilities	Accessible and affordable port reception facilities can facilitate the retrieval and delivery of ALDFG (Anonymous 2011, 2013a). There are several programs designed to encourage the port disposal of unwanted gear and ALDFG retrieved at sea, such as paying fishers to retrieve marine debris and deliver it to designated seaports. Several ALDFG reception programs provide opportunities for reuse by the fishing industry, recycling, and conversion to energy (Anonymous 2010a).
Detection and removal of ALDFG	Fishing vessels may be required to attempt to retrieve ALDFG and to report information on lost gear that could not be retrieved (Anonymous 2014, 2010c, 2013b). A key recommendation to report ALDFG is that vessels should be required to log gear losses as a matter of course. However, a "no-blame" approach should be followed with respect to liability for losses, their impacts, and any recovery efforts, it says. The goal should be to improve awareness of potential hazards and increase the opportunity for gear recovery (Good et al. 2010). Several programs periodically survey fishing grounds and sensitive marine habitats in order to locate and remove ALDFG and other marine debris (Suuronen et al. 2012).
Disablement of ghost fishing efficiency of ALDFG	Fisheries with known ALDFG will periodically be swept with trawl nets to remove or damage derelict gear sufficiently to make its ghost fishing ineffective (Anonymous 2005).
Gear technology designed for bycatch mitigation in in-use gear that also increases ghost fishing selectivity in ALDFG	Ghost fishing rates of vulnerable species in ALDFG can be minimized by modifying fishing gear, such as reducing net mesh size, gillnet height, and tiedown length, which helps lower turtle bycatch. Increasing net visibility can reduce bycatch of marine mammals and turtles but may also affect target species catch rates. (Gilman et al. 2021). It is possible to make the net stiffer by increasing the filament diameter, modifying its weaves (e.g., using multi-monofilament instead of single monofilament), adding larger floats to the top rope and heavy weights or lead core to the bottom rope, and infusing compounds (Thorpe and Frierson 2009). Cetacean bycatch can be reduced by adding thick ropes, chains,

Methods	Description
	or metal-infused nylon to nets, enhancing visibility, acoustic reflectivity, or stiffness. Acoustic pingers, alarms, and illuminated nets with light sticks can also help, but their effectiveness declines once the energy source depletes. (Koschinski et al. 2006).
Less durable and degradable gear to reduce ghost fishing duration	Ghost fishing mortality could be reduced by using less durable materials with a breaking strength that allows large organisms to escape (Gilman et al. 2021). The use of degradable materials in gear technology has reduced the fishing power of derelict gear (Antonelis et al. 2011, Matsushita et al. 2008, Anonymous 2014, Chanrachkij et al. 2008). It is possible to reduce ghost fishing by traps by using degradable escape panels and cords (Anonymous 2010a). Synthetic gear materials have been developed that can be broken down by microbes and ultraviolet light (Tabata and Kanehiro 2010).

Source: Anonymous (2016a)

two reasons: first, if the location of lost gear is known, it can often be recovered; second, understanding the extent, locations, and causes of gear loss is critical for developing effective prevention and management strategies. The only way to fully eliminate the harmful effects of lost gear is to recover it. For certain fishing equipment, such as gillnets, retrieval is most effective when the gear is lost. Some nets may deteriorate and lose their fishing capacity over time, so waiting weeks or even years to retrieve them may be ineffective in reducing their negative impacts (Good et al. 2010). In contrast, other gear types, such as traps and pots, cause less immediate harm to marine species, and retrieval performed days or weeks after loss can still significantly reduce adverse impacts on wildlife. Removing lost gear can eliminate risks to navigational safety and prevent habitat damage (Antonelis et al. 2011, Butler et al. 2018). To prevent gear loss and mitigate the harm caused by ALDFG, it is crucial to understand the underlying causes and drivers of loss specific to each fishery. Accurate reporting of fishing gear loss provides valuable information. Commonly collected details include fisher or vessel identification, the location and time of gear loss, the type of gear lost, and an explanation of the circumstances surrounding the loss. By documenting the reasons for gear loss, effective prevention and mitigation strategies can be identified and implemented (Anonymous 2016b).

CONCLUSION

Ghost gear is significantly harming the marine environment and endangering marine biodiversity. To develop effective strategies for preventing gear loss, it is essential first to identify the root causes, as a "one-size-fits-all" solution will not be effective in all fisheries. The most successful programs must be tailored to specific fisheries and developed collaboratively with fishermen, the fishing industry, and fisheries managers. Creating national, regional, and sub-regional policies and voluntary measures is critical for preventing and mitigating ghost gear and will contribute to the fight against ghost fishing. Various strategies to combat ghost fishing should involve the establishment of resolutions, public policies, legal standards, and actions aimed at preventing and remedying abandoned and lost fishing gear (ALDFG). These strategies include using biodegradable materials, raising local, regional, and international awareness, and embracing new technologies. Additionally, we must establish an international treaty that outlines clear responsibilities and goals to prevent and reduce ghost gear. The most crucial component in minimising the impact of ghost gear is the development and implementation of strict codes of conduct, participatory fisheries management actions, and effective fisheries control. To preserve the productivity of our oceans and seas for present and future generations, addressing abandoned and

lost fishing gear must be a collective and urgent priority.

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