REPORTS AND STUDIES

108

GESAMP
Joint Group of Experts on the
Scientific Aspects of Marine
Environmental Protection

SEA-BASED SOURCES OF MARINE LITTER

GESAMP WORKING GROUP 43

IMO FAO UNESCO IOC WMO UNIDO IAEA UN UNDP ISA UN environment

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Published by the
INTERNATIONAL MARITIME ORGANIZATION
4 Albert Embankment, London SE1 7SR
www.imo.org

ISSN: 1020-4873

Cover image: Courtesy of Emma Hedley

Notes:

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ISSN 1020-4873 (GESAMP Reports & Studies Series)

For bibliographic purposes this document should be cited as:

GESAMP (2021). “Sea-based sources of marine litter”, (Gilardi, K., ed.) (IMO/FAO/UNESCO-IOC/UNIDO/WMO/IAEA/UN/UNEP/UNDP/ISA Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection). Rep. Stud. GESAMP No. 108, 109 p.

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EXECUTIVE SUMMARY

Marine or sea-based litter has been recognized as a threat to ocean health since our understanding of the environmental aspects of human actions in the world's ocean started to expand in the 1970s. Of particular concern is plastic litter, which persists in the marine environment for prolonged periods of time. This is compounded by the sheer quantity of plastic that has been manufactured, used and discarded globally since its commercial advent in the 1950s.

It is generally assumed that the majority of plastic waste entering the world's ocean comes from land-based sources. However, marine litter also results from sea-based activities, although this has not been specifically quantified on any scale, and its contribution to the global burden of plastic debris in the world ocean is poorly understood. Furthermore, certain forms of sea-based marine litter may not only be significant sources of plastic litter, but may well have greater impacts on marine biota and habitats than do other forms of marine litter.

The overall objective of GESAMP Working Group 43 (WG 43) on *Sea-based Sources of Marine Litter* is to build a broader understanding of such sources of marine litter, in particular from the fishing and shipping sectors, including the relative contribution of different sources, analysis of plastic use and management within both industries, and the range and extent of impacts from all sea-based sources of marine litter. The Working Group has also been mandated to build a more comprehensive understanding of specific types of sea-based sources of marine litter, and to guide interventions on these sources based on identified priorities, drawing upon the expertise of several relevant organizations and research institutions. This report builds on content initially presented in interim form to sponsoring agencies in January and June 2020.

Principal findings are that sea-based activities and industries contribute to the global burden of marine litter, and this warrants concern largely because synthetic materials comprise significant portions and components of litter entering the world ocean from sea-based and other maritime activities and sources. Note that in reviewing the impacts of sea-based sources of marine litter, this report does not examine the potential toxic effects of plastics on marine life, as this subject is covered in detail in reports produced by GESAMP Working Group 40.

At this time, it is not possible to estimate the total contribution of sea-based activities and industries to the global burden of marine litter because very little quantification of such litter inputs exist in the scientific, peer-reviewed and grey literature. A concerted effort to update a global estimation and to derive a scientifically defensible proportion of the relative contribution of sea-based sources of marine litter is warranted. At the same time, renewed efforts to reduce inputs of marine litter from all sources are urgently required.

Lastly, in 2020-2021, every individual in the world has been impacted in some way by the COVID-19 pandemic. Slowing of global trade and limitations on movement and transport are among the many clear and sobering indicators of the degree to which the pandemic is disrupting economies and livelihoods. We can anticipate significant changes in forecasts for economic development in the coming years in sea-based industries – already to a certain extent in fishing and shipping, and certainly the cruise ship industry has been brought to a temporary halt and may never fully recover. The scientific evidence compiled for this report was derived from publications and databases largely produced pre-COVID-19, so the pandemic is not expected to impact our analyses presented herein. Evaluating how COVID-19-related impacts on ocean industries and livelihoods may influence projections and estimations for the relative contribution of sea-based sources of marine litter to the global ocean plastic burden would be a worthy endeavour.

ACKNOWLEDGEMENTS

GESAMP wishes to recognize the efforts of the working group members, providing their time and expertise over the past two years to complete this report: Ms. Kirsten Gilardi (Chair, United States), Mr. Pingguo He (United States), Mr. Kyle Antonelis (United States), Mr. Lumin Wang (China), Ms. Saly N Thomas (India), Ms. Kelsey Richardson (United States), Ms. Emily Grilly (Australia), Mr. Peter Van den dries (Belgium), Mr. David Santillo (United Kingdom), Ms. Raffaella Piermarini (Italy), Mr. Olof Linden (Sweden) and Mr. Francois Galgani (France).

GESAMP also acknowledges the generous financial support of the Government of Norway that has made the publication of this report possible, as well as the convening of our first in-person meeting. We would also like to extend our gratitude to the co-sponsoring organizations for the working group, and their Technical Secretaries, namely FAO (Mr. Jonathan Lansley), IMO (Mr. Fredrik Haag) and UNEP (Ms. Joana Akrofi), as well as the support provided by the GESAMP Office at IMO and Ms. Chrysanthe Kolia.

We also gratefully acknowledge comments on the draft version of this report provided by GESAMP members and several external peer-reviewers that have helped to significantly improve the report.

The Chair and Working Group members would also like to extend their thanks to the Members of GESAMP for their continuous support during the preparation of this report, including the review and commenting of the manuscript and interim reports.

1 INTRODUCTION and BACKGROUND

1.1 General overview

Marine litter is defined as "any persistent, manufactured or processed solid material discarded, disposed of or abandoned in the marine and coastal environment as a result of human activity", and is also commonly referred to as "marine debris" (Galgani *et al.* 2013). Marine litter has been recognized as a threat to ocean health since our understanding of the environmental aspects of human actions in the world ocean started to expand in the 1970s, prompting international regulations to prevent inputs of marine litter, most notably the London Convention (LC 1972), London Protocol (LP 2006) and the International Convention for the Prevention of Pollution from Ships (MARPOL 1973) first ratified in 1973, with MARPOL Annex V coming into force in 1988, and serving as the focus of several international scientific conferences held since the mid-1980s. The United Nations 2030 Agenda for Sustainable Development (UNSDG 2030) includes Sustainable Development Goal 14.1 to significantly reduce marine pollution of all kinds, including marine debris, by 2025.

Of particular concern is plastic litter, given its inherent strength and durability that allows it to persist in the marine environment for indefinite periods of time, compounded by the sheer quantity of plastic that has been manufactured, used and discarded globally since its commercial advent in the 1950s. Thousands of scientific papers documenting the presence of plastic in the ocean and its distribution, composition, physical and biological chemistry and toxicology, as well as its direct and indirect impacts on marine biota and habitats, have been published. The Joint Group of Experts on Scientific Aspects of Marine Environmental Protection (GESAMP) Working Group 40 (WG 40) has produced several reports on the ocean plastic pollution issue, focusing on the sources, fates and effects of microplastics (e.g. GESAMP 2015, 2016, 2019, 2020).

It is generally assumed that most of the plastic waste entering the world ocean comes from land-based sources – of an estimated 275 MMT generated by 192 coastal nations in 2010 alone, approximately 4.8 – 12.7 MMT entered the ocean that year (Jambeck *et al.* 2015). Research compiled from observations in all European seas suggests that land-based litter accounts for more marine litter than sea-based litter (Interwies *et al.* 2013), with sea-based sources of marine litter comprising an estimated average of 32%-50% of total marine litter found in some European basins (Eunomia 2016), but estimates vary by region. In the Adriatic Sea, for example, on an aggregated basis at the regional level, marine litter items derived from sea-based activities accounted for 6.3%, compared to 34.7% of total marine litter items attributed to land-based sources (Vlachogianni *et al.* 2018). A study using beach litter survey data from the German North Sea coastline identified 17,074 marine litter items collected between 2011 and 2017 with estimations that 60% of the litter was from local and regional sea-based sources (Schäfer *et al.* 2019). These estimates highlight that the contribution from sea-based sources varies substantially from country to country and from site to site.

Despite a variety of land- versus sea-based marine litter estimates available from a diversity of studies around the world, marine litter resulting from sea-based activities, such as fishing, aquaculture, shipping, ocean dumping and other ocean-based activities, has not been rigorously quantified on any scale, and its contribution to the global burden of plastic in the world ocean is poorly understood. Furthermore, certain forms of sea-based marine litter, such as abandoned, lost or otherwise discarded fishing gear (ALDFG) that largely comprise a variety of manufactured, synthetic materials that do not degrade in seawater, may not only be significant sources of marine plastic but may well have greater impacts on marine biota and habitats than do other forms of marine litter. Studies indicate that among the sea-based contributors to the problem of marine litter, the fishing sector features quite dominantly, e.g. Arcadis (2012) estimates a 65% share for the fishing sector alone, with the recreational sector also comprising a significant share, and the remaining sea-based marine litter coming from the merchant shipping sector (Eunomia 2016; OSPAR 2009; UNEP MAP 2015).

While reference is commonly made to the "fact" that 80% of litter in the world's ocean comes from land, and (therefore) 20% comes from the sea, this oft-cited statistic is not traceable to a published scientific paper or technical report and its history is an active area of investigation by GESAMP. The quantity of "640,000 tonnes of abandoned, lost or otherwise discarded fishing gear lost in the ocean every year" is similarly oft-quoted, but is poorly substantiated (Macfadyen *et al.* 2009; NAS 1975). Unfortunately, since those studies there have been few attempts other than Jambeck *et al.* (2015) to estimate global inputs of plastic litter into the ocean from land, and no efforts to determine inputs of marine litter from sea-based sources on a global scale. Richardson *et al.* (2019) reviewed the scientific literature to estimate the proportion of commercially deployed fishing gear worldwide that becomes abandoned, lost and discarded in the ocean. While this review was able to identify estimated losses for categories of gear, extrapolating to a quantitative assessment of ALDFG entering the world ocean annually was beyond the scope of the study. In the absence of data, the "80/20" and "640,000 tonnes" figures are cited in numerous papers and reports.

Despite the absence of global estimations of sea-based marine litter, the number, geographic spread, quality and consistency of research studies documenting the distribution of marine litter and microplastics have increased in recent years. In the vast majority of marine litter studies, results are reported as numeric counts of the abundance or density of plastic items or particles, sometimes sub-divided by size class or by type (e.g. fibers, fragments, films etc.) or sometimes only as aggregate values for the entire size range included in the counts (GESAMP 2019). While these reporting methods allow for comparison of plastic contaminant loadings within and among studies (insofar as methods are consistent), they do not allow for more specific estimations of plastic contaminants from sea-based sources of marine litter, as they often do not distinguish between land versus sea-based origins of the documented litter items. As well, variability among data sets and how data is recorded make it difficult to determine trends and sources.

Marine litter is a pressure upon marine habitats and species, ecosystem services and human welfare. Measuring impacts from marine litter is complex. Harm caused by plastic marine litter is social (e.g. causing a reduction in aesthetic value and public safety), economic (e.g. conferring cost burdens to tourism, damage to vessels, fishing gear and facilities, losses to fishing operations, cleaning costs) and environmental (e.g. morbidity and mortality caused to living resources, habitat degradation and destruction). Given that litter (and anything on or in it) can be transported over large distances, it may result in social, economic, and environmental costs to areas that are far away from its point of origin and may place burdens on sectors and communities that are not responsible for its generation.

GESAMP Working Group 43 (WG 43) on *Sea-based Sources of Marine Litter* is aiming to build a broader understanding of sea-based sources of marine litter, in particular from the fishing and shipping sectors, including the relative contribution of different sources, analysis of plastic use and management within both industries, and the range and extent of impacts from all sea-based sources of marine litter. Ultimately, new knowledge and greater understanding around sea-based sources of marine litter can guide interventions on these sources based on identified priorities, drawing upon the expertise of the UN Food and Agriculture Organization (FAO), International Maritime Organization (IMO), UN Environment Programme (UNEP) and other relevant organizations and research institutions.

1.2 GESAMP Working Group 43

1.2.1 *Scoping Activities*

FAO and IMO have stepped up their efforts to address the challenge posed by the relative lack of knowledge on sea-based sources of marine litter. Both organizations have adopted policy instruments to address sea-based sources of marine litter (FAO 2019; IMO 2018), and both organizations have been mandated by their members to increase their efforts on this issue, including the establishment of relevant strategies and action plans.

The forty-fifth session of GESAMP, which took place at FAO Headquarters in Rome, 17-20 September 2018, supported the establishment of a new working group on sea-based sources of marine litter, under the co-leadership of FAO and IMO, pending the development of a full working group proposal, including detailed terms of reference, in the intersessional period. At the seventy-third session of IMO's Marine Environment Protection Committee (MEPC), held in London, 22-26 October 2018, the MEPC adopted an IMO Action Plan to Address Marine Plastic Litter from Ships [resolution MEPC.310(73)] to further strengthen efforts on this issue (IMO 2018). The Committee instructed the IMO Secretariat, in cooperation with FAO, to request GESAMP to also include shipping related sources of marine litter in the scope of work for the GESAMP Working Group on *Sea-based Sources of Marine Litter* to inform future study of marine plastic litter from ships.

WG 43 has also been mandated to build a more comprehensive understanding of specific types of sea-based sources of marine litter, and to guide interventions on these sources based on identified priorities. The outputs of WG 43 are intended to support the mandates and programmes of work related to marine litter within FAO, IMO and UNEP. The Working Group has also addressed data gaps, including those that have been highlighted through the respective relevant governing bodies of these organizations, such as FAO's Committee on Fisheries (COFI), and the IMO's MEPC and LC/LP. Note that in reviewing the impacts of sea-based sources of marine litter, this report does not examine the potential toxic effects of plastics on marine life, as this subject is covered in detail in reports produced by GESAMP WG 40, *Sources, Fate and Effects of Plastics and Microplastics in the Marine Environment.*

1.2.2 *Terms of Reference*

The Working Group has been requested to address two concurrent work-streams: (1) an overarching scoping study, which will generate the information required by IMO for implementation of its Action Plan to Address Marine Litter from Ships and help identify priorities within this overarching scope; and (2) a specific focus on the science underlying ALDFG as a particularly damaging form of sea-based marine litter, in order to inform and advance interventions. The terms of reference (ToRs) for WG 43 are as follows:

Workstream 1

1 Identify sources of marine litter from sea-based sources, including but not limited to:

   a. fishing operations; aquaculture; shipping; dumping of waste and other matter at sea; and

   b. other sea-based sources (e.g. offshore oil and gas extraction).

2 Estimate the relative contribution and impacts of different sea-based sources of marine litter.

3 Analyse how much plastic is produced and used by the fishing and shipping industries, including what kind of plastic is manufactured and used by these industries, as well as an overview of the existing waste management streams for these plastics and how these vary by region.

4 Assess data gaps, as identified under ToRs 1 to 3, and prioritize for further work.

Workstream 2

1 Identify ALDFG hotspots.

2 Quantify the environmental, social and economic impacts of ALDFG.

3 Review and compare options for solution delivery by way of analysis of all available data from existing sources, including quantification of benefits, mapping of solution "hubs" against ALDFG hotspots and identifying common themes and gaps that have emerged through recommendations.

1.2.3 *Defining "sea-based marine litter"*

For the purposes of WG 43's mandate and scope and this report, "sea-based marine litter" is any form of human-made, synthetic (non-natural) debris deposited directly into seawater from a vessel, facility or activity that is situated in or on, or is taking place entirely on or within, the ocean, from the intertidal to pelagic zones, and encompassing open ocean-adjacent seawater bodies including harbours, bays, estuaries and lagoons. For illustration, the following types of marine litter would not be considered sea-based, because they represent marine litter resulting from land-based sources: input from freshwater systems (e.g. rivers); marine litter washing from beaches after high tides or storm surges and catastrophic damage to coastal infrastructure resulting in marine debris deposited in the ocean.

1.3 General approach

The Working Group launched its efforts in June 2019 after an initial meeting held by teleconference, wherein an overall workplan was developed and it was agreed that to undertake the substantial work inherent in terms of reference (ToRs) 1 and 2 (see Section 1.2.2 for detail), these large topics would be taken up by subgroups to optimize efficiency and avoid duplicative work. This report represents work conducted by WG 43 from June 2019 to November 2020. WG 43 members have conducted comprehensive reviews of the published scientific literature and unpublished grey literature (e.g. technical reports, white papers) on fishing and aquaculture (through May 2020), shipping (through July 2020), ocean dumping (through February 2020), and other at-sea activities (e.g. offshore oil and gas, marine research; through May 2020) as sources of marine litter. Select papers and reports published in the latter half of 2020 are also referenced. WG members have summarized all available information on categories and composition, as well as on causes of, or reasons for, sea-based marine litter inputs. An important effort has been to ascertain the degree to which the quantity of marine litter entering the ocean from sea-based sources has been documented, calculated, modelled or conjectured.

WG 43 then met in person at the FAO headquarters in Rome, Italy, for 2.5 days in October 2019 to review progress and outline the first interim report, which underwent an internal GESAMP review process and was then finalized for submission to the sponsoring agencies on 29 January 2020. A second interim report building on content initially presented in the first interim report completed work on ToR 1, and summarized new and further work on ToRs 2, 4, and 6. Final work to fully address ToRs 3, 5, and 7 are now also addressed in this report.

2 FISHING AS A MARINE LITTER SOURCE

2.1 Background and introduction

GESAMP Working Group 43 (WG 43) conducted an extensive literature review to identify sources, levels, impacts, preventative measures, knowledge gaps and research priorities for abandoned, lost, or otherwise discarded fishing gear (ALDFG) from artisanal, commercial and recreational fishing operations. The review included relevant scientific publications from the peer-reviewed and grey literature, including technical reports. Wherever possible, attempts were made to recover the primary sources for data cited from studies reviewed, so that the data available are cited to their original publications. A summary of the initial and comprehensive ALDFG literature review conducted by the Working Group is presented in Annex I. [Note that marine litter generated by fishing vessels from other than fishing operations is addressed in Chapter 4 of this report.]

2.1.1 Defining ALDFG

The term "fishing gear" in this document refers to "any physical device or part thereof or combination of items that may be placed on or in the water or on the seabed with the intended purpose of capturing or controlling (for subsequent capture) or harvesting, marine organisms", in accordance with the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex V, Prevention of Pollution by Garbage from Ships (MARPOL[1]). Because abandoned, lost or otherwise discarded fishing gear (ALDFG) is a major component of sea-based marine litter, FAO, through expert and technical consultations, developed *Voluntary guidelines on the marking of fishing gear* (VGMFG) to *inter alia* prevent ALDFG and to reduce its harmful impact (FAO 2019).

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[1] https://www.imo.org/en/OurWork/Environment/Pages/Garbage-Default.aspx

The VGMFG define ALDFG as follows:

- “Abandoned fishing gear” means fishing gear over which that operator/owner has control and that could be retrieved by owner/operator, but is deliberately left at sea due to *force majeure* or other unforeseen reasons.
- “Lost fishing gear” means fishing gear over which the owner/operator has accidentally lost control and that cannot be located and/or retrieved by owner/operator.
- “Discarded fishing gear” means fishing gear that is released at sea without any attempt for further control or recovery by the owner/operator.

While the term “derelict fishing gear” is sometimes used synonymously with ALDFG, it does not imply how the gear ended up in the ocean. The terms “ghost gear” or “ghost fishing gear” are also often used synonymously with ALDFG, but are more nuanced terms related to the impacts arising from ALDFG. Ghost gear is defined as ALDFG that has “the ability … to continue fishing after all control of that gear is lost by the fisherman” (Smolowitz 1978). Therefore, ALDFG without any potential to continue catching fish or other animals would not be called ghost gear. ALDFG can comprise a variety of forms, from full to partial gear types and/or components including: a complete gear item of any type with the full complement of gear components (e.g. a complete gillnet with leadline, corkline, netting and marker buoys); a portion of a gear item with one or more of the gear components present (e.g. a piece of netting with or without a portion of the leadline attached); or a piece or portion of one component of a fishing gear type (e.g. a small fragment of netting, a section of rope from a variety of gears, or a marker buoy).

2.1.2 *Fisheries, fisher populations and fishing fleets*

2.1.2.1 Global Capture Fisheries Production

In 2018, global fish production reached a peak of 179 million tonnes, with 54% of production from capture fisheries and 46% from aquaculture. Approximately 87% of total production was for human consumption. Capture fish production totalled 96.4 million tonnes, with the marine sector comprising 87.6% (84.4 million tonnes) and the inland sector 12.4% (12.0 million tonnes) (FAO 2020a) (Figure 2.1). Overall, marine capture production has plateaued since the late 1980s, with the exception of a 5.4% increase in 2018 compared to previous years, primarily due to increased anchovy (*Engraulis ringens*) capture in Peru and Chile (FAO 2020a). Note that all figures reflect legal production, not quantities harvested by illegal, unregulated, unreported (IUU) fisheries, which are by their nature very difficult to estimate.

