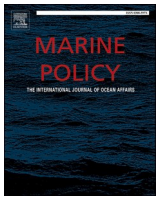
Marine Policy 129 (2021) 104522

Contents lists available at ScienceDirect

Marine Policy

journal homepage: http://www.elsevier.com/locate/marpol



Short communication

Challenges and misperceptions around global fishing gear loss estimates

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ARTICLE INFO

Keywords:
Abandoned, lost or otherwise discarded fishing gear (ALDFG)
Derelict fishing gear
Fisheries management
Marine debris
Marine litter
Sustainable fisheriesData availabilityAll data used in discussion by authors is referenced in-text with citations provided. The authors did not include any original data, nor did they use data to inform new estimates or other new information.

ABSTRACT

Abandoned, lost or otherwise discarded fishing gear (ALDFG) represents a major sea-based source of marine debris globally, with far-reaching socioeconomic and environmental impacts. Estimates of the amount of ALDFG entering the ocean have implications for managers and policy makers as they work to tailor solutions at scale. While scientists have worked since the 1970s to develop quantitatively rigorous estimates for ALDFG, the estimate that 640,000 tonnes of ALDFG enters the ocean annually has been repeatedly and erroneously cited for over a decade. We trace the history of this misinformation and discuss the implications of the perpetuation of this estimate. We also discuss major challenges around the creation of statistically robust global ALDFG estimates, and present opportunities to refine and improve estimates of lost fishing gear.

Sustainable fisheries are critical to food security, economies and livelihoods around the world. Since the 1950s, global increases in fishing effort and capture production have resulted in historic declines in fish stocks [1,37]. Recent estimates show that more than a third of wild fish stocks are fished at biologically unsustainable levels, with global fisheries values estimated at $401 billion USD [1].

As a major sea-based source of marine debris globally, abandoned, lost or otherwise discarded fishing gear (ALDFG) compromises fisheries sustainability through losses of gear and catch; and adverse impacts to marine habitats, target and non-target species, gear efficiency and associated fisheries profits [2–5]. Lost gear also presents hazards to navigation and safety at sea [2,6]. The scale of ALDFG impacts on fisheries, marine ecosystems and associated human users inspired the United Nations (UN) to call upon member countries to take actions to reduce ALDFG [7–10]. These reduction efforts support the UN 2030 Agenda for Sustainable Development Goal 14, which asks members to regulate destructive fishing practices and significantly reduce marine pollution [11]. The Food and Agriculture Organization of the UN (FAO) has additionally emphasized the need for fishing gear marking and ALDFG reporting and recovery through its Committee on Fisheries, Code of Conduct on Responsible Fisheries and Voluntary Guidelines on the Marking of Fishing Gear [7,12,13]. The International Maritime Organization's "Action Plan to Address Marine Litter from Ships" further outlines actions to reduce ALDFG from fishing vessels [14].

In 2009, Macfadyen et al. were attributed with producing the estimate that 640,000 tonnes of ALDFG enters the world's oceans each year. While many of the numerous actions taken to reduce ALDFG over the last decade rely on this estimate, with this figure used widely by media, decision makers and researchers alike – we argue that this figure is inaccurate, and its origins miscited and misunderstood. In this paper, we trace the history of the 640,000 tonnes estimate, and discuss the implications of this perpetuated misinformation. We also discuss key challenges around the creation of global ALDFG estimates, and present opportunities to improve future estimates.

1. The history of global ALDFG estimates (1975–2019)

Knowing how much fishing gear enters the world's oceans can inform interventions by policy makers, managers, port authorities, the seafood industry and fishers. Most estimates have been limited to specific gear types and/or geographic locations, largely due to the nature of fishing gears being tailored for target species, which can vary widely

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https://doi.org/10.1016/j.marpol.2021.104522
Received 10 February 2021; Received in revised form 26 March 2021; Accepted 31 March 2021
Available online 10 April 2021