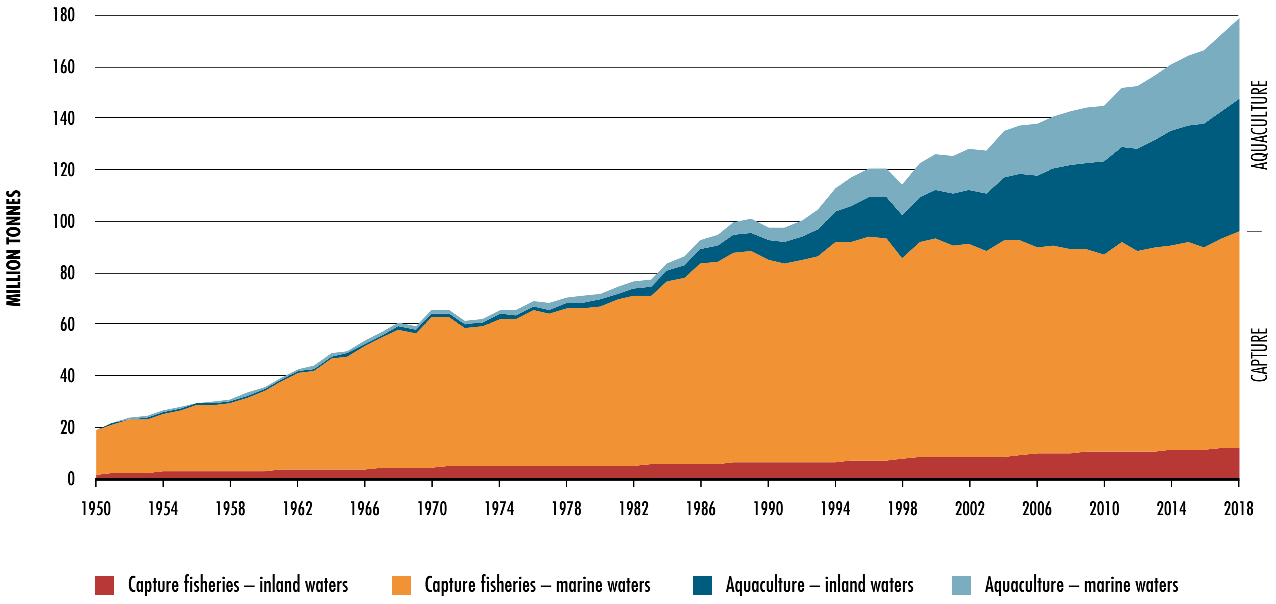

Figure 2.1: *World capture fisheries and aquaculture production (FAO 2020a).*

Capture fisheries comprise those that are artisanal, recreational, commercial and industrial, within traditional, small-scale and large-scale sectors. “Commercial fishing” denotes the activity of catching fish and other seafood, mostly from wild fisheries, for profit, and includes small-scale and large-scale fishing sectors (World Bank *et al.* 2012). An absolute definition exists for recreational fisheries, but not for the other capture fisheries, as there are no clear-cut boundaries among them.

2.1.2.2 Small-scale Fisheries

Small-scale fisheries (SSF) vary across countries and regions. The interchangeability of SSF-related terms – e.g. “artisanal”, “coastal”, “local”, “low-tech”, “non-industrial”, “small”, “subsistence”, “traditional” – indicates the diversity in values and characteristics underlying these terms (Natale *et al.* 2015).[2] SSF are generally local and community-based, rich in customs, traditions, and values. The SSF sector provides food and supports livelihoods for local populations around the world, employing an estimated 37 million people, with an additional 100 million employed in associated activities such as processing and marketing (Ben-Yami and Anderson 1985; FAO 2018; Pauly 2017; Sumaila *et al.* 2001; Weber 1994). A term often used in the SSF sector is “artisanal fisheries”, which are “traditional fisheries involving fishing households (as opposed to commercial companies), using relatively small amounts of capital and energy, relatively small fishing vessels (if any), making short fishing trips, close to shore, mainly for local consumption” (FAO 2015). A 24 m vessel length is generally accepted as the differentiator between small- and large-scale fisheries (Sumaila 2017; World Bank *et al.* 2012).

2.1.2.3 Large-scale Fisheries

The large-scale fisheries sector is characterized by large high-capacity vessels which may be equipped with onboard freezing and processing facilities. These vessels are 24 m or longer, some with more than 2,000 tonnes of fish holding capacity. Similar to SSF, different terms and phrases such as “deep sea”, “freezer trawlers”, “industrial”, “large-scale”, “off-shore”, and “over sea” are used to describe large-scale fisheries (Schuhbauer *et al.* 2017). Large-scale vessels typically include factory vessels, purse seiners and trawlers (World Fisheries Trust 2008). Fishing trips for both national and foreign large-scale fishing vessels and fleets may last anywhere from a few weeks to several months. The term “industrial fishery” is often used in large-scale fisheries and typically refers to the high level of technology and investment utilized in the fishery. Industrial fisheries typically deploy large, multimillion-dollar vessels equipped with technology capable of yielding large catches with high efficiency. While large-scale fisheries account for half of the total global captured fish production used for direct human consumption, only 10% of the total global capture fisheries workforce is represented in the large-scale fisheries sector (World Bank *et al.* 2012).

2.1.2.4 Fishing vessels and fisher populations

The variety of fishing vessels deployed around the world reflects the variability in geographic and climatic conditions, local and regional economies, and target species. Vessels range from very small, one-person canoes (SSF) to large factory vessels (large-scale fisheries). In 2018, the global fishing fleet was estimated to include 4.566 million vessels (FAO 2020a). Asian vessels comprised 68% of the global fleet, with 3.1 million vessels. Engine-powered vessels comprised 63% of the global fleet, with 2.86 million vessels (FAO 2020). Vessels 24 m or longer in length overall (LOA) (i.e. large-scale fishing vessels) comprised about 3% of all motorized vessels, and most are registered in countries in Asia and Africa, even though Europe and Oceania have the highest proportions of these larger vessels in their fleets. The majority of non-motorized vessels are deployed in Asia (947,000) and Africa (643,000). The global fishing population in 2018 was estimated to include 59.51 million fishers, of which 65.5% (39.0 million) were engaged in capture fisheries and the rest in aquaculture (20.5 million) (FAO 2020a). Approximately 85% of fishers were based in Asia, 9% in Africa, 4% in the Americas and 1% each in Europe and Oceania. Women accounted for approximately 14% of all fishers in 2018.

2.1.3 *Fishing gear: Types and components*

The types of fishing gear examined in this report follow to the extent possible the International Standard Statistical Classification of Fishing Gear (ISSCFG) (Nédélec and Prado 1990), Revision 4 (FAO 2014) as adopted by the FAO’s Coordinating Working Party on Fishery Statistics at its twenty-fifth session held in Rome in 2016 and presented in FAO Fisheries and Aquaculture Technical Paper No. T672 entitled Classification and illustrated definition of fishing gears (He *et al.* 2021). The ISSCFG provides two levels (hierarchies) of classifications for major global fishing gear types, with the top level identifying major, overarching gear types (e.g. surrounding nets) and the second level identifying major sub-gear types (e.g. purse seines and surrounding nets without purse lines). The top ISSCFG gear classification level includes 10 fishing gear types (plus “gear not known”): surrounding nets, seine nets, trawls, dredges, lift nets, falling gear, gillnets and entangling nets, traps, hooks and lines, and miscellaneous gear.

While the ISSCFG provides useful, broad categorical terms and descriptions for fishing gears globally, there are hundreds of other specific fishing gear subtypes employed by fishers around the world that are not included in the ISSCFG. These more specific gear types and variations often originate from traditional fishing cultures and are developed by fishers according to specific capture efficiency requirements. Fishing gears may additionally be modified by fishers in accordance with the fishing method, gear structure and operational approach. While it does not capture in full the hundreds of different sub-gear types used globally, FAO does provide a more detailed “Fishing Gear Type Fact Sheet” database online, with pictures and descriptions for 82 different gear types, which at the date of publishing are in the process of being updated.[3]

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[2] The challenge in agreeing on a clear, universally accepted definition and distinction between small- and large-scale fisheries was acknowledged by the FAO Advisory Committee on Fisheries Research in 2003 (FAO 2004). This was further supported by global documents, such as the *Voluntary guidelines for securing sustainable small-scale fisheries* (VGSSF), where country-level definitions are applied (FAO 2015).

[3] http://www.fao.org/fishery/geartype/search/en

Fishing gear components that contribute to the global ocean burden of plastic marine litter can be generally categorized as follows. The general construction type and component materials are presented in Table 2.1:

- Netting, largely comprising mono- or multifilament fibre polymers woven into knotted and knotless meshes. The main types of netting polymers include polyethylene (PE), polyamide (PA) and polyether sulfone (PES), which are non-biodegradable.
- Ropes and lines, comprising a variety of non-biodegradable polymer materials, including polypropylene (PP), PE, ultra-high molecular weight polyethylene (UHMWPE) and PA.
- Floats and buoys, commonly comprising PE, acrylonitrile butadiene styrene (ABS), expanded polystyrene (EPS), ethylene vinyl acetate (EVA) and polyurethane (PUR).
- Sinkers and anchors composed of lead blocks and iron chain.
- Metallic materials also constitute the frames, beam and otter boards for net spreads, and also constitute the core material for pots, along with accessories such as thimbles, shackles, swivels, purse rings and anchors.

Gear Type	Gear Structure	Gear Materials composition
Surrounding Nets • Purse seines • Surrounding nets	Bag or "purse" shaped net with a codend, bunt or "harvest" section; edges defined by a purse line with a purse string; float line with floats; sinker line; pulling lines	Netting: woven polymer fibres, e.g. PA/nylon, PES Lines: polymer fibres, e.g. PP, PE, UHMWPE, PA Floats: PVC, EVA Sinkers: lead Purse rings: iron or brass
Seine Nets • Beach seines • Boat seines	Long-walled nets with floating and sinking lines, may or may not have a codend (bunt)	Netting: PE, PA Floating lines: PP/PE/PA with PVC/ABS floats Sinking lines: same as above with lead blocks or other weights
Trawl Nets • Beam trawls • Bottom trawls • Mid-water trawls	Net top, bottom and side panels and a codend (bunt), with a float (head) line and sinking (footrope) line, bridle/sweep lines, and warp for towing, +/- otter boards	Netting: woven polymer fibres of PA/nylon, PE, (occasionally UHMWPE) Lines: PP/PA/UHMWPE Sinking lines: same as above with rubber, ABS or metal blocks Otter boards: steel, wood Beam: metal, wood, bamboo
Dredge Nets • Towed dredges • Mechanized dredges • Hand dredges	Metal frame with "cutting bar" on bottom edge and net or chain bag attached; mechanized dredges include a high-pressure hydraulic pump; hand dredges (artisanal) are typically a pole leading to a metal frame with a mesh bag with teeth on its lower edge	Netting: PE or chain metal Frame and cutting bar: iron
Lift Nets • Portable • Stationary • Boat-operated • Shore-operated	Netting, lift lines and sinking lines, lateral poles	Netting: PE/PA fibre Lift lines: PA/PP fibre Sinking lines: same as lift lines with lead blocks Poles: natural, PVC/ABS, or metal
Falling Nets • Cast nets • Lantern nets	Netting attached to hand or brail lines, and sinking line	Netting: PA/PES fibres Sinking line: PVC/ABS with lead blocks

Gear Type	Gear Structure	Gear Materials composition
Gillnets • Set (anchored) • Fixed (staked) • Drift • Encircling • Trammel	Single or three-walled netting; floating (head) lines and sinking (footrope) lines, buoys, +/- anchors (for set gillnets)	Netting: monofilament nylon or woven fibres comprised of PES, nylon or PE Float Lines: PP/PE with PVC/EVA/ABS floats Sinking Lines: PP or PES with lead blocks or lead core Buoys: vinyl/PVC/PUR
Traps[#]	Netting; floating (head) line and sinking (ground) line; beams or T-frames for spreading net; anchors and buoys. Pots are typically metal or wooden frames with synthetic or wire mesh.	Netting: woven polymer fibres, typically PE. Float and sink lines: PP/PA with PVC/EVA floats and lead sinkers T-frames or beams: “plastic” or steel pipes, or natural materials (e.g. wood, bamboo) Buoys: PVC/PUR/vinyl Anchor: iron Pot: PVC coated wire, wood, PE netting Rope: PP
Hooks and Lines • Hand-operated pole and line • Mechanized pole and line • Longlines (set and drift) • Trolling lines • Vertical lines	Main line, branch lines, hooks, lures, floats and sinkers	Main Lines and branch line: PP/PA multifilament, PA monofilament Hooks: steel Lures: metal, PVC, rubber Floats: PVC Sinkers: lead

[#] Includes pots, barriers, fences, weirs, stationary uncovered pound nets (e.g. large fish traps, Japanese set nets, etc.), fyke nets, stow nets, andand aerial traps. The terms “pot” andand “trap” are often used interchangeably in fisheries literature andand regulations. The ISSCFG categorizes “pot” as a second-level gear type under “trap” andand defines them as “transportable box-like or basket-like enclosures designed to capture fish by attracting them to the pot andand luring them inside through one or more ‘one-way’ entrances” (Thomsen et al. 2010).

Table 2.1 Major fishing gear types as classified in the International Statistical Standard Classification of Fishing Gears Rev. 4 and their common structural and material composition. Table content derived in part from Nédélec and Prado (1990).

2.1.4 *Recreational fisheries*

Recreational fishing is defined as the “fishing of aquatic animals (mainly fish) that do not constitute the individual’s primary resource to meet basic nutritional needs and not generally sold or otherwise traded on export, domestic or black markets” (FAO 2012). Recreational fishing is a large economic driver worldwide, with an estimated 225 million to 700 million recreational fishers active in both marine and inland (fresh) waters (FAO 2012; Kelleher *et al.* 2012). In 2016, 9.6 million recreational saltwater anglers in the United States undertook more than 63 million fishing trips, approximately half of which were from shore, while the other half were onboard vessels (NMFS 2018). While hook and line is the predominant recreational gear type, other recreational gears include pots and traps, spears and spear guns, bows and arrows, fyke nets and gillnets (Arlinghaus and Cooke 2009). For the purposes of this report, hooks and lines and pot gear and their relative contributions to ALDFG are reviewed. For other recreational gears, there is a near total lack of available information regarding their contribution to ALDFG.

While hook-and-line fishing is the predominant style of recreational fishing around the world, it is not exclusive to the recreational sector, and is also a common gear type used by artisanal and commercial fisheries. Therefore, hook-and-line ALDFG cannot always be easily categorized and/or distinguished by sector without analysis of other factors related to hook-and-line gear (e.g. region, location, size, configuration, composition, water depth). Recreational hook-and-line fishing gear types typically include a monofilament line attached to a lead sinker and one or more baited hooks or lures.

The most common recreational pot fisheries target a variety of lobster, crab, and shrimp species, and typically occur in North America, Europe, Australia, and parts of Asia. Recreational pots are typically cage-like structures made of plastic, metal wire mesh, nylon-coated wire mesh, or nylon mesh around a steel frame and wood, depending on the target species. They are commonly equipped with escape vents (or rings) to allow escape of sub-legal target species, non-target species, and/or females, depending on the fishery management scheme and regulations. Recreational pot fisheries typically target species that are also targeted by commercial fisheries. Therefore, in many places it is challenging to discern between recreational and commercial ALDFG. In contrast, in other fisheries recreational gears frequently differ from commercial gears in shape, weight, size, and/or design (e.g. for Dungeness crab on the United States West Coast), making it more easily distinguishable as recreational. Of note, recreational trap fisheries in Canada require tags to identify the fishery, harvester, location and other data that aid in distinguishing between commercial and recreational gear.

2.1.5 Fish aggregating devices

Fish, particularly large pelagics, tend to be attracted to floating objects in the sea. Fish aggregating devices (FADs) are “a permanent, semi-permanent or temporary object, structure or device of any material, man-made or natural, which is deployed, and/or tracked, and used to aggregate fish for subsequent capture” (FAO 2019). FADs can either be anchored (aFADs) in nearshore or coastal areas or drifting (dFADs) following deployment in open seas. Drifting FADs are often equipped with electronic buoys and are satellite-tracked by owners from a vessel or from the shore. Although data remain limited, available assessments indicate an overall increasing trend in dFAD deployment, particularly in the Pacific Ocean (Gershman *et al.* 2015), and an increase in the proportion of dFADs not recovered in the Eastern Pacific fisheries (Hall and Roman 2017).

Due to current practices and legal mechanisms regarding ownership, abandonment, loss and discard by various fleets, and Regional Fisheries Management Organizations or Arrangements (RFMOs/RFMAs) (Gilman *et al.* 2018), FADs are treated separately from other fishing gear types for marking requirements in FAO’s VGMFG. FAD ownership, abandonment and loss in the VGMFG are additionally undefined and left to “relevant authorities” to articulate and manage. Gilman *et al.* (2018) conducted a study on behalf of FAO on stakeholder views regarding dFAD ownership, abandonment, loss and discards that included interviews with a variety of stakeholders, including purse seine vessel owners and operators, captains and crew, fishery observers, fishery managers and researchers, gear technologists and electronic buoy manufacturers. Stakeholders broadly defined owners of dFADs as “the company that owns the satellite buoy that is currently attached to the dFAD”. If a satellite buoy is not attached, “the company that last had their satellite buoy attached, if this can be determined, should be considered the dFAD’s owner”. This study also suggested the definition of “abandoned”, “lost” or “discarded” dFADs as follows:

- A dFAD is considered “abandoned” when: (a) dFAD drifts out of fishing grounds, including into areas where a vessel does not have access and into areas with piracy, and (b) when transmission is switched off (decommissioned).
- A dFAD is considered “lost” when: (a) the buoy is “switched” (i.e. the FAD is stolen); (b) the buoy malfunctioned and stopped transmitting; (c) the buoy is detached from the dFAD, and (d) the dFAD sank.
- A dFAD or its component(s) is considered discarded when it is thrown back to the sea from a vessel. “Discarding” of aFADs or its components was considered “rare” (Gilman *et al.* 2018) as a retrieved dFAD or its components were often refurbished.

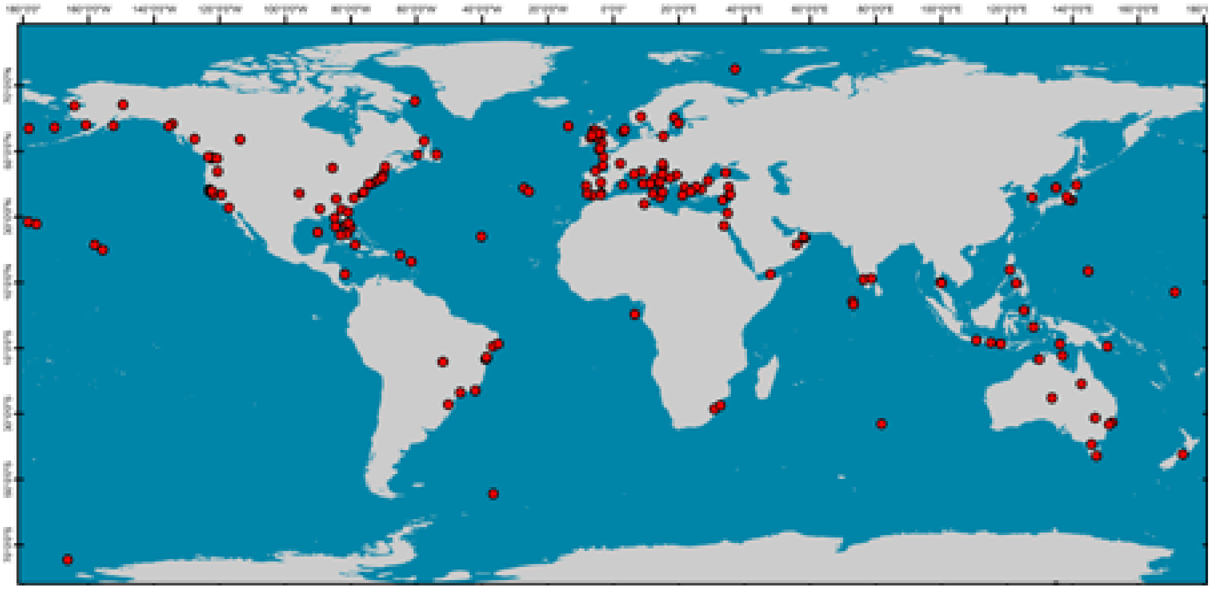

Figure 2.2: *Nations or regions where ALDFG is reported in the scientific literature reviewed for this report.*

2.1.6 *Geographic trends*

At present there is no global geographic assessment of quantities and categories of abandoned, lost and discarded fishing gear that allows for definitive identification of areas of high concentration or accumulation of ALDFG (i.e. “hotspots”). Nations or regions where ALDFG surveys and research are being conducted and published in the peer-reviewed literature provide a snapshot of where ALDFG exists and is of sufficient concern to drive scientific inquiry (Figure 2.2). These publications provide evidence for where ALDFG occurs, but cannot be extrapolated to any kind of global measure of presence/absence or relative density due to limited ALDFG presence and absence data, i.e. areas or regions with sparse to no data do not indicate less or no ALDFG.

A study estimating global rates of fishing gear losses also provides a snapshot of where quantitative gear loss studies have been conducted and the major gear types lost (Richardson *et al.* 2019a) (Figure 2.3):

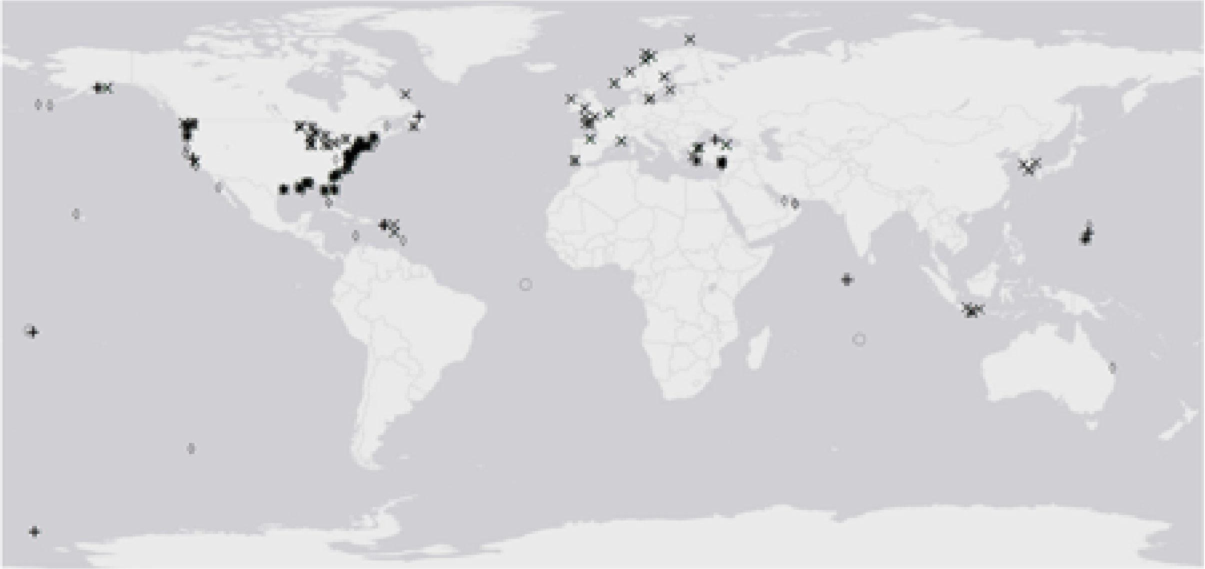

Figure 2.3: *Geographic areas for studies reviewed in Richardson et al. 2019a.*
Studies focusing on net fisheries indicated by X*; traps by* ◊*; lines:* o*; fish aggregating devices (FADs):* +*.*

Fig. 2.4: *Countries contributing ALDFG data to the GGGI database (Map courtesy of the GGGI).*

The Global Ghost Gear Initiative (GGGI) collates data collected worldwide on the occurrence and impacts of ALDFG through its ghost gear data portal.[4] This data repository contains data from 49 countries, as of 2020 (Figure 2.4). Again, it is important to note that this map is not a map depicting areas of high concentration or accumulation, because it does not convey quantity or type of ALDFG, and therefore does not illustrate whether some countries or regions have more or less data in the repository, and by extrapolation, more or less ALDFG. Similarly, this map does not reflect ALDFG "absence" data, i.e. areas where ALDFG surveys have occurred and no ALDFG was observed.

2.2 Causes for abandonment, loss or discard of fishing gear

A range of environmental, conflict-based, management-related and operational causes result in ALDFG; the frequency and magnitude of ALDFG events vary across fisheries and regions. Gear can be lost on a regular basis as a result of the normal use of gear (e.g. hook bite-offs in longline fisheries). In multi-user areas, vessel traffic and gear conflict with other harvesters often results in gear loss. Gear can also be lost episodically or catastrophically when an irregular situation occurs during normal fishing operations (e.g. an extreme weather event). ALDFG can include a complete gear or a portion of a gear with or without one or more components still present (e.g. section of net mesh, with or without a lead line, or a rope and buoy).

The potential for fishing gear to become ALDFG depends on the geographic, operational and gear-type context, such as the depth where fishing occurs, whether the gear is tendered by a vessel and how often, gear size, soak times, and whether the gear contacts the seafloor or other obstacles. For example, bottom gears such as bottom trawls, and set gillnets and longlines, are often more at risk of becoming ALDFG compared to midwater or pelagic gears because these gears are more likely to become snagged upon obstacles on the seafloor. Passive and/or unattended gear types where fishers have less control over the gears while fishing, such as many types of traps, gillnets and entangling nets, are also more likely to become ALDFG as there is less opportunity for a fisher to intervene to prevent gear loss without active monitoring and/or control of their gear(s). Pots are generally more likely to become ALDFG compared to other trap types, often due to influences from bottom contact, weather events, interactions with other vessels and relatively larger numbers deployed (Gilman *et al.* 2021; Macfadyen *et al.* 2009). Hooks and lines are additionally often lost as a result of normal operations (e.g. regular bite-offs from wildlife or breakage of lines into fragments) (Richardson *et al.* 2019a).

In recreational fisheries, line and lead weights are often discarded or lost during tackle manipulation (Forbes 1986). The amounts of discarded recreational line and weights found in the aquatic environment varies depending on the intensity of the fishing pressure, type of aquatic habitat and angler skill (Rattner *et al.* 2008). Shoreside anglers in the United States are prone to lose more gear due to terrain compared to vessel-based anglers (Radomski *et al.* 2006), and the depth range of target species significantly influences the amount of gear losses that can occur (i.e. pelagic vs. demersal).

2.2.1 *Environmental causes*

The environmental conditions under which fishing occurs contribute to the abandonment, loss or discard of fishing gears in a variety of ways. Seafloor topography, primarily in the form of naturally occurring and man-made underwater obstructions, can cause gear to become snagged, making it difficult or impossible to recover the gear during fishing operations (Ayaz *et al.* 2010, Erzini *et al.* 2008; FAO 2016; Macfadyen *et al.* 2009; MacMullen *et al.* 2002; Matsuoka *et al.* 2005; Santos *et al.* 2003; Thomas *et al.* 2020; Wibowo *et al.* 2017). When gear is snagged on seafloor obstructions, fishers may attempt to recover as much of the gear as possible before cutting the remaining gear loose (often nets), thus leaving the snagged portion and the section of gear leading to the sea surface at the snag location. If gear retrieval is initially unsuccessful, fishers may return to the location where gear was left under better weather or ocean conditions (such as during a slack tide), sometimes with assistance from other fishers, to re-attempt the recovery of the snagged gear (Antonelis 2013; FAO 2016).

Tides, currents, waves, and heavy winds also play a role in gear losses (Breen 1989; Erzini *et al.* 2008; FAO 2016; Macfadyen *et al.* 2009; Özyurt *et al.* 2012). Strong currents and heavy winds can force marker buoys and surface-set nets underwater, making it difficult for fishers to find and retrieve the gear. Forceful currents, winds, and waves can sweep underweighted gear off position, making it difficult or impossible to locate (Bilkovic *et al.* 2016; Drinkwin 2016; Erzini *et al.* 2008; Sumpton *et al.* 2003). Extreme cases of such gear loss incidents occur during natural hazard events such as hurricanes and tsunamis, which can lead to large localized and regional accumulations of ALDFG (Lewis *et al.* 2009; Macfadyen *et al.* 2009; Uhrin 2016; Uhrin *et al.* 2014). In colder regions, sea ice can drag static gear, cut buoy lines and force buoys underwater, resulting in gear damage and losses (CFCL 1994; Long *et al.* 2014; Mallet *et al.* 1988; Webber and Parker 2012). Dangers associated with fishing operations in inclement weather and poor sea conditions may cause gear abandonment, in addition to gear loss, as fishers may choose not to retrieve their gear due to the hazards present (FAO 2016; Macfadyen *et al.* 2009).

Wildlife interactions with fishing gear can also foul, damage, and move gear off position, which can lead to gear losses. This is more likely to occur with static gears such as longlines, set gillnets and pot gear. Likely the most publicized version of this type of gear loss concerns large whale entanglements in vertical lines from fixed-gear fisheries in North America. North Atlantic right whale entanglements in United States lobster pot and in Gulf of St. Lawrence snow crab fisheries, and more recently humpback, grey, and blue whale entanglements with vertical lines in the Dungeness crab fisheries on the United States West Coast, have raised serious concerns about wildlife impacts due to

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[4] https://globalghostgearportal.net

the strict levels of federal and international protections placed on these large cetaceans (NOAA Fisheries 2018). While the associated cetacean injuries and mortalities are the primary concern in these gear interactions, the gear components that they are entangled in essentially become ALDFG following the cetacean's interaction with the gear even if the gear was active when the entanglement occurred (Richardson *et al.* 2019b). Distinguishing between whale entanglements originating from active gear and ALDFG is a current knowledge gap described in Chapter 8 of this report. Other examples of wildlife interactions causing ALDFG include large sharks breaking longlines, gillnets and marker buoys (Anderson and Waheed 1990; Campbell and Sumpton 2009), and sea lions puncturing inflatable marker buoys (High and Worlund 1979).

2.2.2 *Conflicts with other fishing gear and vessels*

Gear conflicts primarily occur in areas with high concentrations of fishing activities. Passive gear such as pots and set gillnets are particularly prone to being towed away or damaged, either unintentionally or deliberately, by active gear such as trawls, trolls, or dredges in places where they are used concurrently (FAO 2016; Macfadyen *et al.* 2009). Inversely, relatively lighter active gear such as troll gear can become snagged, broken, and eventually abandoned or lost due to entanglement in passive gear such as pots, bottom longlines or anchored nets. When gear items are set too close to other gear, even for the same gear types and even when the gears are properly marked, gear components such as lines can wrap and become entangled with other nearby gear items (Al-Masroori *et al.* 2009; Antonelis *et al.* 2018; Drinkwin 2016; Erzini *et al.* 2008; Kim, Park *et al.* 2014; Özyurt *et al.* 2012). Overcrowded fishing grounds can additionally put pressure on fishers to set gear in marginal areas, which can eventually lead to gear loss from other causes (e.g. gear snagged on seafloor obstructions, gear run over in shipping lanes) (Antonelis 2013; Richardson *et al.* 2018).

Popular fishing grounds can also lead to conflicts among fishers in the form of tampering, sabotage, vandalism and theft of fishing gear, all of which can cause ALDFG. Cross-sectoral (i.e. across commercial, recreational, and/or artisanal fishing sectors) and intra-sectoral competition for fishing grounds and harvest can cause animosity and adversarial relationships among fishers, which often occur where fixed/static gear are the primary gear type (Ayaz *et al.* 2010; Macfadyen *et al.* 2009). In such situations, buoy lines are cut, leaving passive gear and a portion of the buoy line on the seafloor and/or in the water column (Breen 1989 Guillory *et al.* 2001; NRC 2018; Perry *et al.* 2003; Swarbrick and Arkley 2002). Vandalized buoy lines are also sometimes coiled after being cut and stuffed into the pot with the buoy before being re-deployed as discarded fishing gear, leaving no markers for gear identification and/or retrieval (NRC 2013, 2018).

High concentrations of ALDFG from commercial and recreational fisheries occur in high vessel traffic areas. Passing vessels of all kinds can strike marker buoys and their associated lines, resulting in either a severed buoy line, net or other pieces of gear wound in the propeller of a vessel, or the buoy line and all attached gear being dragged away with the passing vessel, thereby making it more difficult to find (Al-Masroori *et al.* 2009; Antonelis *et al.* 2011, 2018; Bilkovic *et al.* 2016; Long *et al.* 2014; Macfadyen *et al.* 2009; NRC 2018; Thomas *et al.* 2020).

2.2.3 *Fisheries management and regulations*

Inadequate fisheries management, including insufficient controls that limit the amount of fishing effort, such as soak time, gear size, number of vessels, number of new entrants and number of fishing days available per year, can also contribute to ALDFG (Antonelis 2013; FAO 2016; Gilman 2015; Richardson *et al.* 2018). When multiple fisheries using different gear types are allowed to fish on the same fishing grounds without spatial or temporal restrictions, the likelihood of gear loss increases from overcrowding, competition and conflicts among fisheries (FAO 2016; Gilman 2015; Macfadyen *et al.* 2009; Thomas *et al.* 2020). The lack of adequate port waste reception facilities for end-of-life fishing gear can cause ALDFG via deliberate discarding of old, damaged, and unwanted gear at sea due to the time, cost, inconvenience and/or lack of availability of gear disposal at land-based waste facilities (FAO 2016; Gilman 2015; Macfadyen *et al.* 2009; Matthews and Glazer 2010). (Additional discussion on discarding of fishing gear is covered in Chapters 4 and 5).

Fishery management schemes with insufficient gear-marking or no gear-marking requirements at all also contribute to ALDFG. Gear that is poorly marked, i.e. with no marker buoys or buoys made of balloons or reused plastic bottles, may not be seen by other vessels or fishers, and as a result gear may be lost due to entanglement with other fishing gear, interaction with vessels, or simply because it is not possible to locate where the gear was originally set (Gilman 2015; Guillory *et al.* 2001; Macfadyen *et al.* 2009). No gear marking requirements, or minimal requirements that do not include sufficient owner identification or are not connected to a centralized gear loss reporting system, can result in an increased propensity by fishers to abandon or intentionally discard their fishing gear without repercussions for doing so if the ALDFG cannot be traced back to them (FAO 2016; Gilman 2015; He and Suuronen 2018).

Deliberate gear abandonment or discard is often related to IUU fishing. IUU contributes to ALDFG through deliberate lack of communication among fishers and other resource users; gear abandonment when operating in marginal or unauthorized areas, operating in poor weather or at night to conceal activity, and abandonment of illegal fishing gear from the boat when inspection authorities approach the vessel (CFCL 1994; FAO 2016; Gilman *et al.* 2016 ; Hareide *et al.* 2005; Macfadyen *et al.* 2009; Masompour et al. 2018; Richardson *et al.* 2018). While these authors and others posit that IUU fishing contributes to ALDFG, there are no estimates on the quantity of ALDFG that is resulted from IUU fishing. Exact quantification of the economic impacts arising from IUU activities is rather difficult due to the basic nature of IUU fishing (FAO 2020b).

In some parts of the world certain fisheries management measures and regulations may unwittingly contribute to ALDFG. For example, in some parts of the United States and Canada, local or regional regulations may forbid fishing vessels to carry on board any fishing gear owned by another fisher (NRC 1990). This law is understandably in place to deter fishers from stealing and/or tampering with other fishers' gear. However, in situations when fishers observe ALDFG on fishing grounds or during transit, these laws essentially prohibit the recovery of such gear, and the legal penalties can outweigh the benefits of gear retrieval. In contrast, in northwestern Europe, Fishing for Litter campaign enables and encourages the recovery of ALDFG and other types of marine litter by fishers, at no cost to the fishers for disposal.[5]

2.2.4 *Operational losses and operator error*

ALDFG often simply results from normal fishing operations onboard a vessel or from common operational error by the captain and/or crew. For example, the footrope (and in some locations, the dolly ropes) on a bottom trawl may break due to constant wear on the seafloor if not properly maintained or replaced in a timely manner (Dolly Rope Free 2018). Hooks and parts of branch lines on longline gear are frequently bitten off by target and non-target species (Richardson *et al.* 2018; 2019b, Ward *et al.* 2008). Combinations of risky environmental conditions and gear types more prone to gear losses can increase the likelihood for ALDFG, such as the use of demersal gear on a rough seafloor in inclement weather. Gear may be abandoned or cut adrift and discarded for safety reasons during fishing operations occurring in severe weather conditions or when gear inadvertently drifts into high-traffic shipping lanes (Antonelis 2013; Macfadyen *et al.* 2009; FAO 2016; Gilman 2015). Vessels may deploy more gear than can be retrieved on a trip, which can lead to longer soak times and, in turn, greater potential for gear to become lost due to a variety of factors such as conflict, strong currents, and inclement weather (FAO 2016; Gilman 2015; Macfadyen *et al.* 2009; Richardson *et al.* 2018). Old and/or damaged gear is more likely to break and produce pieces of gear that are lost, and often the operational costs of attempting to recover old and damaged gear outweigh the benefits of gear retrieval (Macfadyen *et al.* 2009).

To some degree, gear losses can also be associated with the level of operator and competency, experience and knowledge of crew. Standard operations can cause unintended gear entanglement, snagging, vessel interactions or movement that can eventually result in gear abandonment if a fisher is not aware of changes in water depth, tidal shifts, currents, or vessel traffic in a given area (Antonelis 2013). While vessels equipped with navigation technologies such as radios, depth-sounders, GPS, benthic mapping instruments, and gear marking/tracking features improve a fisher's awareness of fishing grounds, even when such technologies are employed, the normal, often complex nuances of fishing operations regularly create challenges at sea that are best addressed with fishing competency gained by experience. Greater overall fishing experience can prevent gear losses arising from incorrectly assembling and maintaining gear or using damaged or faulty equipment that fails during fishing operations (Bilkovic *et al.* 2016; Hareide et al, 2005; Macfadyen *et al.* 2009; NRC 2018; Perry et al. 2003). Accidental loss of gear under repair on board due to improper stowage can occur.[6]

2.3 Quantity and impact of marine litter from fishing

2.3.1 *Historical Estimations of ALDFG*

The oft-referenced estimate that 640,000 tonnes of ALDFG are lost annually to the world's ocean likely originated from a now 45-year old study by the National Academy of Sciences (NAS) of the United States that examined marine litter, including litter from commercial fishing, as part of a larger study around assessment of ocean pollutants (NAS 1975). The NAS study estimated that 6.4 million tonnes of litter enter the world's ocean each year from a variety of sea-based sources, including passenger vessels, merchant vessels (crew and cargo), recreational boating, commercial fishing (crew and gear), military, oil drilling and platforms and catastrophic events. The NAS study assumed that all litter generated onboard vessels was discharged overboard, and noted that this is likely to be concentrated in the Northern Hemisphere and along coastlines, given the scope of vessel activity in these regions at the time of the study.

A crude approximation of ALDFG as comprising less than 10% of global marine litter by volume was later posited by a 2009 UNEP-FAO study (Macfadyen *et al.* 2009). Ten per cent of the NAS study estimation of 6.4 million tonnes of marine litter from sea-based sources equates to 640,000 tonnes, which could explain where this frequently cited estimate of the global annual burden of ALDFG was derived. However, the 1975 NAS study roughly estimated the portion of marine litter comprising gear from commercial fisheries (as distinct from other categories of marine litter coming from fishing vessels) to be 1,350 tonnes per year.[7] Any estimate will always be subject to uncertainties and unknowns, given the nature of what is being estimated. Considering the dramatic variances in these two estimates – 1,350 tonnes versus 640,000 tonnes – and the significant changes that have occurred over the last 50 years in the global scale of commercial fisheries and the materials used in the manufacturing of gear, a more current and accurate estimate on the portion of marine litter that is ALDFG is urgently needed. Undertaking this estimation will require reliable data from fisheries, whether they are obtained from surveys of fishers or from mandatory or voluntary reporting of loss or abandonment, and the application of statistical modelling to published and unpublished data on fishing effort and location, quantities of gear deployed, and rates of loss (and replacement), especially in parts of the world where data is scant.

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[5] https://fishingforlitter.org

[6] https://www.wur.nl/en/news-wur/Show/Fishing-net-litter-on-beaches-what-can-be-done-to-prevent-this.htm

[7] This number was derived by multiplying FAO's estimations for numbers of fishing vessels over 5 gross tonnes globally in 1971 by a 1972 commercial fishing equipment loss rate for Alaskan fisheries in the Gulf of Alaska. The Gulf of Alaska commercial fishing gear loss rate was determined by dividing the amount of gear losses in the Alaskan Gulf in 1972 by the number of ships in the Alaskan Gulf in 1972, using data from the US Department of Commerce.

2.3.2 *Quantity of ALDFG*

It is important to know the amount of ALDFG, including the loss rates for different gear items, to understand the size and scope of the problem and associated impacts, and to identify appropriate prevention and mitigation interventions at scale. Fishing gears are custom designed to catch target species, which themselves vary across regions and for which gears designed to catch them vary also. Therefore, most research conducted on amounts of ALDFG is specific to particular gear types and/or geographic areas (Al-Masroori *et al.* 2009; Bilkovic *et al.* 2014; Dagtekin *et al.* 2018; Hareide et al. 2005; Kim, Lee *et al.* 2014; Kim, Park *et al.* 2014; Maufroy *et al.* 2015; Santos *et al.* 2003; Shainee and Leira 2011; Webber and Parker 2012). Such gear and location-specific research on amounts of ALDFG is important for understanding the issue on local levels, and for designing prevention and mitigation interventions appropriate to these locations and gear types. Some areas of the world have conducted considerable work in quantifying ALDFG locally and for specific gear types, such as research around blue crab pot losses in the United States (Bilkovic et al, 2014, 2016; Guillory et al, 2001; Havens et al, 2008; McKenna and Camp 1992; Scheld *et al.* 2016); Dungeness crab pot losses in the United States (Antonelis *et al.* 2011; Barry 1983; Breen 1989; Northup 1978; Paul et al, 1994; PMFC 1978; Tegelberg 1974); gillnets and entangling nets, and pot and trap losses in Turkey (Ayaz *et al.* 2004, 2010; Özyurt et al, 2008, 2012; Tasliel 2008; Yildiz and Karakulak 2016); and gillnet and entangling net losses in Europe and the UK (Hareide et al, 2005; MacMullen *et al.* 2002, Santos et al. 2003). The first study from India on the causes and levels of ALDFG in selected gillnet and trammel net fisheries found significant losses of both fish and gear (Thomas *et al.* 2020).

While studies on amounts of ALDFG are important and relevant in their local contexts, large knowledge gaps remain concerning amounts and rates of ALDFG on regional and global scales, and across many major gear types. For example, quantitative information about ALDFG amounts and loss rates are minimal to non-existent in Africa, Antarctica, Asia and South America; and for FADs (both anchored and drifting), handline and pole-line losses and trawl net losses. Most ALDFG studies that summarize amounts of ALDFG and/or gear loss rates that are larger in geographic scope were conducted more than a decade ago (Breen 1989; Brown and Macfadyen 2007; Gilman *et al.* 2016; Macmullen *et al.* 2002; Macfadyen *et al.* 2009; NRC 1990; O'Hara and Iudicello 1987). For parts of the world where little to no information exists about amounts and types of ALDFG, applicable regional and global ALDFG estimates could be useful as proxies for managers and decision-makers in attempting to understand the scale of the ALDFG issue for their respective localities and fisheries.

Efforts to estimate ALDFG globally were completed by Richardson *et al.* (2019a). For this study, a total of 68 publications from 1975 to 2017 were reviewed to estimate fishing gear losses over specified time intervals to determine amounts and rate of loss of ALDFG, while identifying key gear characteristics and operational and environmental contexts that influence gear loss. The reviewed literature spanned 32 countries and territories across the Atlantic, Indian, Pacific and Southern Oceans and the Baltic, Caribbean and Mediterranean Seas (see Figure 2.3). Publications were generally more biased to the United States and Europe, and toward pot and net fisheries, with limited literature for line fisheries. Recognizing limitations in the availability of literature and existing knowledge gaps, the authors estimated that 5.7% of all fishing nets, 8.6% of all traps and 29% of all lines are lost to the world's ocean annually (Richardson *et al.* 2019a). More specific estimates for a variety of sub-gear types, as well as how loss rates vary with different benthic habitats, were also evaluated (Tables 2.2, 2.3 and 2.4).