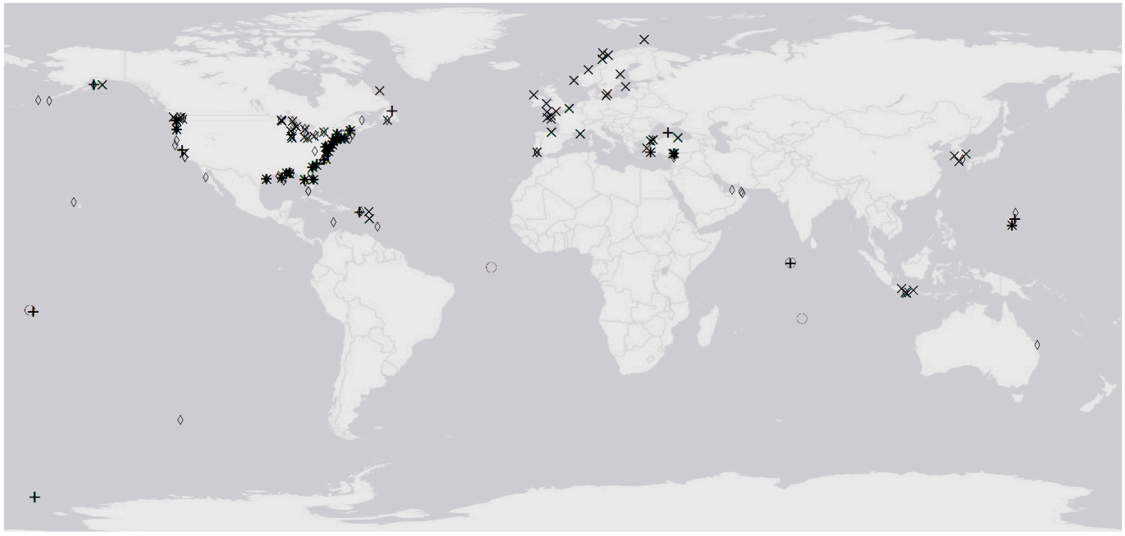

Fig. 1. Geographic areas for ALDFG studies from 1975 to 2017. Studies focusing on net fisheries are indicated by X; traps: ◊, lines: ○, fish aggregating devices (FADs): +
Reproduced from Richardson et al. [15].

across geographic areas (Fig. 1) [15]. The earliest global estimate of fishing gear losses was presented by the USA's National Academy of Sciences (NAS) in 1975, who estimated that around 1000 tonnes of commercial fishing gear was lost to the world's oceans each year [16]. Five years later, Merrell [17] used a combination of the marine litter estimates provided by NAS [16] and Alaskan beach litter surveys to estimate that globally, 134,628 metric tonnes of fishing gear are lost each year [17]. Most recently, a meta-analysis of ALDFG estimated that 5.7% of all fishing nets, 8.6% of all traps and 29% of all lines are lost to the world's oceans each year [15], though the authors did not provide an estimate in weight.

Despite these publications, the estimate that 640,000 tonnes of ALDFG enters the world's oceans each year continues to be the most popularly reported estimate (e.g. 332 citations attributed to [2], Google Scholar search, access date 26 March 2021). Ironically, however, Macfadyen et al. [2] do not state this number in their report.

2. Where does the 640,000 tonnes of ALDFG estimate originate?

Despite stating that "… there is no overall figure for the contribution of ALDFG to marine litter", Macfadyen et al. [2] do report "**a crude approximation of ALDFG comprising less than 10% of global marine litter by volume**" (Fig. 2.3). No references are provided. The authors did, however, include estimates of the magnitude of ALDFG arising from fisheries around the world, which ranged between 0.02–30% annually – none of which are used in the 640,000 tonnes estimate ([2], p. 27).

The report additionally states: "In 1997, the United States Academy of Sciences estimated the total input of marine litter into the oceans at approximately **6.4 million tonnes per year**" (Fig. 2.3a). This is the closest reference to 640,000 tonnes, with ten percent of 6.4 million tonnes of marine litter equating to 640,000 tonnes of ALDFG. The authors' citation for this statement is not provided for the "1997 United States Academy of Science" study, but instead cites a 2005 UN Environment Programme report on marine litter (Fig. 2.3b) [18]. Review of the UNEP report revealed that it also referenced the 6.4 million tonnes of marine litter figure to a 1997 "US Academy of Sciences" study without providing any citation (Fig. 2.2).

A literature search revealed that the 6.4 million tonnes estimate originated from a *1975* publication by the USA's National Academy of Sciences, which estimated that 6.36 million tonnes of marine litter enter the world's oceans each year (Fig. 2.1) [16]. This estimate included sea-based sources of marine litter from passenger vessels, merchant ships, recreational boats, commercial fishing vessels, military vessels, oil and drilling platforms and catastrophic events (Fig. 2.1) [16]. The study specifically estimated that around 1000 tonnes of commercial fishing *gear* is lost globally each year, or almost 0.02% of the total marine litter estimate (Fig. 2.1) [16].