Net Type	**Average annual percentage of net loss**
Gillnets and Entangling Nets	***5.8***
Drifting gillnets	3.1
Set and fixed gillnets:	8.4
Hard bottom	2.7
Soft bottom	7.2
Mixed bottom	4.9
Bottom type unknown	19.0
Miscellaneous nets	***1.2***
Purse seines*	***6.6***
Seine nets*	***2.3***
Trawl nets*	***12.0***
Midwater trawls	7.0
Bottom trawls:	18.0
Soft bottom	10.0
Bottom type unknown	26.0
All net types	***5.7***

* Net fragments, not whole nets

Table 2.2. Average percentages of nets lost globally (calculated with 95% confidence intervals), applicable to vessels and fleets. Major gear types are presented in bold, with corresponding sub-gear types and habitats in which sub-gear types are deployed (as relevant), are listed under them. Table content from Richardson *et al.* (2019a).

Trap Type	Average annual percentage of net loss
Pots	***19.0***
Hard bottom	25.0
Soft bottom	18.0
Mixed bottom	22.0
Bottom type unknown	11.0
Fyke nets	***4.1***
Hard bottom	5.9
Bottom type unknown	2.4
Pound nets	***2.6***
All trap types	***8.6***

Table 2.3. Average proportion of traps lost globally, including pots, fyke and pound nets (calculated with 95% confidence intervals), applicable to vessels and fleets. Major gear types are presented in bold, with corresponding bottom types in which gear are deployed (as relevant), are listed under them. Table content from Richardson *et al.* (2019a).

Line Type	Average proportion of net loss
Handlines	0.23
Pole-lines	0.65
Longlines	0.20
Hooks, longlines	0.17
Trolling lines	0.22
All line types	0.29

Table 2.4. Average proportion of lines lost globally (calculated with 95% confidence intervals), applicable to vessels and fleets. From Richardson *et al.* (2019a).

The study by Richardson *et al.* (2019a) posits that while estimates should be applied conservatively and recognizes data limitations of the review, the data and their synthesis are useful for further analysis. For areas of the world where more extensive research has already been undertaken, such locally focused and fishery-specific studies should be considered most relevant for estimating quantities of ALDFG (i.e. referred to preferentially) over updated global estimates (Bilkovic *et al.* 2016, Dagtekin *et al.* 2018, Erzini et al. 2008, Maufroy *et al.* 2015, Özyurt et al. 2012, Yildiz and Karakulak 2016). However, for areas of the world and gear types with major knowledge gaps, global estimates can be used as a proxy and additional reference in exploring the nature of ALDFG where no data or information may otherwise exist.

Despite the fact that large numbers of people fish recreationally, no estimates of ALDFG resulting from recreational fishing exists. Annual estimates of lead fishing tackle sold by wholesalers, which could help estimate fishing gear lost in the aquatic environment (marine and inland/freshwater) are 2,000 to 6,000 metric tonnes per year in Europe and 5,500 metric tonnes per year in the United States and Canada combined (Haig *et al.* 2014; Rattner *et al.* 2008). However, because many anglers purchase new gear as surplus (Radomski *et al.* 2006), these numbers do not easily correlate with the amount deposited in the marine environment (Haig *et al.* 2014). Research conducted in the United States reported that shoreside anglers lost 0.18 lead sinkers per hour and 0.23 hooks and lures per hour (Duerr 1999); vessel-based anglers in the North American Great Lakes region reported loss rates of 0.0127 lures per hour, 0.0081 large lead sinkers per hour, 0.0057 small (split-shot) sinkers per hour, 0.0247 jigs per hour, and 0.0257 hooks per hour (Radomski *et al.* 2006). In South Wales, an estimated 13.7 m of fishing line was lost per recreational fisher annually in coastal and inland areas (FAO 2012).

2.3.3 *Impact of litter from fishing*

2.3.3.1 Economic losses

ALDFG causes economic impacts to fishers and associated fisheries, including direct and indirect losses. The direct financial losses from the loss of the gear itself and any target species caught in the gear can be substantial depending on the gear type, magnitude of gear loss and the commercial importance of the target fishery. The indirect or "hidden" costs are multifaceted, and include: lost fishing opportunities due to non-availability of gear in hand (especially for the fishers who do not have spare gear available for an immediate replacement); loss in value of future landings that might have otherwise been available to the fishers from use of the lost gear item; loss in value due to ghostfishing by ALDFG, now no longer available for fishers to catch and from which to profit in the future; retrieval costs including time and fuel costs to search for the lost gear; and costs incurred by fishers to replace lost gear (Arthur *et al.* 2014; Bilkovic *et al.* 2014; Butler *et al.* 2013; NOAA 2015).

Global estimates on economic costs of ALDFG are not available. However, in a global analysis model based on findings from Chesapeake Bay, Scheld *et al.* (2016) esimated that USD 831 million in landings could be recuperated annually if less than 10% of the derelict pots from major crustacean fisheries were removed globally). This estimate around financial returns from recovered ALDFG pots is an indication of the potential level of global economic losses due to ALDFG, especially when considering all major fisheries and associated gear types.

Financial and economic costs incurred from ghost fishing gear on regional and local scales have been reviewed (Macfadyen *et al.* 2009; NOAA 2015). In Oman, a study that simulated ghost fishing from lost fish traps estimated that 90% of the ghost fished catch in the traps was of commercial value, with values estimated at USD 168 million (Al-Masroori *et al.* 2009). An experimental ghost fishing study in the Cantabrian region of Spain estimated cumulative commercial monkfish catches from derelict tangle nets to represent 1.46% of the area's total commercial landings (Sancho *et al.* 2003). Gillnets experimentally set in the Baltic Sea to test cod ghost fishing showed ghost fishing catch rates stabilizing around 5% to 6% of the normal catch for these nets after 27 months of ghost fishing, with the expectation that this catch rate could continue for many more years (Tschernij and Larsson 2003). Deepwater gillnets monitored in the Norwegian Greenland halibut fishery showed ghost fishing catch rates of 20% to 30% of equivalent catch from nets normally operating in this fishery, with this catch rate expected to continue for "long periods of time" (Humborstad *et al.* 2003). Antonelis *et al.* (2011) estimated that 178,874 Dungeness crabs were killed annually in derelict crab pots in Washington state, in the United States, which represented an economic loss of over USD 744,000, or 4.5% of the 5-year average (2004-2008) ex vessel value of recent crab harvest. Sullivan *et al.* (2019) estimated a total ghost fishing loss of USD 19,601, or USD 40 in ghost fishing losses per lost blue crab pot in New Jersey, United States. Additionally, competition between active fishing gear and nearby ALDFG has been shown to reduce catch rates in the active gear, therefore decreasing economic efficiency of fishing operations (DelBene *et al.* 2019). Estimates on economic losses due to lost fishing time resulting from gear losses are very limited; Watson and Bryson (2003) reported GBP 20,000 worth of lost fishing time in 2002 for one creel-based fishery in the UK.

ALDFG recovery costs, compared to the benefits derived from gear recovery, can vary significantly and can sometimes outweigh the economic benefits. Brown and Macfadyen (2007) used data from interviews and published costs and earnings from a UK gillnet fishery to estimate the costs of a hypothetical EU gillnet retrieval programme. Their model showed an overall cost–benefit ratio of 0.49, with financial costs of net recovery outweighing the benefits of removing ghost fishing gillnets (overall net costs of EUR 23,836, which represents the difference between 46,500 euros in costs to remove the gear and EUR 22,664 in net removal benefits). However, other studies have shown economic advantages of gear recovery. In the United States, the cost to remove an abandoned gill net that can cause the loss of more than USD 20,000 worth of Dungeness crab over 10 years was only USD 1,358 (Gilardi *et al.* 2010). Furthermore, in some cases fishers can directly benefit from their recovery efforts, when funding programmes are used, which was the case in a programme described by Sullivan *et al.* (2019) where over the course of four years, USD 42,373 was directly paid to the commercial partners of a lost gear recovery programme. Given significant financial investments required for gear recovery, some form of a cost–benefit analysis is likely to be helpful in determining tradeoffs between economic costs of gear recovery and benefits derived from such recovery efforts. That said, because financial implications are reported in different currencies over different timeframes, comparisons among studies must be made with caution.

2.3.3.2 Reduction of target and non-target resources

Most fishing gear is designed to catch targeted species; however, this attribute can result in negative impacts to target and non-target species when the gear is lost, especially in the case of gillnets and pots. Whether drifting at sea or deposited on the seabed, ALDFG can become a trapping agent for marine organisms, including endangered species. Good *et al.* (2010) reported over 100 species in recovered derelict salmon gillnets in the Puget Sound, United States, including mammals, birds, finfish and invertebrates. Abandoned, lost or otherwise discarded (ALD) pots from the recreational Dungeness crab fishery in the Puget Sound account for the mortality of more than 110,000 harvestable Dungeness crab per year (Antonelis *et al.* 2011). Silliman and Bertness (2002) reported that *Malaclemys terrapin*, the only entirely estuarine turtle species in the Chesapeake Bay and a keystone species due to its influence on the community structure of intertidal marshes, is at high risk of mortality due to impacts from ALDFG and ghost fishing. Abandoned, lost or otherwise discarded blue crab traps on the East Coast of the United States and in the Gulf of Mexico capture and kill not only target species but also a variety of non-target species, several of which are important to regional commercial and recreational fishing (Bilkovic *et al.* 2014; Grosse *et al.* 2009; Hallas 2018; Heiser 2018; VIMS 2019).

2.3.3.3 Marine wildlife morbidity and mortality

Documentation of incidences of marine wildlife entanglement in and ingestion of marine litter have doubled in the period 1997 to 2015 from 267 to 557 (Kühn *et al.* 2015). Of marine wildlife species, 100% of marine turtle species (7 extant species), 66% of marine mammal species (123 extant species) and 50% of seabird species (406 extant species) have been reported to have been entangled with and/or ingesting plastic marine debris (Kühn et al. 2015). Total 192 species of invertebrates and 89 species of fish have been reported as entangled in marine litter, resulting in wounds and/or death (UNEP 2016). Marine organism entanglement in coral reef systems affected 418 species across eight taxa with serious adverse conservation implications (Carvalho-Souza *et al.* 2018).

While marine wildlife entanglement occurs across most major types of marine litter, the bulk of the reported marine wildlife entanglement incidences are due to ALDFG (e.g. Adimey *et al.* 2014; Ainley *et al.* 1990; Allen *et al.* 2012; Casale *et al.* 2010; Galgani et al, 2018; Goldstein *et al.* 1999; Laist 1997; McFee *et al.* 2006). Entanglement is known to cause mortality in sea turtles, pinnipeds and sharks (Jepsen *et al.* 2019); Parton *et al.* 2019; Stelfox *et al.* 2015, 2016, 2019). Almost 98% of the marine litter entanglements of cetaceans were by ALDFG, mostly by pot lines and nets (Baulch and Perry 2012); however, to what extent those gears were already ALDFG versus active gear at the time of entanglement (becoming ALDFG after entanglement) is not known (Simmonds 2012). For example, Nitta and Henderson (1993) described entanglement of Hawaiian monk seals and green sea turtles in ALDFG as secondary interactions with gears no longer actively in use. A global review on ghost gear interactions with wildlife revealed that more than 5,400 individuals representing 40 species were either entangled in or associated with ghost nets (Stelfox *et al.* 2016), compromising 3,834 marine mammals, 1,487 reptiles and 119 elasmobranchs. The proportion of species of seabirds recorded entangled in marine litter ranges from 25% (Kühn *et al.* 2015) to 36% (Ryan 2018). Papers published from 1940 to 2019 and social media reports on shark and ray entanglement with marine debris showed that 74% of 557 entangled sharks and rays were entangled in ghost fishing gear (Parton *et al.* 2019).

Impacts from entanglement include reduction in food intake and limitation in movement, which is especially important in protection against predator attack (Kühn et al. 2015); wounds on body parts that can result in secondary infections (NOAA 2014) and death from starvation following compromised feeding capacity due to entanglement (Cho 2011; Erzini *et al.* 2008; Good *et al.* 2010; June 1990). Records of entanglement in ALDFG are easier to collect than those of ALDFG ingestion, which require detailed analyses including dissection of gastrointestinal tracts to determine the material ingested (Richardson *et al.* 2019b). All sea turtle species, more than half of all marine mammal species, and 40% of procellariform species (albatrosses and petrels) have been reported to suffer from fishing gear ingestion (Werner *et al.* 2016). Ingestion of fishing hooks, lures and lead sinkers also cause injury and mortality to birds, turtles, fish, and marine mammals through toxicity and perforation or obstruction of the alimentary tract (Butterworth et al. 2012; Dau *et al.* 2009; Haig *et al.* 2014; Rattner *et al.* 2008; Raum-Suryan *et al.* 2009; Reinert *et al.* 2017).

ALDFG impacts to marine wildlife from gears commonly associated with hook-and-line fisheries and recreational fisheries are well documented. Monofilament line that is looped around the neck or flipper of marine mammals can become embedded in the animal's skin, muscle and fat, causing severe and chronic open wounds and infection, and in some cases, necrosis-induced loss of limbs (Butterworth et al. 2012; Reinert *et al.* 2017). Monofilament line entanglements can have similar impacts on sea turtles (Laist 1997; Robins *et al.* 2007). Monofilament line that entangles seabirds can cause loss of body parts or prevent birds from flight, nesting, and/or foraging activity (Butterworth *et al.* 2012; Dau *et al.* 2009).

2.3.3.4 Damage to marine habitats

ALDFG that settles on seafloor habitats, especially in rocky and coral substrates, can adversely affect surrounding benthic communities. Once ALDFG settles at the bottom, the corals and other benthic organisms beneath the nets become smothered by sediments, causing mortality (Erftemeijer *et al.* 2012; Katsanevakis *et al.* 2007; Rogers 1990). In a study examining the impact of ALDFG on corals around Koh Tao, Thailand, 143 ALDFGs were observed to have caused tissue loss, damage and fragmentation for 340 corals underneath and 1,218 corals close to the ALDFGs (Ballesteros *et al.* 2018). Tissue loss and fragmentation in corals in contact with debris are reported in the reef areas of the Gulf of Mannar in southeast India (Edward *et al.* 2020). Entanglement with lost longlines caused extensive damage to gorgonians in the Portofino Marine Protected Area, Ligurian Sea, NW Mediterranean Sea) (Betti et al. 2020). Similar damage was recorded in the Tyrrhenian Sea (Mediterranean Sea), where the highest percentage (49.1%) of impacts caused by ALDFG (primarily longlines) was observed on coralligenous biocenosis within depth ranges of 41 m to 80 m (Consoli *et al.* 2019). These habitat impacts are further exacerbated by risks associated with ALDFG removal and retrieval, which can lead to fragmentation, abrasion and tissue damage to corals already impacted by ALDFG (Consoli *et al.* 2019). Extensive studies to follow up on impacts of bleaching on coral reefs in the Indian Ocean from 1999 to 2008 noted damage due to lost fishing nets and lines on reefs in all the countries where investigations were undertaken (Tanzania, Mozambique, Kenya, Seychelles, Mauritius and Sri Lanka) (Linden *et al.* 2002; Obura *et al.* 2008; Souter *et al.* 2000, Souter and Linden 2005). Lost hook-and-line gear has been documented to impact sponges and benthic cnidarians, primarily via individual colony mortality (Chiappone *et al.* 2005). Monofilament line degrades coral colonies, leaving them damaged with high rates of mortality compared to those without ALD monofilament line present (Asoh *et al.* 2004; Consoli *et al.* 2019; FAO 2012). Al-Jufaili *et al.* (1999) reported that ALDFG caused 49% of coral damage along the Sultanate of Oman and accounted for 70% of all severe human-induced impacts. Similar ALDFG impacts by other fishing gear types on the coral reefs of the Northwestern Hawaiian Islands were documented in Donohue *et al.* (2001) and Donohue and Schorr (2004). Risks also exist around the introduction of invasive species, including pathogens that can settle and colonize on ALDFG and other floating litter items (Katsavenakis *et al.* 2014; Kiessling *et al.* 2015; Link et al. 2019; Pham *et al.* 2012; Sweet *et al.* 2019).

2.3.3.5 Social impacts

An understanding of the social impacts of ALDFG remains limited (Ten Brink *et al.* 2009). ALDFG negatively impacts people's quality of life by reducing recreational opportunities, loss of aesthetic value of recreational facilities and natural areas, and the loss of non-use values such as clean beaches and coastal areas (Cheshire *et al.* 2009). Secondary impacts from ALDFG damage to marine biota and benthic habitats can result in compromises to the availability and effectiveness of ecosystem services for coastal communities (GESAMP 2015). Additional resource costs can be incurred by coastal communities from ALDFG prevention and clean-up initiatives, and losses to tourism presence and revenue. Most of the ALDFG-related socio-economic impact studies more broadly cover impacts from a wider range of marine litter items, including ALDFG, to beaches and coastal areas, often with a focus on adverse impacts to coastal tourism. For example, a beach closure due to marine pollution and debris wash up in New York in 1988 resulted in a loss of USD 379 million to USD 1.6 billion to the tourism industry and USD 3.6 billion to other associated revenue streams (Ofiara and Brown 1999).

2.3.3.6 Loss of human life

It must be noted that at least one incident of a vessel sinking as a result of debris entanglement has been reported, resulting in significant loss of life: the Korean Maritime Accident Investigation Agency reported that the 110 GT ferry *M/V Soe-Hae* sinking in 1993 was caused in part by fishing ropes around the propellers, leading to 292 human fatalities (Cho 2005).

2.3.4 *Case study: the Chesapeake Bay*

An example of definitive research on the ecological and economic impacts of ALDFG in a specific water body was conducted in the Chesapeake Bay on the US Atlantic Coast (Bilkovic *et al.* 2016). The Chesapeake Bay is an 11,600 km2 estuary on the US Mid-Atlantic Coast situated between the states of Virginia and Maryland. While a variety of fisheries occurs in the Chesapeake Bay, the most prominent are pot fisheries that target blue crab (Callinectes sapidis). Blue crab harvest from the Chesapeake Bay supplies 50% of the national market for blue crab. Bay-wide, over 350,000 blue crab pots are deployed each year as part of a commercial fishery, and 12% to 20% of those are lost. The standard blue crab pot is a rigid, square-shaped, galvanized or vinyl-coated wire pot, approximately 0.6 m × 0.6 m × 0.6 m. Most crab pots are deployed in shallow waters, less than 10 m in depth, with single buoys. The primary reason for pot loss in the Chesapeake Bay is from buoy lines being separated from pots, often caused by vessel propellers running over the lines, faulty buoy lines, and vandalism. Storm events also cause pot loss and abandonment, as buoys are pulled below the sea surface and/or pots are tumbled and swept off position. Scientists and watermen from Maryland and Virginia have been conducting ALD pot surveys, removals, and research in the Chesapeake Bay since 2006.

In partnership with the NOAA Marine Debris Program, researchers integrated available ALDFG datasets from the region to conduct a complete assessment of the ecological and economic effects of ALD blue crab pots across the Chesapeake Bay. Using a geographically weighted regression model to predict spatial distribution and densities of ALD pots throughout the Chesapeake Bay, a bay-wide total of over 145,000 pots was estimated (Figure 2.5). The predicted quantity and spatial distribution of these pots, combined with blue crab catch and mortality rates were used to estimate that ALD blue crab pots kill over 3.3 million blue crab per year, which is equal to 4.5% of the total 2014 annual harvest. ALD pots were also estimated to entrap over 3.5 million white perch and nearly 3.6 million Atlantic croaker (*Micropogonias undulatus*) throughout the Bay each year. Habitat impacts on submerged aquatic vegetation and oyster beds were also observed but were relatively less impactful compared to the ALD pot impacts on marine species.

Economic analysis of ALD pots impacts on Chesapeake Bay blue crab and the results of removal of such pots suggest that previously conducted pot removals in Maryland and Virginia increased blue crab harvest by over 17.2 million kg bay-wide, which equates to 23.8% of the total harvest, and USD 33.5 million over a six-year period. The model indicated an increase in efficiency of active pots when ALD pots were removed, estimating that on average, the cumulative blue crab harvests in the active fishery increased by 394 kg over the course of a year for each pot removed. This study provides an example of how ALD pot removals, especially in high concentration areas (i.e. “hot spots”) can not only reduce mortality of target and non-target species, but also produce significant economic benefits. Investigation of ALD pot density and the primary causes of pot losses led to the proposal of three management scenarios to reduce prevalence of and mitigate impacts from ALD blue crab pots:

- conflict avoidance between resource users by reducing the overlap between commercial crabbing and recreational boating/commercial shipping;
- targeted ALD pot removal efforts in heavily fished areas, with support from resource management agencies to enforce removal of abandoned pots that still have marker buoys attached; and
- pot modifications that provide egress routes for entrapped animals after degradation of biodegradable escape panels.

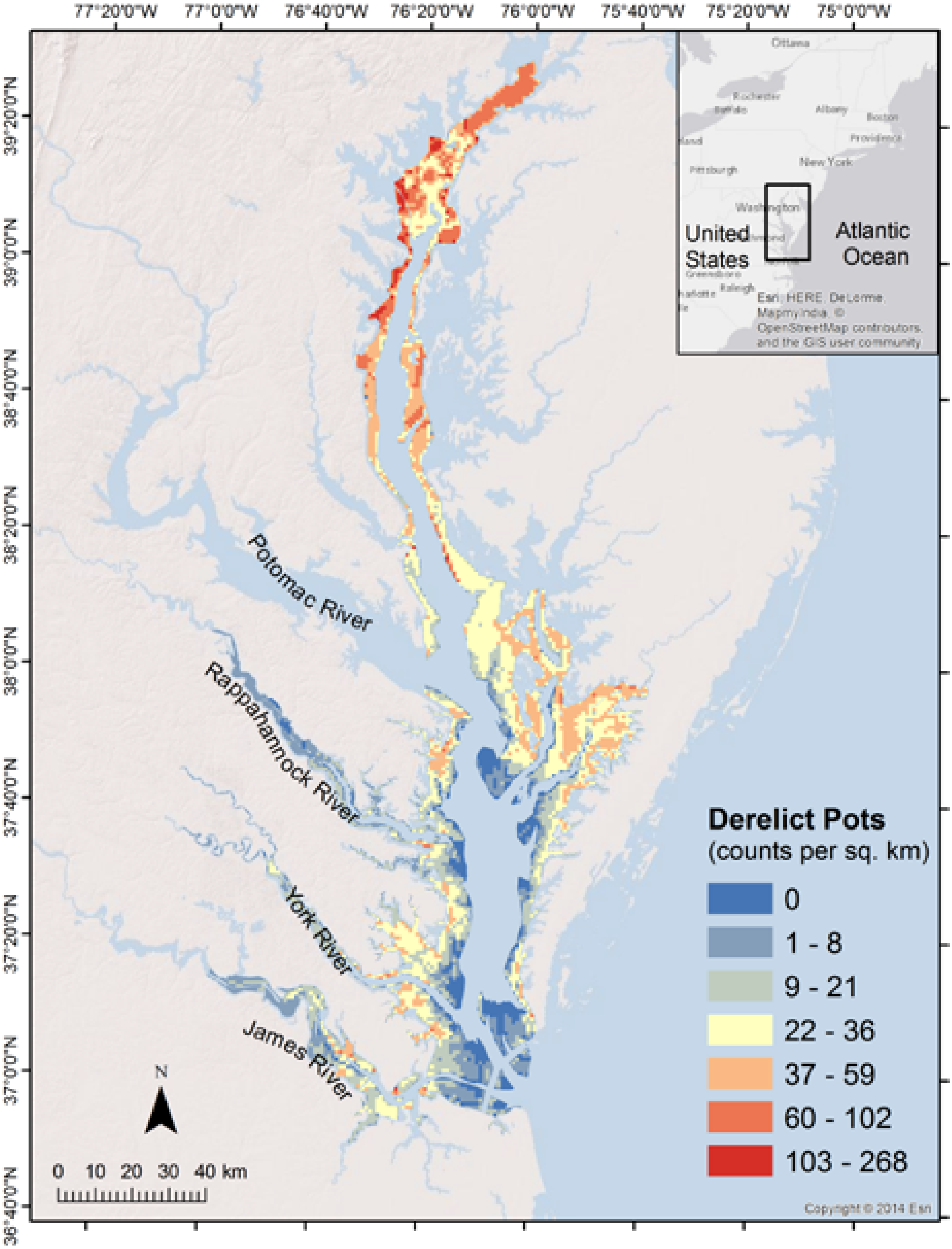

Figure 2.5: *ALD crab pot densities and spatial distribution in Chesapeake Bay (Bilkovic et al. 2016)*

2.4 Chapter summary

- Wild capture fish production was 96.4 million tonnes in 2018, with the marine sector comprising 87.6% (84.4 million tonnes). In 2018, the global fishing fleet was estimated to be 4.56 million vessels. Asian vessels comprised 85% of the global feet, with 3.1 million vessels. Globally, 59.5 million fishers (14% of which are women) were estimated to be engaged in fisheries in 2018, of which 65.5% (39.0 million) were engaged in capture fisheries.
- Fishing gear components that contribute to the global ocean burden of plastic marine litter can be generally categorized as: netting, which is largely comprised of mono- or multifilament polymers woven into knotted and knotless meshes; traps and pots, comprised of multifilament polymers woven into meshes, monofilament ropes, and floats; ropes and lines, comprised of a wide variety of non-biodegradable polymer materials; and floats and buoys, commonly comprised of polymers including EPS.
- Causes of ALDFG in the marine environment that can arise from a range of environmental, conflict and management-based, and operational fishing pressures, with the frequency and magnitude of ALDFG events varying across fisheries and regions. Because fishing gears are custom-designed to catch specific target species that can vary significantly across geographic areas, most of the research undertaken around amounts of ALDFG is specific to particular gear types and/or geographic areas.
- Significant knowledge gaps remain concerning amounts and rates of ALDFG on larger regional and global scales and across many major gear types. On a global scale, there are no absolute figures on the weight, lengths or other quantitative metrics of ALDFG entering the world's ocean each year, although rate estimations do exist. A 2009 UNEP-FAO study (Macfadyen *et al.* 2009) estimated a less than 10% loss rate across all fishing gears; a more recent estimation is that 5.7% of all fishing nets, 8.6% of all traps and 29% of all lines are lost to the world's ocean annually.
- Certain types of fishing gears are more risk-prone to gear loss and impacts (e.g. entanglement and/or ingestion). Whether drifting at sea, or deposited on the seabed, ALDFG can become a trapping agent for marine organisms, including endangered species. Incidences of marine wildlife entanglement in and ingestion of ALDFG have doubled from 1997 to 2015. Increases in marine wildlife entanglement and ingestion records are documented for marine turtles (100% of the 7 extant species), marine mammals (66% of the 123 extant species) and seabirds (50% of 406 extant species).
- ALDFG causes serious economic impacts to fishers and associated fisheries. The direct financial losses from the loss of gear itself and any target species caught in the gear can be substantial. The indirect or "hidden" economic costs are multifaceted, and include lost fishing opportunities due to non-availability of gear in hand (especially for the fishers who do not have spare gear available for an immediate replacement); the loss in value of future landings that might have otherwise been available to the fishers from use of the lost gear item; the loss in value of ghost catch in the ALDFG, now no longer available for fishers to catch and from which to profit; retrieval costs including time and fuel costs to search for the lost gear; and costs incurred by fishers in replacing lost gear.

3 AQUACULTURE AS A MARINE LITTER SOURCE

3.1 Background and introduction

Despite a steady increase in aquaculture production of seafood for consumption and human use in recent decades, there is a paucity of scientific studies and reports documenting aquaculture as a sea-based source of marine litter. Fortunately, two reports on the subject of aquaculture-derived marine litter (Huntington 2019; Sandra *et al.* 2019) provide excellent summaries of the available knowledge base. Combined with scientific publications on the occurrence of aquaculture-derived marine debris, this report presents as complete a view to date on aquaculture as a contributor to global ocean litter.

Marine aquaculture takes place in the open ocean and coastal areas (e.g. bays, fjords, coastal ponds). Inland aquaculture takes place on land, and for the purposes of this report, includes aquaculture practiced in more inland and constrained water bodies (e.g. estuaries and lagoons). For the purposes of this report, "aquaculture" refers to ocean and coastal farming; this report does not address inland aquaculture as a source of marine litter.

3.2 Global aquaculture production

Exponential growth of human populations worldwide has occurred concomitantly with an increasing sociocultural demand for seafood (e.g. Clark *et al.* 2018). Aquaculture production has steadily risen at a rate of approximately 5.8% annually between 2001 and 2010 and 4.5% between 2011 and 2018 (FAO 2020), with double-digit growth in Indonesia and Ecuador. As of 2016, 202 nations were engaged in aquaculture (FAO 2018), and as of 2018, global aquaculture produced 114.5 million tonnes in live weight product, and a total farmgate sale value of USD 263.6 billion (FAO 2020) (Figure 3.1). World aquaculture production now contributes nearly half (46%) of the world's total global output from fisheries and aquaculture combined, with growth of aquaculture in China contributing substantially to this trend (FAO 2020). In 2018, 39 nations accounting for approximately half of the world's human population were producing more farmed than wild-caught fish.

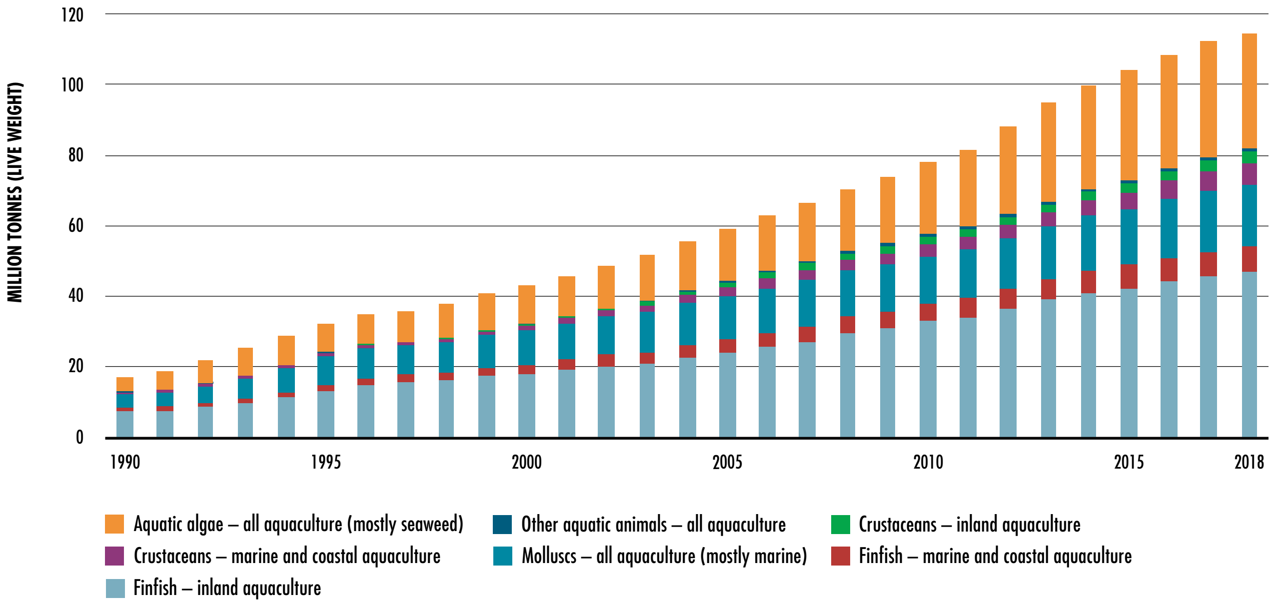

Figure 3.1: *World Aquaculture Production of Food Fish and Aquatic Plants (from FAO 2020).*

While inland (land- or freshwater-based) aquaculture is providing an increasing proportion of the world's farmed food fish (62.5%), coastal and marine aquaculture remain predominant systems for food fish production in many ocean basins and coastal nations (FAO 2020). Aquaculture is practiced around the world, but only a handful of nations dominate as major producers. China produces more farmed food fish than the rest of the world combined and produces more fish than it catches from the wild (FAO 2018, 2020). If one examines marine and coastal finfish aquaculture only (not including inland operations), Norway, Indonesia, Chile, Philippines, Vietnam, Japan, United Kingdom, Canada, Turkey, Bangladesh and Greece also dominate as producers (in descending order of tonnage produced); production of marine crustaceans (not including inland shrimp production operations), Vietnam, Indonesia, India, Ecuador, Thailand, Mexico, Bangladesh, Philippines, Myanmar and Brazil are dominant producers (in descending order of tonnage produced) (FAO 2018).

A diversity of aquatic species (nearly 600) is cultured for human consumption, although 84.2% of global production in 2016 was of just 20 species and species groups (FAO 2018). The farming of marine macroalgae (primarily seaweeds) for both human consumption and extracts (e.g. carrageenan, a thickening agent used in foods and beverages) has more than tripled from 2000 to 2018, reaching over 32.4 million tonnes in 2018; most of this growth in seaweed farming has occurred in Indonesia (FAO 2020). Open-ocean finfish farming is primarily centred on salmon (primarily *Salmo salar* but also *Onchorhyncus sp.*), trout (e.g. Oncorhynchus mykiss), tuna (primarily *Thunnus thynnus*), seabass (multiple species), sea bream (multiple species), and yellowtail (*Seriola lalandi*) production, while coastal aquaculture facilities mainly produce shellfish (mussels, oysters, clams), shrimp (multiple species) and marine plants (seaweeds) (FAO 2018).

3.3 Aquaculture as a source of marine litter

3.3.1 *Aquaculture equipment and plastics*

A significant portion of gear utilized for both marine and freshwater aquaculture systems comprises plastic. The use of plastics in fisheries and aquaculture has been extensively reviewed (FAO 2017). Fisheries and aquaculture as a source of ocean microplastic pollution is an active area of inquiry by GESAMP (GESAMP 2015, 2016, 2019).

Generally speaking, marine aquaculture systems incorporate ropes, buoys, mesh bags, and anti-predator netting (FAO 2017). Marine aquaculture for finfish is conducted using net pens or floating sea cages for grow-out of fish stocks. Net pens are constructed with a "collar" floating at the surface, from which a net enclosure is suspended in the water column. Sea cages are enclosed and comprise rigid flotation materials, are either partially of fully submerged, and are anchored to prevent drift. In contrast, shellfish culture equipment typically comprises rope that hangs from a floatation apparatus (e.g. buoys, rafts) and is either anchored at the bottom, or by upright poles embedded in the seafloor, with or without mesh bags attached that contain young animals for grow-out (typically for mussels and oysters). Bottom-cage systems are also used for clams, oysters, and scallops. While crustaceans (shrimp) are mostly grown in land-based, plastic-lined ponds adjacent to coasts where seawater can be pumped into the ponds, they can also be farmed in plastic mesh bags suspended in shallow estuarine and lagoon environments.

At the broadest categorical level, both thermoplastic (which softens or hardens with changes in temperature) and thermoset plastic (which permanently hardens once moulded) are used in the manufacture of aquaculture equipment and supplies; elastomer plastics (elastic polymers used in tubing and neoprene) are used to a much lesser extent (FAO 2017). Forms of plastic used in aquaculture include: expanded polystyrene (EPS, commonly referred to as styrofoam™ DuPont) for buoys and insulated containers; high-density polyethylene (HDPE) for flotation, ropes, net webbing, storage tanks, pots, tubs and buckets, and piping for water and air supplies; nylon for twine, ropes and nets; polyethylene and polyester (polyethylene terephthalate) for rope and bags, polypropylene for rope, bags, tubs, buckets, and trays; polyvinyl chloride (PVC) for piping, valves, floats, cage and net pen collars, crates; and ultra-high molecular weight polyethylene for ropes, and fibre-reinforced plastic (FRP) for fish transport tanks, floats and boats.

To better understand aquaculture as a source of marine litter, the Aquaculture Stewardship Council commissioned a study that summarized both the published literature and industry standards on the plastic composition of equipment used in marine and coastal aquaculture systems worldwide, including in inland aquaculture (Huntington 2019) (Table 3.1).

Equipment	Plastic components	PMMA	EPS	FRP	HDPE	LLDEP	LDPE	PA	PE	PET	PP	PVC	UNHwPE
Open-water cages and pens	Floating collars				X							X	
	Collar floatation		X										
	Buoys		X		X		X		X			X	
	Ropes							X		X	X		
	Net enclosures				X			X			X		X
	Predator-exclusion netting				X			X	X				
	Feeding systems			X	X							X	
Ropes and lines	Buoy moorings				X		X		X				
	Ropes				X			X		X	X		
	Raft floatation		X		X								
	Stock containment (netting)				X			X			X		X
Coastal ponds	Pond liners				X	X	X						
	Harvest nets				X			X			X		X
	Housing						X						
	Aerators/ pumps				X								
	Feeding systems			X	X								
Tanks	Spawning, incubation and stock-holding			X	X								
	Pipework			X	X							X	
	Laboratory fixtures	X	X				X	X				X	

Table 3.1. Overview of types of plastic used in aquaculture operations, all of which contribute to marine litter through weathering, abrasion, wear and tear with use, and/or catastrophic breakage, with possible exception of ultra-high molecular weight polyethylene (UHMwPE), which is very strong and may not degrade as easily in the ocean environment. PMMA (acrylic); EPS (expanded polystyrene); FRP (fibre-reinforced plastic); HDPE (high-density polyethylene); LLDPE (linear low-density polyethylene); LDPE (low-density polyethylene); PA (nylon, polyamide); PE (polyethylene); PES (polyester); PET (polyethylene terephthalate), PP (polypropylene), PVC (polyvinyl chloride); and UHMwPE. Table content largely adapted from Huntington (2019).

3.3.2 *Aquaculture-related litter*

A comprehensive assessment of aquaculture as a source of marine litter in the North, Baltic and Mediterranean Seas was recently published (Sandra *et al.* 2019). The report inventories types, distribution and quantities of marine litter from aquaculture operations in these regions in detail. Using scientific papers and publicly available datasets, authors compiled an inventory of 64 different items of marine litter attributable to aquaculture, including ropes, nets, cage netting, floats and buoys (EPS and moulded polyethylene), buckets, fish boxes, and strapping bands and clips, with 19 of those items unique to aquaculture (e.g. mesh screens, mussel socks), especially to bivalve farming.

EPS is the most frequently documented form of aquaculture-sourced marine litter in the scientific literature. Plastic marine debris collected from 12 beaches in South Korea in 2013 and 2014 revealed that EPS was the overwhelming dominant debris type, representing 99.1% and 90.1% of large micro- and meso- plastic particle categories, respectively (Lee *et al.* 2015). The authors posited that EPS buoys used extensively in aquaculture farms along the Korean coast were the likely source of EPS particles. This substantiated earlier findings that EPS buoys were the major debris type identified on Korean beaches (Hong *et al.* 2014). In Taiwan, approximately 120,000 to 200,000 EPS buoys are utilized annually in shellfish aquaculture operations, with approximately 36,000 to 60,000 of those buoys lost or discarded (Chen *et al.* 2018).

Similarly, shellfish culture facilities in southern Chile have been identified as a major source of at-sea derived plastic marine debris in the region: shipboard surveys conducted between 2002 and 2005 revealed that EPS, plastic bags and plastic fragments comprised 80% of the floating marine debris documented in southern Chilean fjords, gulfs and channels (Hinojosa and Thiel 2009). The presence of EPS was attributed to the extensive use of EPS buoys in the mussel farming industry in the northern region. Another study posited that floating marine debris, including EPS, corresponded with the distribution of coastal human activities, with floating marine debris concentrations highest along sections of the Chilean coast where aquaculture activities are most intense (Hinojosa *et al.* 2011). Subsequent legislation in Chile aims to reduce aquaculture facilities as sources of marine litter (Urbina *et al.* 2020). Antipredator nets used by clam aquaculture facilities have also been documented as marine litter (Bendell 2015), and pearl oyster culture facilities in French Polynesia have also been documented as sources and types of marine plastic litter (Andréfouët *et al.* 2014). The quantity of plastic generated by oyster and mussel farming in France was estimated at 5,500 and 1,160 tonnes per year, respectively, for an equivalent annual production of 80,000 tonnes of oysters and 50,000 tonnes of mussels (FranceAgriMer 2020).

It is generally assumed that aquaculture operations produce marine litter primarily through normal wear and tear of plastic gear, accidents that damage equipment (e.g. interaction of aquaculture equipment with vessels), catastrophic losses during extreme weather events and improper waste management by aquaculture operators (FAO 2017); further research is required to substantiate these assumptions. A causal risk analysis for plastic loss from aquaculture systems using established methods (Bondad-Reantaso *et al.* 2008) revealed that open-water cages and pens are especially high risk for plastic loss due to poor waste management practices; poor siting, installation and maintenance; and extreme weather events (Huntington 2019). Coastal pond aquaculture is also considered a high-risk source for plastic litter due to farm de-commissioning and subsequent degradation due to lack of maintenance, as well as extreme weather events that can result in aquaculture gear losses. A study of Atlantic salmon net pen farming in Scotland suggests that poor waste management practices by operators is the main cause of marine litter (Nimmo and Cappell 2009). An aquaculture producers' survey is currently underway in the North, Baltic and Mediterranean seas to better understand causes of aquaculture gear loss.[8]

3.4 Quantity and impact of marine litter from aquaculture

No global estimates exist for the amount of plastic waste generated by the aquaculture sector (FAO 2017), and there is no systematic monitoring of plastic waste generated by aquaculture operations at the farm, regional or national levels anywhere in the world (Huntington 2019). Almost no non-scientific data exists either, such as claims filed with aquaculture insurance agencies by operators. Typically, claims are for stock losses after extreme weather events, disease outbreaks, and/or damage due to unforeseen events (e.g. accidents), and therefore insurance claims do not provide quantitative or qualitative data on the amounts of aquaculture gear lost to the ocean following storms or accidents.

Data and assessments that do exist on marine plastic litter arising from aquaculture operations are regionally specific. In the European Economic Area (EEA), aquaculture-associated gear and debris losses are grossly estimated to range from 3,000 to 41,000 tonnes annually, and aquaculture debris already present in the EEA's marine environment may range from 95,000 – 655,000 tonnes of litter (Sherrington *et al.* 2016). The Norwegian aquaculture industry was estimated to have generated 12,300 metric tonnes of plastic waste in 2011, of which approximately 21% was recycled (Sundt *et al.* 2014); the fate of the remaining 79% of waste not recycled is unknown, although it is reasonable to assume a portion enters the ocean rather than is disposed of on land. More recently, Sundt (2018) estimated that in Norway 25,000 tonnes of plastic from aquaculture is discarded at sea annually (e.g. net pen collars, pipes, nets, feed hoses and ropes). The AquaLit project estimated that 14.75% of seafloor debris, 11.25% of sea surface debris, and 4.08% of beach debris in the North, Baltic and Mediterranean Seas is derived from aquaculture operations in these ocean regions, with hotspots in the northwest Adriatic Sea and around Corfu Island, Greece.

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[8] AQUA-LIT: https://aqua-lit.eu

In Korea, 39,700 tons of plastic debris in the form of nets, ropes and EPS buoys were estimated to enter the ocean in 1999 (Cho 2005). In Taiwan, a rough estimate of 120,000 to 200,000 EPS buoys are used every year in shellfish aquaculture operations, and approximately 36,000 to 60,000 of these buoys are lost or discarded (Chen *et al.* 2018).

3.5 Chapter summary

- Aquaculture production has steadily risen at a rate of approximately 5.8% annually between 2000 and 2010, and 4% between 2011 and 2018, with double-digit growth in Indonesia and Ecuador. As of 2016, 202 nations were engaged in aquaculture (FAO 2018), and as of 2018 global aquaculture produced 114.5 million tons in live weight and a total farmgate sale value of USD 263.6 billion (FAO 2020). Aquaculture now contributes nearly half (46%) of the world's total global output from fisheries and aquaculture combined.
- Aquaculture is practiced around the world, but only a handful of nations dominate as major producers. Coastal and marine aquaculture remain predominant systems for food fish production in many ocean basins and coastal nations.
- A significant portion of gear utilized for aquaculture both in marine and freshwater systems comprises plastic. EPS is the most frequently documented form of aquaculture-sourced marine litter in the scientific literature.
- It is generally assumed (although scant data exist to support these assumptions) that aquaculture operations produce marine litter primarily through normal wear and tear of plastic gear, accidents that damage equipment such as the interaction of aquaculture equipment with vessels, catastrophic losses during extreme weather events, and improper waste management by aquaculture operators
- No global estimates exist for the amount of marine plastic litter generated by the aquaculture sector, and there is no systematic monitoring of plastic waste generated by aquaculture operations at the farm, regional or national levels.