The first publicized use of the 640,000 tonnes estimate was a 6 May 2009 news briefing published by FAO. The briefing reported: "estimates that **abandoned, lost or discarded fishing gear in the oceans makes up around 10% (640,000 tonnes) of all marine litter…**" (Fig. 2.4) [19]. This estimate was reiterated by FAO's 2016 contribution to the Seventeenth Meeting of the UN Open-Ended Informal Consultative Process on Oceans and Law of the Sea, which stated: "There is no robust estimate for the amount of ALDFG. **Based on an extrapolation of the crude approximation of 6.4 million tonnes of marine litter added to the oceans each year and that less than 10% of this is comprised of fishing gear** [2]**, this implies about 640,000 tonnes of ALDFG each year**" [20] (Fig. 2). The UN Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) Working Group 43 on Sea-based Sources of Marine Litter also briefly discuss the extrapolation of Macfadyen et al.'s [2] ten percent estimate to the [16] study, and the urgent need for current and accurate estimates [21].

3. Costs and consequences of misinformation

Since its first use in 2009, the 640,000 tonnes estimate has been referenced on hundreds of occasions across the scientific literature and media.[1] The 640,000 tonnes estimate serves as a strong communications tool that represents the size and scale of the problem. This number has been compared to "more than 50 thousand double decker buses" [22], "as heavy as two Empire State buildings" [23], "65 Eiffel Towers-worth of fishing tackle" [24] and "the weight of over 4266 blue whales" [25]. Such comparisons help the public to more quickly visualize and comprehend the scale of this issue.

The proliferation of this estimate however misinforms knowledge

[1] A Google Scholar search for "Macfadyen et al. [2]" revealed 332 citations for this publication (access date 26 March 2021), and searches in Google Scholar for "640,000 **tonnes/tons** abandoned lost or otherwise discarded fishing gear" revealed 141 and 570 results, respectively (access date 26 March 2021).

2.1 National Academy of Sciences 1975

Table 8-13. Total Litter Estimates (NAS 1975, p 422)

Source	Amount of Litter Generated (10^6 tons/year)
Passenger Vessels	0.028
Merchant Shipping	
Crew	0.110
Cargo[i]	5.600
Recreational Boating	0.103
Commercial Fishing	
Crew	0.340
Gear	**0.001**
Military	0.074
Oil Drilling and Platforms[ii]	0.004
Catastrophe	0.100
Total	**6.360**

2.2 UNEP 2005: Marine Litter, an analytical overview

"In 1997, the US Academy of Sciences estimated the **total input of marine litter into the oceans, worldwide, at approximately 6.4 million tonnes per year**." → *No references provided; p 4*

2.3 Macfadyen et al 2009

2.3a "Attempts at broad-scale quantification of marine litter enable only **a crude approximation of ALDFG comprising less than 10 percent of global marine litter by volume**" → *No references provided; pp xv and 1*

2.3b "In 1997, the United States Academy of Sciences estimated the total input of marine litter into the oceans at approximately **6.4 million tonnes per year**" → *Cited to UNEP 2005 report; p 11*

2.4 FAO press release, 6 May 2009

"**abandoned, lost or discarded fishing gear in the oceans makes up around 10 percent (640,000 tonnes) of all marine litter**." → *summarizing Macfadyen et al 2009*

Fig. 2. Summary of the origins of the 640,000 tonnes of ALDFG estimate. [i]NAS [16] states that "We assume an unknown percentage of the waste is released in harbors, ports or nearshore areas. [ii]NAS [16] include the note that "Litter produced should not be interpreted as released. In the U.S. disposal of waste from oil platforms and drilling rigs is strictly regulated [29]. The degree of regulation in other areas is unknown".

around how much fishing gear is lost to the world's oceans each year, including how ALDFG compares to other types of sea-based debris. The estimate is cited by scientists, media and international bodies such as the UN, which results in a perception that the question of how much fishing gear is lost around the world each year is known. This can potentially stymy funding to support what is perceived as an answered question. In contrast, significant progress has been made over the last twenty years in improving estimates for how much land-based plastic enters the world's oceans annually [26–28,30,31].

This mis-estimation may additionally distract from other relevant fishing gear metrics, such as proportions of gear losses, gear sizes, material types, gear lifespans and potential for ghost fishing and wildlife entanglements. For example, monofilament fishing lines generally weigh substantially less than most pots and traps and fishing nets. Thus,

a weight-based comparison of the amount of monofilament line losses compared to other naturally heavier gear types is ultimately misleading in terms of how much gear is lost across different fisheries and gear types. Proportions of gear losses provide more comparable metrics across different gear types and are to be encouraged (sensu [15]).

4. Challenges and opportunities for estimating ALDFG

A recent global ALDFG meta-analysis identified the variety of disparate ALDFG reporting metrics as an overarching challenge in comparing estimates around the world [15]. This included *amounts* (e.g. reporting by proportion, numbers/counts, lengths, and weights of gear lost) and *temporal and spatial scales* of gear loss (e.g. gear lost per set/-trip/seasonally/annually and gear lost locally/nationally/regionally/globally). Measures of fishing effort that can be used to convert different gear loss estimates into comparable units will be most useful to address these disparate metrics. Prioritizing the inclusion of relevant effort data will allow for the conversion of estimates that are comparable across different reporting metrics.

The meta-analysis also found that many ALDFG studies did not include measures for certainty/uncertainty [15]. Future studies that clearly identify uncertainty through confidence intervals, standard deviations and sample sizes to provide a reference for the strength of their estimates will be most valuable. A statistical power analysis is a useful tool to determine the necessary sample size required to achieve a significant effect, as well as to understand the probability of detecting an effect using an already achieved sample size. Power analyses can be especially useful in designing interviews with fishers and other stakeholders around gear losses, and in determining the effectiveness of an already established number of interviews in a given location. Generally, the larger the geographic area and/or population covered in an estimate, the larger the required sample size, with global estimates requiring major investments in sampling and monitoring to achieve representative data.

Another major challenge in comparing ALDFG estimates is that many studies do not report the proportion of the gear item lost (e.g. whether the entire gear item was lost, or some portion of the gear). Reporting the proportions (including means, medians and range) of gear lost will improve estimations of size, weight or other metrics. The inclusion of more explicit information can help improve understanding of the type, scale and nature of gear losses and potential impacts.

Similarly, many ALDFG estimates do not provide information on gear characteristics such as sizes and material types. Gear characteristics are known to relate to their likelihood for loss [15], and to impacts on marine wildlife and habitats after loss [3,32]. Identifying average gear sizes, especially when coupled with the average proportion of gear lost, will improve both gear loss estimates themselves, and can improve biological impact assessments. While most line fisheries can simply provide the length of line lost, net fisheries that provide net length, width, depth and/or height measurements will be instructive. Pot and trap fisheries that provide relevant length, width and height measurements will also improve our understanding and management efforts. Other associated gear components such as buoys, floats and attachment lines can also be included in loss reporting. Inclusion of gear characteristics with ALDFG estimates will better inform the potential for impacts arising from losses, and assist policy makers, managers and fishers with cost-benefit analyses of gears allowed and employed.

The size and scale of fisheries where gear loss is estimated is also worth considering. Many of the same gear types are employed by small and large-scale fisheries, as well as by recreational fisheries (e.g. pots and traps and lines). Given differences between fisheries (small-scale, artisanal, large-scale, industrial, recreational), communicating the size and scale of fisheries examined is important to frame and better understand the nature of and impacts from gear losses from diverse fisheries. Consideration of socioeconomic influences both within fishing communities and across different fisheries is also important as these can influence both the types and quality of gears employed, and gear stewardship behaviours such as gear maintenance and replacement [33].

Understanding causes of gear losses additionally informs management interventions [33]. When possible, inclusion of gear loss causes including identification, quantification and monitoring can further assist in evaluations of ALDFG scope and impacts. Finally, with changes to the state of global fisheries, including impacts from global climate change [34–36], changes in fish stocks and fisheries effort [1,34], impacts from illegal, unreported and unregulated fishing (IUU) [38,39] and an increasing shift to aquaculture as a global protein source [1,40], fisheries management that is responsive, flexible and adapts to change will be critical to ensure long-term sustainability.

5. Conclusion

As a major sea-based contributor to global marine debris, estimates of the amount of abandoned, lost or otherwise discarded fishing gear entering the ocean annually are useful for development and implementation of management interventions and solutions aiming to reduce gear losses. To date, mis-citation of the erroneous global estimate that 640,000 tonnes of fishing gear is lost annually has been perpetuated, potentially hampering efforts to increase understanding of the true scope and scale of the issue. The inclusion of relevant effort data, gear characteristics including the average proportion and size of gear lost, appropriate sample sizes, uncertainty measures, and consideration of socioeconomic influences and changing global fisheries trends will contribute toward improved future gear loss estimates – ultimately contributing to more sustainable and better managed fisheries.

CRediT authorship contribution statement

Kelsey Richardson: Conceptualization, Methodology, Investigation, Writing - original draft, Writing - review & editing. **Chris Wilcox**: Conceptualization, Methodology, Resources, Writing - review & editing, Supervision. **Joanna Vince**: Resources, Writing - review & editing, Supervision. **Britta Denise Hardesty**: Conceptualization, Resources, Writing - review & editing, Supervision, Project administration.

Acknowledgements

We thank CSIRO Oceans and Atmosphere, and the University of Tasmania's School of Social Sciences and Centre for Marine Socio-ecology for supporting this research.

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