4 SHIPPING and BOATING AS A MARINE LITTER SOURCE

4.1 Background and introduction

International maritime trade is closely tied to the development of the global economy. From 1970 to 2017, global maritime trade increased an average of 3% annually. In 2018, international maritime trade increased 2.7%, a slow-down in growth from 4.1% in 2017 (UNCTAD 2019). The total volume of cargo, including dry bulk commodities, containerized cargo, other dry bulk, oil, gas and chemicals, reached an all-time high of 11 billion tons in 2018 (UNCTAD 2019). Annual growth rates in containerized and dry bulk shipping are forecasted to be 4.5% and 3.9%, respectively, from 2019 to 2024, while tanker trade will grow an estimated 2.2% over that same period (although it should be noted that the COVID-19 pandemic has reduced shipping in some regions; see Depellegrin *et al.* 2020; EMSA 2021). In 2018, dry bulk commodities (e.g. iron ore, bauxite, grain, coal) accounted for more than 40% of the total dry cargo trade, while containerized cargo and minor bulk cargoes (e.g. steel and forest products) accounted for 24 and 25.8% respectively. Although total volume of tanker cargo (e.g. oil, gas, chemicals) increased more than 120% since 1970, the tanker trade accounted for 29% of the total maritime trade in 2018 compared to 55% in 1970 (UNCTAD 2019). The significant relative decrease in the tanker trade is likely a reflection of the constraints in petroleum consumption following oil price spikes since the 1970s, the development of pipeline transport, and the use of renewables.

Regarding regional distribution of global maritime transport by volume, Asia dominates: in 2018, 41% of the total goods loaded and 61% of goods offloaded globally took place in Asia (UNCTAD 2018, 2019). There has also been a large increase in the interregional shipping of goods manufactured in multiple locations within and across Asia. In contrast, the maritime trade in Africa and Latin America decreased, particularly in terms of dry bulk and liquid cargo loaded (UNCTAD 2018). While these decreases were not compensated for by increases in more valuable goods, such as industrial products or processed food, there was some increase in the export of other raw materials from these regions.

At the time of preparing this report, approximately 53,000 merchant ships were registered by International Maritime Organization (IMO) globally, comprising general cargo ships (32%), tankers (oil, gas and chemicals) (30%), bulk carriers (22%), and passenger ships (10%). In early 2018, the total carrying capacity of the world's merchant fleet was 1.9 billion dead-weight tons (dwt), an increase of 62 million dwt from 2017, or an increase of about 4% per year during 2013-2018. Except for general cargo ships, all categories of merchant ships increased considerably in tonnage. The most important ship-owning economies accounted for about 50% of the world's fleet. These included companies based in Greece (17%), followed by Japan, China, Germany and South Korea. The leading countries for flags of registration included Panama; the Marshall Islands; Liberia; Hong Kong, Special Administrative Region of the People's Republic of China; and Singapore (Lloyd's List 2019).

The global ocean cruise industry has shown remarkable growth, from some 4 million passengers annually in the early 1990s to an estimated 27 million in 2020 (Figure 4.1) – the equivalent of an annual growth of nearly 7% (Cruise Market Watch 2021). In 2018, 13 new ocean cruise ships with a capacity of more than 33,000 passengers were added to the fleet. Forecasts from the ocean cruise industry indicated that from 2018 to 2020, 37 new cruise ships would add about 100,000 to the passenger capacity of the global fleet (although at the time of reporting, the COVID-19 pandemic has significantly impacted passenger numbers).

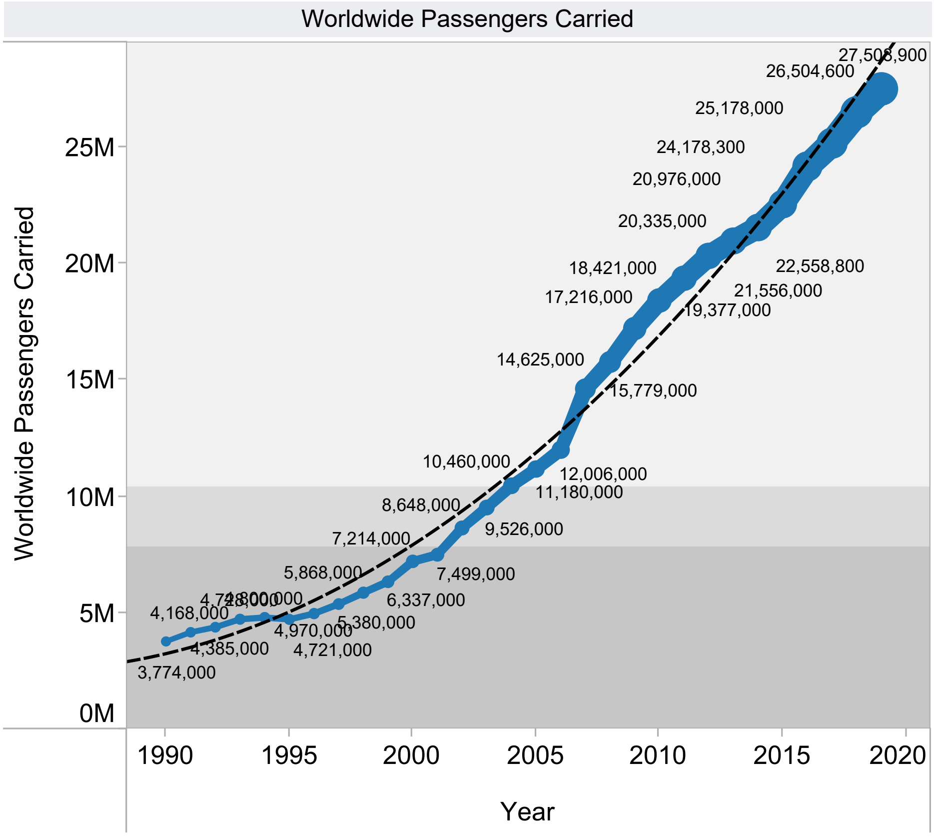

Figure 4.1: *Trends in passenger cruise shipping showing doubling of passengers carried every 10 years (from Cruise Market Watch 2021).*

Expansion in merchant shipping has led to more congested shipping lanes, which increases the risk of environmental impacts to the ocean from both normal shipping and accidental events. These risks are likely to be further exacerbated by adverse weather conditions and extreme weather events as a result of climate change (e.g. hurricanes/typhoons). Environmental impacts resulting from shipping include: air and water pollution from daily operations, including chemicals such as oil, sewage, garbage, sulphur oxides and particulates, nitrogen oxides, and greenhouse gas emissions, as well as noise and collisions between ships and marine mammals; introduction of invasive species by ships; and impacts related to the processes involved in scrapping of decommissioned vessels (Jägerbrand *et al.* 2019).

It should be noted that, separate from shipping operations that result in marine litter, extreme weather events (tsunamis, flooding, hurricanes, etc.) may transport large amounts of plastic debris from ships to the sea and cause significant impacts on biodiversity. For example, in the case of the Great East Japan Earthquake and tsunami that occurred on 11 March 2011, an estimated 5 million tons of debris, largely from ships, were washed into the ocean in this single, tragic event (Murray *et al.* 2018). The increase in debris influx to surveyed North American and Hawaiian shorelines was substantial and significant, representing an up to tenfold increase over previously recorded marine debris baselines in some areas (e.g. Washington state). Amongst the various types of debris documented along the shorelines, 12.4% were identified as debris arising from ships.

4.2 Types of marine litter from shipping

Plastic debris contained in a ship's operational garbage, microplastics in grey water and ballasts, and even floating wrecks or items from shipping operations (e.g. lost containers, quays, navigation marks, and debris from harbours) is largely responsible for the marine plastic litter in the sea attributable to shipping.

Large shipping (including fishing) vessels with crew members may carry supplies for several months and generate solid wastes daily that may end up as marine litter (GESAMP 2016). Cargo waste from cargo holds (e.g. wire straps, packaging materials, plastic sheets, boxes etc.), waste generated during the normal operations of the ships and sewage are among the numerous waste items deposited into the marine environment from merchant ships and cruise liners. Noting that the discharge of garbage and sewage is regulated by MARPOL, these items are most often disposed of accidentally through bad handling or unfavorable weather conditions. The mishandling of waste can be due to inadequate onboard storage facilities or the lack of waste reception facilities in ports (GESAMP 2016). Microplastics can also be generated after routine ship hull cleaning, mishandling of cargo comprising plastic items or accidental spills of industrial plastic resin pellets (GESAMP 2016) or plastic polymers in solution (Suaria *et al.* 2018). Similarly, fishing industry vessels such as supply or catch transport vessels may deliberately or accidentally release litter items such as gloves, fish boxes, storage drums and personal waste into the marine environment (Richardson *et al.* 2017).

Garbage categories are defined in Regulation 1 of MARPOL Annex V and include (but are not limited to) food, domestic and operational wastes, single-use plastics, cargo residues, incinerator ashes, fishing gear and cooking oil generated during normal ship operations. The analysis around sources of marine litter from shipping involves several challenges that result in an inherent degree of associated uncertainty. Marine litter generally is not only composed of a large fraction of unidentifiable items, but also of items which originate from an array of different shipping-related activities (Veiga *et al.* 2016). The geographic origin of marine plastic litter items is also often difficult to identify because of the persistent nature and the ease by which it is transported across long distances. Remote oceanic areas such as islands and polar regions are disproportionately impacted by sea-based litter in comparison to the quantity of plastic debris they generate (Portz *et al.* 2020; Vesman *et al.* 2020), with the dominant litter type(s) often reported as fishing-derived; however, recent trends show that stranding of items from merchant shipping is increasing (Ryan *et al.* 2019). Furthermore, as garbage from ships is regulated, any analysis is starting from a base assumption of compliance, making it difficult to determine what garbage is being discharged into the sea from which ships, in which location and why.

Identifying the different types and categories of marine litter specifically derived from shipping operations requires local knowledge regarding where, how and when different types of litter are being lost or disposed of into the marine environment. Most non-operational waste (e.g. galley waste) has non-exclusive sources. Earll *et al.* (2000) provided a thorough methodology and guidelines to identify and assess marine litter from shipping activities (including fisheries operations) on beaches in the United Kingdom. Typically, sites that are heavily contaminated by shipping litter often contain large, conspicuous items such as pallets, buoys, nets, pots, gloves, and paints, which mostly originate from fishing operations. Certain marine litter items or groups of items found together can often indicate shipping litter, such as galley wastes, domestic waste generated by crews, maintenance wastes and lubricants.

Some marine litter items are exclusive to shipping sources, such as large ropes, injection gun cartridges/ oil drums, light bulbs/tubes, and clinkers (residues from coal-burning steamships, originating from shipping operations). Ship-generated solid waste also includes glass and tins (Jägerbrand *et al.* 2019). More generally, a variety of heavy litter types, likely ship-generated, are often found on the seafloor along shipping lanes (Ramirez-Llodra *et al.* 2013), including anchors, other pieces of metal from engines, barrels, and cables. A distinctive characteristic of shipping-related litter is that it may comprise items that are used for another purpose (e.g. plastic containers cut to use as bailers or as paint pots; tyres used as fenders). Litter items collected on North East Atlantic beaches have been attributed to specific sources, including items from shipping operations (MCS 2013). These include plastic cleaner bottles, foreign plastic bottles, plastic oil bottles, industrial packaging / crates / sheeting, mesh bags (e.g. for fresh produce), strapping bands, aerosol/ spray cans, metal food cans, oil drums, cartons (e.g. milk), pallets, crates, light bulbs/tubes, tetra packs, and plastic gloves.

Marine litter that washes ashore may correspond to the spatial distribution of plastic debris inputs at sea. These connectivity patterns are important to consider when addressing remote areas (Ryan *et al.* 2019) compared to areas around more heavily trafficked shipping lanes (Van Gennip *et al.* 2013). For example, generally speaking it is often very difficult to trace marine litter that is encountered in a marine protected area to its source. However, a study of six marine protected areas in the Mediterranean Sea determined that 55%–88% of stranded litter items originated from shipping activities due to the short distance of the protected areas from shipping routes (Liubartseva *et al.* 2019). A correlation between deep sea litter and shipping routes was also described by Ramirez-Llodra *et al.* (2013), which indicated that litter found accumulated in canyons or bathyal plains comprising high proportions of plastics has predominantly a coastal origin, while litter collected on the open slope, dominated by heavy litter items, is mostly ship-originated, especially at sites located under major shipping routes.

Marine litter on the seafloor also includes clinkers. In some areas, clinkers comprise up to 28% by weight of total litter (Garcia-Rivera *et al.* 2018). In the Mediterranean Sea, trawl data for fish stock assessments indicated that clinker is a very common type of marine litter, representing up to 28.4% of total litter in weight of total litter items (an equal percentage to plastic litter), and mainly located in urban areas and along shipping routes (Garcia Rivera *et al.* 2018).

Paraffin or wax pieces are also included in some marine litter monitoring programmes because they are identified by beach surveys and are a good indicator of shipping-sourced marine litter (OSPAR 2010). Paraffins or waxes are unrefined crude oils that are often used for “stripping” solid residuals in tanks (tank-washing). Following tank-washing, these are either sent for waste disposal treatments that are administered by port waste reception facilities or are discharged at sea under certain conditions. In the North-East Atlantic region, paraffin- or wax-shipping-related litter items were found in 371 of 2,824 litter surveys performed on 151 different beaches. Most of these items were found in the North Sea, with a mean estimated abundance (in areas with wax presence) of 14.6 items per meter of strandline (max 738 items per meter). Wax pieces were also commonly found during beach litter surveys in California (USA), Panama, South Korea, Brazil, Spain, Italy, Bulgaria, South Africa, Hawaii (USA), Russia, and even in remote areas such as the Pitcairn Archipelago and Tristan de Cunha (British Overseas Territories), and Macquarie Island (Australia (Suaria *et al.* 2018).

Few studies have examined the amount of plastic that comprises shipping-related marine litter items, and, as a result, identification of the composition of shipping-related litter that is plastic is challenging. In a recent study examining marine litter items on the remote island of Tristan da Cunha in the South Atlantic Ocean, plastic beverage bottles showed the fastest growth rate in recorded marine litter items compared with other debris types, with 90% of bottles observed date-stamped to within two years of stranding (Ryan *et al.* 2019). Asia-sourced bottles comprised 73% of accumulated and 83% of newly arrived bottles to the island, suggesting that plastic bottles on Tristan da Cunha shorelines likely originated from transiting Asian shipping vessels, rather than from the South American or African continents. In another study, the quantity of plastic cups compared to glass bottles found on the seafloor suggests shipping as the source (Galgani *et al.* 2000). Another study around marine litter in the Gulf of Cadiz, Northeastern Atlantic, Spain indicated that different habitats collect different types of litter, with litter accumulation dependent upon bottom current flows, and maritime and fishing routes (Mecho *et al.* 2020).

In a study on pollution incidents reported by observers on board fishing vessels in the Western and Central Pacific Ocean, more than 10,000 pollution incidents were reported by fishery observers from 2003-2015 (Richardson *et al.* 2017). When the subcategories included under “waste accidentally dumped” were analysed further and compared to total pollution incidents, plastics were found to comprise the largest portion of total pollution incidents, at 37% for purse seine and 60% for pelagic longline fishing vessels, respectively, followed by metal, at 15% for purse seine fishing and 1% for longline fishing, and general garbage, at 8% for purse seine fishing and 15% in longline fishing. Expanded polystyrene (EPS) fish boxes and fish boxes made from other types of plastic have also been identified as one of the major waste types generated by fishing industry vessels (BIPRO 2013), representing more than 80% of marine litter in some fishing and aquaculture areas (Hinojosa and Thiel 2009). In some countries, plastics-based fish containers may constitute more than 50% of the total production of EPS (NOWPAP MERRAC 2015).

4.2.1 *Microplastics from shipping and boating*

At sea, ships generate a variety of waste streams that can result in discharges of microplastics to the marine environment, including sewage, grey water, hazardous wastes, oily bilge water, and ballast water. Note that while ballast may not be considered a significant source of microplastics, ballast may in fact contain released particles (e.g. from tank paints) and ballast waters serve as an indirect source of microplastics acquired at charge sites and discharged elsewhere.

Ships also emit pollutants to the air and water, which can also contribute as a source of microplastics. Particular types of wastes, such as sewage and grey waters, may be of greater concern for cruise ships relative to other seagoing vessels, because of the large numbers of passengers carried by cruise ships and the large volumes of wastes that they produce. Microplastics are also generated from marine paints and antifouling coatings used to treat the fouling of a ship’s hull and in the management of grey water and discharge systems, as well as transported through ballast waters as a result of ballasting operations (i.e. the uptake of ballast water from the sea) (Table 4.1).

Vessel source	Emission materials	Emission Pathway
Above-water hull and superstructures	Paints and other coatings	Cleaning and wear and regular wear tear generate particles that transmit to sea water or are aerosolized
Underwater hull	Paints and other coatings	Cleaning and wear and regular wear tear generate particles that transmit to sea water
Onboard decks	Paints and other coatings	Cleaning and wear and regular wear tear generate particles that transmit to sea water or are aerosolized
Onboard tanks, equipment	Tank contents and machinery effluents	May accidentally empty or transmit directly to seawater
Ballast water	Stored water (ballast) loaded at port (not generated on board).	Direct transmission to seawater

Table 4.1. Potential emission pathways for microplastics from large passenger vessels (adapted from Folbert 2020).

Ships and other marine structures made of metal are often covered in epoxy-based paint with an overcoat, as epoxy is not resistant to ultra-violet light. For many years tributyltin (TBT) was used as an antifouling agent until evidence for its significant environmental impact became known. Copper-based compounds have been used as the main antifouling alternatives following the ban of TBT, along with a variety of other metallic, non-metallic, polymeric and combination compounds (Tornero and Hanke 2016). Paint flakes from ships and other maritime vessels and structures thus consist of a complex mix of polymers, anticorrosive and antifouling compounds. Particle sizes of material recorded by Chae *et al.* (2015) were generally in the range of 50 µm to 300 µm and were considered equivalent to the general size ranges of living microplankton, thus having significant potential to be taken up by planktivorous species (IMO 2019a).

The polymeric backbone of binding agents in biocidal ship coatings are designed to release the biocide by dissolution/erosion (free-association paints), hydrolytic reactions in seawater (self-polishing coatings) or a combination (hybrid) thereof. Therefore, the use of in-water cleaning to manage the fouling on a ship's hull may significantly increase localized microplastics pollution (Sciani and Georgiades 2019).

Cruise ships, large tankers, and bulk cargo carriers use a tremendous amount of ballast water to stabilize the vessels during transport. Ballast water is essential to the proper functioning of ships (especially cargo ships), with water often taken onboard in the coastal waters in one region and discharged at the next port of call. In this context, ballast water discharges may contain microplastics that are then transported across the oceans.

4.3 Causes of marine litter from shipping

4.3.1 *Shipwrecks and abandoned vessels*

Ships of all kinds have sunk as a result of severe weather, armed conflict or human error, especially during the First and Second World War periods when large numbers of vessels were sunk in a short time. The largest concentrations of wrecks are located in the western Pacific, the northeast Atlantic, and northwest Pacific (Michel *et al.* 2005), with 25% of wrecks found in the North Atlantic and 4% in the Mediterranean Sea (European Parliamentary Assembly 2012). Shipwrecks are particularly problematic where they occur in small, enclosed ocean regions like the Baltic Sea (Zaborska *et al.* 2019), which was the scene of intense naval actions in the last century.

Abandoned boats are another common and a growing problem in coastal regions around the world (Eklund 2014). Boats that have been damaged, are commercially obsolete, or are simply no longer wanted, affordable or repairable, are sometimes deliberately grounded, sunk offshore or abandoned on the substrate in the intertidal zone. Boats range from small dinghies to much larger commercial craft, and from recently discarded vessels in a reasonable state of repair to derelict wrecks abandoned many decades ago.

In addition to the presence of shipwrecks and abandoned boats, the deployment of decommissioned vessels for use as artificial reefs is a common practice in many coastal countries, such as Australia, Malta, New Zealand and the USA. A global database has been published that identifies vessels and wrecks serving as artificial reefs around the world (Ilieva *et al.* 2019). This database contains 1,907 records from 88 sources, with most of the records (1,739 or 91%) from the USA, and the majority of the records (1,118 or 71%) for the use of vessels as artificial reefs.

Shipwrecks and abandoned ships as a source of marine litter is little studied (Avio *et al.* 2017; Galgani *et al.* 2000). An inventory in two estuaries in eastern England that host an abundance and variety of abandoned vessels recorded items and materials associated with or adjacent to each boat (Turner and Rees 2016). Materials most commonly observed included paints, plastics, timber, EPS and masonry, while other items also logged included ropes, tires, canisters, electronic equipment and a variety of metal objects that were either fixed to or contained by the boats.

Fibre-reinforced plastics (FRP) have also been commercially available for boat production since the 1950s with a life expectancy of 30-50 years (IMO 2019b). FRP vessels represent an increasing number of end-of-life vessels with limited options for their disposal at landfills. Challenges around end-of-life FRP vessel disposal have been raised since the 1980s, and resulted in a study to review the possible options for the disposal and recycling of end-of-life FRP vessels without fully viable financial markets for recycling (IMO 2019b). While limited research is available on FRP vessels, it is evident that dumped FRP vessels do not make suitable artificial reefs, as they are likely to break up and may even be moved by currents and wave action, potentially harming sensitive features (e.g. reefs, seagrass) and communities (IMO 2019b). In addition, FRP material (e.g. fibreglass embedded in polymer resin) will ultimately break up to potentially become microplastics, including fibres. Further information on artificial reefs as sources of at-sea marine debris is covered in Section 6.1.4.

4.3.2 *Lost containers and cargoes*

Vessels and containers are most commonly lost at sea during heavy weather conditions when forces cause large rolls coupled with significant pitch motions that place the hulls, stacked containers, and lashings under excessive stress (Danish Maritime Accident Investigation Board 2014; Surfrider Foundation 2014). In some cases, infrastructure failures may also be linked to or be exacerbated by negligence (Surfrider Foundation 2014). Containers that are improperly loaded, in poor condition (unsecured), or illegally overloaded are at greater risk of falling overboard. Depending on the conditions at sea, a lost container may remain intact or lose its content after the collisions with other vessels, rough seas, reefs, or the shore, and thus is a potential source of littering.

The estimation of containers lost at sea every year is quite controversial. No centralized database exists to maintain comprehensive container loss statistics. Damage and loss reports are rarely shared beyond shipping line operators, local maritime authorities and protection and indemnity insurance providers (Frey and DeVogelaere 2014). Estimates for total annual container losses vary massively, from 350 to 10,000 per year (Frey and DeVogelaere 2014; Vero Marine 2011; WSC 2014, 2017, 2020). Shipping container loss is usually not included in assessments of sources of beach litter because shipping companies are reluctant to release data about the weight and nature of goods lost at sea (Galafassi *et al.* 2019).

An estimated average of 675 containers were lost at sea each year durring 2008-2010 (WSC 2020); this figure rose to an annual average loss of 2,683 containers in 2011-2013, reflecting the 2011 sinking of the *M/V Rena* (900 containers) in the South Pacific Ocean and the 2013 sinking of the *MOL Comfort* in the Indian Ocean, which resulted in the loss of all 4,293 containers on board – the worst containership loss in history. A 2017 survey by the World Shipping Council gathered input on container losses from 2014-2016: the average number of containers lost at sea, excluding catastrophic events, was 612, which is approximately 16% less than the average of 733 units lost each year for the previous three-year period. When catastrophic losses are included, the total containers lost at sea averaged 1,390, with 56% of those losses attributed to catastrophic events: for example, in 2015 almost 43% of the containers lost at sea were due to the loss of the *El Faro vessel*, which sank in the Bahamas with all its containers on board as a result of Hurricane Joaquin (WSC 2017).

The loss rate for containers in the Bay of Biscay from 1992 to 2008 totaled 159 incidents with 1,251 containers lost, which are likely conservative estimates due to under declaration (Kremer 2009). The project also demonstrated a higher risk for container losses in the northern hemisphere winter, in relation to weather conditions, with 51% of losses in January and February only, and more than 90% of losses during the six-month period between October and March. Losses were far lower in the Mediterranean Sea (one accident, one container) and from the English Channel (six accidents; Galgani *et al.* 2012).

While global container loss statistics are scant, there have been several well-documented container losses that have resulted in significant quantities of plastic marine litter. In October 2011, the vessel *Rena* ran aground near Tauranga, New Zealand, resulting in an oil spill and the loss of containers of plastic beads (Elvines *et al.* 2013). In Hong Kong, after Typhoon Vicente in July 2012, containers with over 165 tons of plastic pellets were lost at sea, washing up on southern Hong Kong coasts (Seltenrich 2015). In July 2015, as a result of an accident involving the motor ship *Ivy*, 56 bales of plastic, paper and textile fibres were lost in the Gulf of Follonica (Italy) (Greenpeace Italy 2020) (see for example, Figure 4.2, a and b). In 2017 in Durban Harbour, South Africa, approximately 49 tonnes of plastic pellets were released from containers lost at sea (Schumann 2019). On June 2018, 83 shipping containers carrying plastic hygiene products (e.g. surgical masks and diapers) were lost from a vessel in the Tasman Sea. As mentioned earlier, in January 2019 the *MSC Zoe* lost at least 342 containers in Dutch waters of the North Sea during a severe storm, many of which contained raw materials for plastics manufacturing: one single container resulted in the release of 22.5 tons of polymeric plastic beads into the ocean. Millions of polyethylene 4-mm beads washed up on the beaches immediately after the event, and wind continued to disperse these plastic particles (Dutch Safety Board 2020).

Figure 4.2: *Field Recovery of "ecoballe" lost in Tirrenian Sea, Italy in 2015 (Courtesy of Pierpaolo Giordano, © ISPRA)*

4.3.3 *Passenger ships*

While cruise ships comprise only a small percentage of the global shipping industry, it is estimated that around 24% of all waste produced by shipping comes from this sector (Caric and Mackelworth 2014) and its growth may aggravate environmental, social and economic impacts (Lourenço Sanches *et al.* 2020). Interestingly, the issue has attracted attention, mainly because new changes to Annex V of MARPOL came into effect in March 2018. These are related to wastes harmful to the marine environment, which are now required to be recorded in log books, including data on waste and solid bulk cargo, plastics, operational waste, fishing gear and electronic waste (e-waste) (Slišković *et al.* 2018). These changes are related to the introduction of new waste categories such as electronic waste and cargo residues that are either harmful or non-harmful to the marine environment, and amendments to the format of the garbage record book.

A large cruise ship (with 3,000 passengers and crew) generates approximately eight tons of solid waste in a one-week cruise (US Senate 2010). Cruise ship waste is similar to communal waste in its composition, often a mix of organic and inorganic compounds with a portion of hazardous substances such as cleaners, paints, and medicines. The problem of waste storage on board cruise ships also remains a significant issue, especially as space is limited. This is exacerbated in regions where port facilities lack appropriate disposal mechanisms. Cruise ships typically manage solid waste by a combination of source reduction and waste minimization for recycling. As much as 75% of solid waste is incinerated on board; however MARPOL Annex V bans the discharge of the resulting ash and residues at sea. That said, when ash/residues and garbage (e.g. glass and aluminium that cannot be incinerated) is offloaded at port, cruise ships can put a strain on port reception facilities, which are rarely adequate to the task of serving a large passenger vessel (e.g. US Senate 2010).

Furthermore, cruise ships generate, on average, 31.8 L per person per day of sewage, and a large cruise ship (3,000 passengers and crew) can generate an estimated 56,800 L – 113,600 L per day of sewage (US Senate 2010). Human sewage, whether generated at land or sea, contains microplastics (Schwabl *et al.* 2019). Cruise ships also generate an average of 253.6 L per person per day of grey water (or approximately 706,000 L per day for a 3,000-person cruise ship); by comparison, terrestrial residential greywater generation is estimated to be 193 L per person per day. MARPOL Annex V requires vessels to treat sewage before discharge (into the sea, as permitted under Annex IV of MARPOL), but does not require that greywater be treated before discharge.

4.3.4 *Fishing vessel operations*

It is important to note that the fishing industry does not only comprise fishing vessels, but also vessels not directly deployed for fishing operations, such as supply ships and catch transport vessels. Amongst a wide range of factors that are relevant to the generation of litter by fishing vessels (Mengo 2017), those relating to vessels operations include: the number, size and power of vessels, and the amount of time spent at sea and the number of crew, which may affect the amount of waste that might be generated; the space and facilities on board for the storage of waste; the density of vessels; the availability of adequate on-shore facilities for the disposal of waste generated at sea; the cost of disposal ashore and how costs are distributed and charged; awareness of the potential harm caused by marine litter and the willingness to reduce it; and the regulatory requirements for the control and disposal of waste, and the level of enforcement. Identification and characterization of litter from the fishing industry includes litter from all types of vessel operations, not just litter in the form of abandoned, lost or otherwise discarded fishing gear (ALDFG; discussed in Chapter 2). For example, in the Western and Central Pacific Ocean, an estimated 71% of purse seine pollution incidents were documented as waste dumped overboard, with only 13% identified as ALDFG (Richardson *et al.* 2017). For longline fishing, 80% of these pollution incidents were in the form of waste dumped overboard, and 17% as ALDFG.

4.3.5 *Recreational boating*

People participating in sea-based leisure activities, such as recreational boating and fishing, accidentally and deliberately generate marine litter such as plastic bags, food packaging and containers, plastic and glass bottles, aluminium cans, six-pack yokes, and recreational fishing gear (Mouat *et al.* 2010; UNEP 2009). Plastic bags, aluminium cans, and glass bottles are the most frequently reported litter items associated with recreational boating (Widmer *et al.* 2002). However, because these types of materials are common debris items that can also arise from almost any source of human activity, it is challenging to discern between land- and sea-based materials, and between sea-based recreational litter and sea-based litter from other marine activities. Research compiled from observations in European seas suggest that land-based litter accounts for more marine debris than sea-based litter (e.g. Arcadis 2012); where litter specifically from recreational boating could be discerned, recreational boating accounted for 5.6% to 10% of marine litter observed, with highest levels observed in in the Northeast Atlantic (Interwies *et al.* 2013). More recently, in a study in the North Sea, the proportion of data from standardized beach litter monitoring surveys collected during a 16-year period that could be attributed to potential sources estimated that 7% of source-identified items were from recreational boating (Schäfer *et al.* 2019). In some coastal areas and harbours, the majority of plastic debris is likely sourced from recreational boaters, who discarded an estimated 100,000 tons of garbage in the ocean (Milliken and Lee 1990). The seafloor and water column at boat harbours and marinas are commonly littered with debris, and in many cases it can be assumed that the litter in these areas originates from recreational boating activities. In the Mediterranean Sea, an inventory made through participatory science and diving activities in 468 surveys conducted between 2011 to 2018 clearly demonstrated the importance of single use plastics, of which some types (e.g. beverage bottles [19.3%] or cutlery [7.1%]) were linked to recreational boating (Consoli *et al.* 2020).

4.3.6 *Decommissioning / ship-breaking*

Approximately 70% of commercial ships are dismantled in South Asia (India, Bangladesh and Pakistan), very often on exposed shorelines, with a further 19% dismantled in China (UNEP 2016). In 2012, it was estimated that 10-15 million tonnes of ships would have to be scrapped by the world's maritime community on a yearly basis (Deshpande *et al.* 2012). Since the 1980s, ship-breaking or recycling has been a catalyst for local economies by supporting the steel, shipbuilding, furniture, building construction, machinery and electrical industries (Hossain *et al.* 2016). Ship-breaking, however, presents a variety of negative environmental and social impacts that hinder the sustainable development of this blooming sector, including the production of marine litter, such as glass fibre (glass wool), solid foam (shell of glass fibre products) and PVC (plastics and cable coatings, floor coverings) (Du *et al.* 2018). Accumulation of small plastic debris has been found in the intertidal sediments of one of the world's largest ship-breaking yards in Alang-Sosiya, India (Srinivasa Reddy *et al.* 2006). Small plastics fragments were collected by flotation and separated according to their basic polymer type under a microscope, and subsequently identified by Fourier transform infrared spectroscopy as polyurethane, nylon, polystyrene, polyester and glass wool. The morphology of these materials was also studied using a scanning electron microscope. An average 81 mg of small plastics fragments per kg of sediment was identified and believed to have originated directly from the ship-breaking activities at the site.

4.4 Quantity and impact of marine litter from shipping

4.4.1 *Quantity of marine litter from shipping and boating*

Few detailed studies are available that quantify the amounts and types of plastic litter from shipping. Even though the general categories of waste generated from different types of ships are relatively well known, few detailed studies have been carried out to investigate more precisely the quantities, and to compare waste outputs among ships of the same type. Fortunately, one relatively recent comprehensive study provides a detailed review of the waste management practices of ship-generated waste from a range of ships in EU ports (CE Delft-EMSA 2017; Table 4.2). The study provides both an average and range of quantities of different types of waste from cruise ships, oil tankers, gas carriers, bulk carriers, container vessels, cargo vessels, ferries, recreational boats and fishing vessels, following the definitions in MEPC 1./Circ 854 (IMO 2015), with the addition of estimations of quantities and types of exhaust gas and exhaust gas cleaning system effluents.

Waste type	Generation rate	Driver(s)	Management options
Bilge water	0.01-13 m^3/day	Condensation and leakage in engine room	Oil/water separators can reduce volume by 65%-85% by allowing for discharge of water fraction to the sea
Oily residues („sludge")	0.01-0.03 m^3/tonne of heavy fuel oil; 0 and 0.01 m^3/tonne of marine gas oil	Type of fuel; rate of fuel consumption	Evaporation can reduce sludge by 75%; incineration can reduce sludge by 99% or more
Tank washings ("slops")	20-100s of cubic metres	Number of tank cleanings; size of ship's loading capacity	After settling, the water fraction may be discarded at sea
Sewage	0.01-0.06 m^3/person/ day. When mixed with other waste water, can be 0.04 - 0.45 m^3/ person/day	Number of persons on board; types of toilets; length of voyage	Effluent from treatment plants is discharged to sea where permitted under MARPOL Annex V
Plastics	0.001-0.008 m^3/person/ day	Number of persons on board	Often not incinerated; dirty plastics (e.g. food packaging) often treated as a separate waste stream
Food wastes	0.001-0.003 m^3/person/ day	Number of persons on board; provisions	Where permitted under MARPOL Annex V, often discharged at sea
Domestic wastes	0.001-0.02 m^3/person/ day	Number of persons on board; type of products used	Onboard storage and delivery to port reception facilities
Cooking oil	0.01-0.08 L/person/day	Number of persons on board; type of food prepared	Although not permitted, cooking oil is sometimes added to the sludge tank
Incinerator ashes	0.004-0.06 m^3/month	Use of incinerator; cost of using incinerator	Incinerators mostly used to manage paper and sometimes oily waste
Operational wastes	0.001-0.1 m^3/person/day	Size of the ship; type of cargo	Onboard storage and delivery to port reception facilities
Cargo residues	0.001%-2% of cargo load	Size of ship; type of cargo	Onboard storage and delivery to port reception facilities

Table 4.2. Types, quantity, drivers and options for management of ship-generated waste. Generally speaking, larger ships generate larger quantities (adapted from CE Delft-EMSA 2017).

The CE Delft-EMSA study provides an empirical overview of the management drivers, technologies, and quantities of different categories of ship-generated waste. The findings were based on ship audits, interviews, a literature review, an online survey among stakeholders, and audits of waste notification forms. The report concludes that for almost every type of waste on a ship, there are several different waste flows and treatment methods exist, and that different ships use different waste treatment methods and often only treat part of a waste stream.

Some geographic areas are more exposed to accumulation of and impacts from sea-based litter due to their proximity to shipping routes (Table 4.3). Malta and the North Sea, with heavy maritime traffic, are good examples of higher geographic exposure, with up to 78% and 25% of litter (respectively) on beaches estimated to originate from shipping vessels (Liubartseva *et al.* 2018. For the Mediterranean Sea, estimated inputs of plastic marine debris from shipping lanes were approximately 20,000 tons per year (Liubartseva *et al.* 2018).

Location	% sea-based litter from shipping	Literature cited
Malta	78.0	Liubartseva et al. 2018
Australia (New South Wales)	48.0*	Smith et al. 2018
Libya	43.0	Liubartseva et al. 2018
Cyprus	33.0	Liubartseva et al. 2018
North Sea	25.0	Strand et al. 2015 2016
Greece	23.0	Liubartseva et al. 2018
German North Sea	21.0	Schaefer et al. 2019
Adriatic Sea (Italy)	14.6	Vlachogianni et al. 2018
Greece	13.2	Vlachogianni et al. 2018
United Kingdom	12.5	Nelms et al. 2020
Baltic Sea	10.0	Strand et al. 2015
Caribbean Sea (Colombia)	9.0	Rangel-Buitrago et al. 2019
French Polynesia	8.0	Verlis and Wilson 2020
South East Asia	8.0	NOWPAP MERRAC 2013
Northern Persian Gulf (Iran)	<8.0	Sarafraz et al. 2016
Adriatic Sea	6.3	Vlachogianni *et al.* 2018
Albania	4.7	Vlachogianni *et al.* 2018
Baltic Sea	4.0	Helcom 2015
Egypt	2.2	Liubartseva *et al.* 2018
Turkey	2.0	Liubartseva *et al.* 2018
Scotland	1.7	Hastings and Potts 2013
Montenegro	1.5	Vlachogianni *et al.* 2018
Malaysia	1.5	Mobilik *et al.* 2016
China	<1.0	Chen *et al.* 2020

* of beached bottles

Table 4.3: Studies estimating (via direction measurement or modelling) the percentage of sea-based litter contributed by shipping in various locations (seas and national waters) of the world ocean.

Quantification of waste discharged at sea is difficult in the absence of directly available global data. However, a 2018 Impact Assessment accompanying the proposal for the amendment of EU Directive 2000/59/EC on port reception facilities (PRF) for ship-generated waste and cargo residues estimated the amount of waste that is (potentially) discharged at sea by ships (Table 4.4). In 2019, the Directive 2000/59/EC was replaced by a new EU Directive 2019/883/EU on port reception facilities for the delivery of waste from ships, repealing Directive 2009/16/EC and Directive 2010/65/EU. Although garbage delivered in ports has increased since the introduction of the EU PRF Directive, a significant delivery gap in waste remains, estimated between 60,000 and 300,000 tonnes, i.e. 7% to 34% of the total to be delivered annually.

To provide for the best estimate of what is (potentially) discharged at sea, an alternative approach was developed. A "waste gap" has been calculated for all waste types, which is defined as the gap between the waste expected to be generated on board of the ship (and the part expected to be delivered in ports), and the waste actually delivered in ports, based on available waste delivery data. This "waste gap" approach has been implemented using:

- A model applied in the context of the Impact Assessment support study (Ecorys 2017), that calculated volumes of waste generation onboard vessels and estimates of expected waste delivery volumes at 29 ports, which together represent 35% of the throughput of all EU merchant ports located across the EU. These volumes were compared to waste delivery data obtained from the same ports included in the list.
- Existing reports and literature, which provide for the calculation of the waste gap for garbage from all types of ships, including fishing vessels and recreational craft. In particular, the European Commission (DG ENV) study "to support the development of measures to combat a range of marine litter resources" (Eunomia 2016) focused particularly around analysis of marine litter from sea-based sources.

As sewage is also a source of microplastic (Schwabl *et al.* 2019), and as it is estimated that approximately 10% of the sewage that should be delivered by merchant ships to land is not received by port reception facilities (and thus potentially discharged illegally), corresponding to a possible waste gap for sewage of 136,000 m^3 (2018, EU Impact Assessment revision PRF Directive), the discharge of sewage may have a relevant negative impact on the marine environment. Available data on sewage deliveries show that after a three-year (2005-2007) decrease in volumes delivered, a slight increase has been recorded since 2008. However, lack of registration of delivered sewage at port reception facilities and insufficient knowledge of onboard treatment and mixing with greywater on board reduce transparency of the data on sewage deliveries. Regarding recreational and fisheries sectors, while volumes of sewage generated are similar to those for the merchant sector, no data on delivery to port reception facilities are presently available to determine whether there is a similar waste gap. However, based on available sources, global estimations point to a possible waste gap for sewage representing 10% of the total sewage volumes delivered globally per annum.

Cargo residues, defined as waste resulting from loading excess and unloading residuals, are normally a matter for the off-load terminals and the shippers to handle, without direct involvement of the port. For this reason, data on cargo residues is limited and a delivery/waste gap could not be calculated for this type of waste. As cargo residues have financial value and delivery implies revenues instead of costs, it is generally considered that this constitutes a sufficient incentive to deliver cargo residues on shore, instead of discharging the residues at sea. Nonetheless, volatile commodity market prices affect their delivery, which is currently the case for oily residues due to the low oil prices. In addition, it may be very expensive to deliver cargo residues containing noxious liquid substances to PRF due to high treatment costs.

Data Source	**Waste to be delivered***	**Waste actually delivered**	**Delivery gap (%)**
MARPOL ANNEX 1			
Merchant Shipping	**1,226,000 m^3**	**1,195,000 m^3**	**31,000 m^3**
All, incl. Fishing and Recreational Vessels	1,290,000 m^3 Merchant: 1,226,000 m^3 Fishing: 55,000 m^3 Rec. vessels: 9,000 m^3	Unknown	Unknown1
MARPOL ANNEX IV			
Merchant Shipping	**1,362,000 m^3**	**1,226,000 m^3**	**136,000 m^3**
All, incl. Fishing and Recreational Vessels	**2,312,000-2,562,000 m^3** Merchant: 1,362,000 m^3 Fishing: 500,000-750,000 m^3 Rec. vessels: 450,000 m^3	Unknown	Unknown
MARPOL ANNEX V			
Merchant Shipping	**434,000 tonnes**	286,000-404,000 tonnes	30,000-148,000 tonnes
All, incl. Fishing and Recreational Vessels	**881,000 tonnes** Merchant: 434,000 tonnes Fishing: 266,000 tonnes Rec. vessels: 171,000 tonnes	580,000-820,000 tonnes	60,000-300,000 tonnes
MARPOL ANNEX VI			
Merchant Shipping	**24,000 m^3 sludge** **360,000 m^3 bleed-off**	Unknown	Unknown

* The models applied have accounted for the waste that is treated on board and/or legally discharged under MARPOL to avoid overestimating the gap between generation and delivery.

Table 4.4. Ship waste generated and delivered annually, and the resulting "waste gap." Content sourced from ***2018 Impact Assessment accompanying the proposal for an EU Directive on port reception facilities for the delivery of waste from ships (repealing Directive 2000/59/EC and amending Directive 2009/16/EC and Directive 2010/65/EU)*****; MARWAS (Annex I-IV waste); Annex V waste estimates are based on Eunomia (2016).**

Approximately 40% of most marine coatings use microplastics as binding agents (e.g. cellulose ester, thermoplastic alkyl resins, and polyurethane) with annual input of marine paints to European waters estimated at 400 to 1,194 tons per year, representing less than 1% of total inputs of microparticles in the marine environment in Europe (Hahn *et al.* 2018). Another study suggested that per capita input could be at the level of 2.3 g per year, resulting in approximately 11,270 tons per year of marine paint-sourced microplastics introduced to the world's oceans, based on a population of 7.55 billion inhabitants (Galafassi *et al.* 2019). It is estimated that marine coatings account for 3.7% of releases of primary microplastics in the world ocean (IUCN 2017) and IMO (2019a) reports 6 to 7% of marine coatings are lost directly to the sea during the lifetime of a vessel. Magnusson *et al.* (2016) highlighted differences among operations, and found that 6% of solid antifouling coating is lost directly to the sea during its lifetime, with a further 1.8% lost during painting, 3.2% during cleaning maintenance and 1% from weathering. Sundt *et al.* (2014) also summarized material losses of the quantities of microplastics that may be released from shipping activities; based on an estimate that above 50% of marine paint is solids of which about 50% is the plastics constituent, the authors calculated that around 0.5 kg of dust material (plastics and related biocides/metals etc.) is created per square metre of ship hull during cleaning. They also mention paint lost in application (estimated by them at 30%) and that this tends to be mist material which coalesces to form particles in the microplastic size range. Sundt *et al.* (2014) also summarized material losses of the quantities of microplastics that may be released from shipping activities and considered this an underestimate and suggested that, as smaller fragments are likely to be washed away, microplastic losses from further maintenance may be estimated at 330 tonnes per year with a fraction to soil and the remainder to sea. The Sundt *et al.* (2014) report also noted that the recreational sector as well creates microplastic waste, from both yards and owners working on their boats.

4.4.2 *Impact of marine litter from shipping and boating*

There are no reports of entanglement of marine organisms in litter specifically from shipping. Other types of impact, such as ingestion, must be considered mainly as a consequence of general waste discarded overboard from ships, without specific impact in relation to their origin.

The release of chemicals, however, could be more important when considering items like lost containers or cargos from shipwrecked vessels that may be the source of industrial pellets and packaging items for which the chemical content may pose risk. Some floating structures, such as pontoons or floats related to shipping operations and items from fishing vessel operations like fish boxes, are made of EPS (Rani *et al.* 2017). These items may degrade rapidly to microparticles and must be considered as potential sources of toxic chemical such as hexabromocyclododecanes, with abundant release observed from the open sea surface and on exposure to sunlight irradiation.

Particulate plastics used within marine paints can enter the marine environment through weathering or during the application and maintenance stage and should therefore be considered a source of particulate polymers. Paints are often made of anticorrosive products like vinyl, lacquers, urethanes, or epoxy-based coatings (Durkin and Toben 2018). In a study conducted by Song *et al.* (2015) on the extent of particulate plastics that reside on the sea surface microlayer around Korea, it was found that the particles present consisted mainly of alkyds (81%) and polyacrylate/styrene (11%). Both these polymers are used in industrial paints, while polyacrylate/styrene is also used in FRP. Due to the characteristics of the polymers, the authors suspected that the source of these polymers originated from ships and fishing boats. Further, work (reviewed by IMO 2019a) showed that general operations emit copper and biocides from vinyl and epoxy coatings, which increases significantly during cleaning maintenance. Antifouling paint particles are also abundant in estuarine sediment impacted by boating activities and are a source of metals to the marine environment (Soroldoni *et al.* 2018). They were identified in the guts of some bottom-dwelling organisms as a result of elevated metal concentrations in sediment (Muller-Karanassos *et al.* 2019).

Perhaps the largest impact of ship-generated waste is economic. There are significant costs associated with mitigating ship-sourced waste, in particular oil, but also solid waste:

- Beach clean-up costs (marine litter): approximately €297 million annually. Although estimated costs for beach clean-up operations also concern marine litter from land-based sources, the average removal cost of a cubic metre of garbage from the beach will not be substantially different for litter from sea-based sources. The removal cost was estimated at €673 per cubic metre of garbage (Panteia 2015).
- Damage to fisheries: estimates range from 1% of the total revenue generated by the EU fleet in 2013 to 5% of revenue, i.e. between €60 million and €300 million per year. The damage is caused through fouling of propellers, blocked intake pipes and valves, snagging of nets, silting of cod ends and contamination of catch (Mouat *et al.* 2010).

One estimate placed the total value of litter damage to shipping in the APEC region at USD 279 million per year (McIlgorm *et al.* 2008). The process of generating, and the presence of, any type of marine litter exerts costs on the commercial shipping sector. The main costs are associated with collisions with marine litter, including lost cargo, and indirect costs relating to operational costs, disruption of service, and public image.

Marine litter clean-up costs in harbours may also fall on the shipping sector. High levels of traffic in harbours and ports increase the risk of collision with waste. Collisions with marine litter can cause significant damage to vessels and even pose a threat to human health. Consequently, many port authorities actively remove marine litter in order to ensure facilities are safe and attractive to users (Mouat *et al.* 2010). Although the available information about the socio-economic impact of marine litter to the shipping industry is limited, it is evident that there is economic damage to the shipping sector. Due to a lack of data, quantification of this issue is difficult. However, there are some studies providing data on a more local scale.

Figure 4.3: *Potential impacts of marine litter and other items on shipping (from Mouat et al. 2010).*

Mouat *et al.* (2010) surveyed harbours and marinas in the North-East Atlantic region to ascertain the costs arising from marine litter (Figure 4.3). The most common incidences in surveyed harbours were as follows: 69% reported fouled propellers; 28% blocked intake valves and pipes; 13.2% fouled rudders; and 7.7% reported fouled anchors. Fanshawe and Everard (2002) included snagged dredging gear among the direct impacts of litter on maritime activities. According to a study that focused on the Dutch area of the North Sea (Ecorys 2012), the size of the vessels appears to be an important factor determining the scale of potential damage due to marine litter, with larger ships being less vulnerable, e.g. to entanglement of propellers. Interviews of fishermen and boatmen could not pinpoint particular hotspots of litter in the North Sea although the majority indicated a greater risk for damage due to litter in shallow areas such as rivers, river mouths and port areas. Looking further afield for evidence of harm to shipping activities from marine litter, McIlgorm *et al.* (2008) found that damage to Hong Kong's high-speed ferry services from marine litter amounted to USD 19,000 per vessel per year. The same study estimated that the value of damage to the shipping industry in APEC region is USD 279 million per annum; however this figure must be treated with caution considering the lack of data on the issue.

As an example of the costs of clean-up, the Port of Barcelona is among the five biggest cargo ports in the Mediterranean and one of the most important ports for cruises in Europe, receiving over three million cruise and ferry passengers annually. The concentration of marine litter found inside the port of Barcelona was estimated to be 20 times higher than the average found in the Mediterranean as a whole. Due to its strategic location, being well integrated in the city and open to tourists and citizens, as well as its infrastructure and its use, the port represents a large receptor of waste, related to both sea-based sources and the dynamics of the surrounding urban environment. Clean-up of the floating litter inside the port of Barcelona is conducted daily throughout the year. In 2012, over 117 tonnes of floating litter were collected and the port authorities reported that the annual cost of collection was approximately €300,000. Probably because of the location and dimension of the port of Barcelona, these costs are relatively high when compared to the costs reported in Mouat *et al.* (2010) for ports in the UK (€8,035 per port per year) and the nine Spanish ports surveyed in the Atlantic (€61,015 per port per year). Finally, this study estimated cost saving of approximately 12% (€37,000 per year) considering a scenario in which policies targeting two very common items removed (fish boxes discarded by fishermen and plastic bottles discarded by tourists on vessels) lead to significant reductions in the occurrence of these items as marine litter (Brouwer *et al.* 2017). Another study of the removal of debris from harbours reported costs as high as USD 86,695 in one year for Esbjerg Harbour in Denmark (Hall 2000).

4.5 Chapter summary

- Approximately 53,000 merchant ships were registered by IMO globally in 2020; international maritime trade has reached a total volume of cargo of 11 billion tonnes in 2018, and between 1990 and 2020 the global ocean cruise industry has grown from 4 million passengers per year to an estimated 27 million.
- Ships generate solid wastes daily that may end up as marine litter, often containing cargo waste, operational wastes (from cargo stowage and handling), sewage, galley waste, domestic waste from crews, and maintenance wastes.

A growing number of end-of-life vessels and associated components, such as FRPs, waste from ship-breaking – including glass fibre, solid foam and PVC – contribute to the marine litter burden.

- The shipping industry is also a source of microplastics, after routine cleaning of ship hulls, mishandling of cargo made of plastic items or accidental spills of industrial resin pellets. Microplastics are also generated from marine paints and antifouling coatings, from wastewater management and discharge systems (greywater, sewage), and transported through ballast waters.
- Fishing vessels may deliberately or accidentally release litter such as gloves, storage drums, EPS fish boxes and other personal waste into the marine environment; people participating in sea-based leisure activities, such as recreational boating and fishing, also generate marine litter, including single-use items.
- While few detailed studies are available that quantify the amounts and types of plastic litter from shipping, 0.001 to 2% of cargo loads are lost annually. As well, 0.01 m^3 to 0.1 m^3 of operational waste and 0.003 m^3 to 0.015 m^3 of plastic and domestic wastes are generated per person per day.
- Most traditional impacts of marine litter like entanglement and ingestion must be considered mainly as a consequence of general waste discarded overboard from ships, without specific impact in relation to their shipping origin.
- The release of chemicals could be more important when considering items like lost containers or cargoes from shipwrecked vessels that may be the source of industrial pellets and packaging items for which the chemical content may pose risk. Some floating structures, such as pontoons or floats related to shipping operations and items from fishing vessel operations, such as fish boxes, are made of EPS that may degrade rapidly to microparticles and must be considered as potential source of toxic chemicals.
- Plastic debris contained in greywater (drainage from shower, laundry, bath, washbasin, dishwasher), microplastics in ballast water, and even floating wrecks or items from shipping operations (e.g. containers, quays, navigation marks, and debris from harbours) may also contribute to the transport of organisms, understanding that the contribution from shipping is difficult to evaluate.
- Perhaps the largest impact of ship-generated waste is economic, with significant costs associated with mitigating ship-sourced solid waste, and collisions with marine litter that can cause significant damage to vessels and even pose a threat to human health.

5 DUMPING OF WASTE and OTHER MATTER AT SEA AS A MARINE LITTER SOURCE

5.1 Background and introduction

Article 210 of the United Nations Convention on Law of the Sea (UNCLOS) places an obligation upon states to “adopt laws and regulations to prevent, reduce and control pollution of the marine environment by dumping” (UNCLOS 1982). Within this context, the term “dumping” is defined as:

- any deliberate disposal at sea of wastes or other matter *from* vessels, aircraft, platforms or other man-made structures at sea; and
- any deliberate disposal at sea *of* vessels, aircraft, platforms or other man-made structures at sea.

The disposal at sea of wastes or other matter considered to be incidental to, or derived from, “normal operations” of those vehicles or structures, as well as of those arising from, or related to the exploration, exploitation and associated offshore processing of sea-bed mineral resources, are excluded from the definition of dumping, as they are regulated under other instruments (including the International Convention for the Prevention of Pollution from Ships (MARPOL, 1973/78) in the case of vessels and a combination of national regulations and Regional Seas Conventions in the case of drill cuttings). Explicitly excluded from the definition of dumping is “placement of matter” for a purpose other than mere disposal (for construction purposes, for example), providing this is not “contrary to the aims” of the London Convention (LC) (e.g. providing that it is not used as a “loophole” to facilitate *de facto* dumping of materials that would otherwise be prohibited and/or could cause pollution).

From its inception in the 1970s, LC has always prohibited the dumping (deliberate disposal) at sea of “persistent plastics and other persistent synthetic materials” (e.g. netting and ropes), though initially based primarily on the concern that they could “interfere materially with fishing, navigation or other legitimate uses of the sea”. Understanding of the scale and complexity of impacts of plastic litter on marine species and habitats has developed greatly since that time, as has acknowledgment of the distribution, fates and effects of microplastics as marine pollutants (GESAMP 2015, 2016). One aspect of that growing understanding is the recognition that plastics can also reach the marine environment as components of, or contaminants in, other waste streams that have continued to be disposed of at sea through dumping activities.

Since the 1970s, parties to LC have placed increasing restrictions on the types of wastes that may be considered for dumping at sea, with the most substantive changes introduced in the 1990s, including prohibitions on dumping at sea of industrial waste and radioactive waste, as well as on sea-based incineration of wastes. After the Rio Earth Summit, the parties developed and agreed on the London Protocol (LP) in 1996 to update LC, with the purpose of consolidating the higher levels of protection into a more precautionary instrument. This entered into force in 2006 as LP (LP 2006). Currently the two instruments are in force in parallel, with some states party to one or the other, and others party to both, and with a total of 100 contracting parties to the LC/LP "family" overall, as of November 2019. The ultimate intent is that LP will eventually replace LC as the global standard for the regulation of dumping activities.

The definition of dumping under LP is very similar to that under LC, though it also explicitly captures two other sea-based disposal activities:

- any storage of wastes or other matter in the seabed and the subsoil thereof from vessels, aircraft, platforms or other man-made structures at sea; and
- any abandonment or toppling at site of platforms or other man-made structures at sea, for the sole purpose of deliberate disposal (LP 2006).

It also adds an explicit exclusion from the definition, to cover the abandonment of, for example, cables, pipelines and marine research devices associated with offshore structures, providing they were placed for a purpose other than disposal.

In contrast to the list of materials and waste streams prohibited for dumping under LC, the LP established a "reverse list" of materials or waste streams that may be considered for disposal at sea (subject to detailed assessment), to the exclusion of all others. Considering the amendments agreed to in 2006 to enable carbon-capture and storage (CCS) in sub-seabed geological formations, the list of wastes or other matter that may be considered for dumping currently includes:

- dredged material;
- sewage sludge;
- fish waste, or material resulting from industrial fish processing operations;
- vessels and platforms or other man-made structures at sea;
- inert, inorganic geological material;
- organic material of natural origin;
- bulky items primarily comprising iron, steel, concrete and similarly unharmful materials for which the concern is physical impact, and limited to those circumstances where such wastes are generated at locations, such as small islands with isolated communities, having no practicable access to disposal options other than dumping; and
- carbon dioxide streams from carbon dioxide capture processes for sequestration (LP 2006).

For the purposes of this report, the degree to which these allowable dumped materials may contribute to marine litter is assessed.

5.2 Sources and characterization of marine litter resulting from ocean dumping

5.2.1 *Dredged materials*

Of these wastes, by far the highest volumes and tonnages reported as being dumped around the world are dredged materials. These are primarily sediments dredged from estuaries, ports, harbours and other coastal locations, either for maintenance of navigation channels, harbours and marinas or for capital projects such as new port or channel construction or from the installation of structures such as pipelines. Dredging is an activity common to all countries with a significant level of sea-based commerce, whether they are party to LC/LP or not, with significant proportions of the material dredged being disposed of at designated dump sites further offshore. In some cases, however, a very significant fraction of the total may be dumped in estuaries, (>50% of the total for the UK, for example). This is not usually the main reason for disposal in estuaries, as many of these operations pre-date the regulation of the disposal at sea of dredged material that came in with LC (1972).

Dredged materials have therefore always dominated the total quantities of wastes dumped at sea, with reported quantities rising steadily worldwide since records began in the 1970s (IMO 2016a). According to the most recent reports on permits issued by parties to LC/LP, for example, somewhere in excess of 300 million tonnes per year of dredged material were routinely dumped at sea each year in the period from 2013-2016 (IMO 2016b, 2017a, 2018a, 2019a). Given that many states are not party to LC/LP, and that even among Parties, reporting rates remain low, this figure is undoubtedly a substantial underestimate of the total quantity of dredged materials dumped globally: actual quantities of dredged material dumped in the world's ocean could be as much as 1,000 million tonnes per year (Vivian and Murray 2009). The tendency for total quantities of dredged material dumped at sea to be underestimated by official reported statistics was also noted in an assessment of dumping activities through the 1980s and the 1990s (Vivian and Murray 2009).

Although most dredged materials originate as sediments in coastal or estuarine waters, their subsequent disposal at sea nonetheless represents a sea-based activity, and a potential route by which contaminants contained in those sediments can become redistributed and more widely dispersed to the marine environment. Contamination of dredged sediments, including with chemicals and plastics (macro-plastic litter and microplastics), may originate from a variety of sources, including directly from industrial, commercial and leisure activities within ports, harbours and marinas, direct localized discharges and run-off from coastal urban communities or through the settlement of contaminants arising from urban, agricultural or industrial sources further upstream within river catchments (Eerkes-Medrano *et al.* 2015). Although a substantial proportion of the tonnage dredged and dumped in many parts of the world is expected to be relatively clean sand and silt from channel maintenance operations, considering the total quantities involved and the fact that some proportion of those sediments will inevitably carry significant burdens of pollutants (including chemicals, plastics and metals), dumping of dredged materials may well be expected to make a significant contribution overall to contamination at, and in the vicinity of, dump sites, and perhaps further afield.

5.2.2 *Sewage sludge*

Sewage sludge, the solids arising from the settlement and treatment of sewage and other waste waters directed to the sewer system, can also carry significant loadings of contaminants, again including chemicals and plastics (especially microplastics) from a wide variety of sources (Zubris and Richards 2005). Although once a common practice in many parts of the world, with reports of permits issued by LC parties for dumping of between 10 and 20 million tonnes per year from the early 1970s to the mid-1990s (IMO 2016a), the dumping at sea of sewage sludge appears to have been in decline in recent decades, in part as a result of national or regional initiatives and regulations. Within European waters, for example, a phase-out of the dumping at sea of sewage sludge by 31 December 1998 was agreed under the 1991 EU Urban Wastewater Treatment Directive (EU 1991). The Republic of Korea, one of the last parties to the LC/LP to report regular dumping of sewage sludge, ceased the practice in 2015 (IMO 2016c). It is important to bear in mind, however, that more than half of the countries in the world are party to neither the LC nor the LP, and that many countries that are parties to one or the other nonetheless do not report regularly on dumping activities or permits issued. It is possible that some quantities of sewage sludge are still being dumped by some states, though evidence one way or another remains elusive.

5.2.3 *Fish waste, organic material of natural origin, and inert inorganics*

Over the years, permits have been issued for many of the other wastes listed on Annex 1 of the LP, either on a regular or more sporadic basis, and in far lower overall tonnage quantities than those for dredged materials. For example, in the four most recent years for which data are available (2013-2016), permits for dumping of fish waste (arising either from wild stocks or aquaculture and consisting of particles of flesh, skin, bones, entrails, shells or liquid stick water) have been reported by Canada, the Republic of Korea and the United Kingdom (IMO 2016b; 2017a; 2018a; 2019a). Over the same period, permits for wastes listed under the rather more loosely defined category of "organic material of natural origin" have been issued by Australia, Costa Rica, Cyprus, New Zealand, the Republic of Korea, the Philippines, the United Kingdom and the United States. In several of these cases, however, permits relate only to burials at sea, to the disposal of seaweed accumulations or of the carcasses of stranded whales. In certain other cases, the suitability of the categorization is questionable given the reported nature of the waste (e.g. unspecified "mining wastes"). In the case of "inert, inorganic geological material" (which should be restricted to materials of geologic nature, comprised only of materials from the solid portion of the Earth, such as rock or mineral), permits were issued during the same period (2013-2016) by Canada, Iceland, Japan and the Philippines, for materials such as "sand and silt from construction activities" and "undisturbed geological till". Historically the quantities of waste dumped under this category were substantially greater, though in large part because reports on the dumping of bauxite residues by Japan, discontinued in 2015 (IMO 2015a), were included under this category.

Assuming that materials have been appropriately characterized under those categories, plastic litter and microplastics would not be expected to constitute significant contaminants within any of these three waste streams (fish waste, organic material of natural origin and inert geological materials). For example, in the case of the geological till dumped by Canada under the heading of inert geological material, the Canadian authorities state explicitly that permits are dependent on debris and other contaminants having been removed prior to disposal (IMO 2017b). A possible exception to this assumption, however, could relate to the occasional use of the category "organic material of natural origin" when reporting the dumping of cargo spoilt in transit by, for example, excessive delay or ingress of water, especially where packaged perishable products are involved. In the majority of cases, however, these special or emergency permits are reported under the specific category of "spoilt cargo", according to separate joint guidance developed by LC/LP and IMO (IMO 2013a), and this is discussed further.

In 2019, Italy presented a paper to the scientific groups of LC/LP highlighting the problems associated with the accumulation of large quantities of seagrass leaves (Posidonia oceanica) on beaches and especially in small ports and harbours around the Mediterranean, noting that tens of thousands of tonnes of material built up on the shores of Italy alone each year (IMO 2019b). Other countries experience similar problems with large quantities of Sargassum washing ashore. Although dumping of this material at sea under the category of "organic material of natural origin" was an option under consideration, in order to reduce the current burden on landfill, the Italian authorities recognize that this option may in practice be limited by the presence of litter, including plastics, as a significant (though currently unquantified) component of the accumulated deposits.

5.2.4 *Vessels, platforms and other man-made structures*

When it comes to wastes considered for dumping under the broad category of "vessels, platforms and other man-made structures at sea", it is clear that such materials could carry a significant residual burden of associated plastics as integral components of those vessels or structures, though most should be removed as part of a pollution prevention plan prior to any application for disposal at sea being considered by national permitting authorities. Indeed, Annex 1 of the LP itself stresses that these types of waste may be considered for dumping only once "material capable of creating floating debris or otherwise contributing to pollution of the marine environment has been removed to the maximum extent" (LP 2006).

What that has meant in practice is extremely difficult to determine, however, because with the exception of a small number of cases, very few details have so far been shared by national authorities as to the procedures they undertake to audit vessels or platforms for the presence of plastics or other potential debris, nor the extent to which their removal is subsequently verified prior to a permit being issued. Canada and the United States have produced guidance documents for using vessels as artificial reefs that provide detailed guidance on their cleanup, and the LC/LP Waste Assessment Guidance (WAG) documents also now address requirements for removal of vessels.

In fact, in the case of vessels, information reported to the LC/LP by permitting authorities has generally been limited only to the numbers of permits issued in a particular year, without information even on the type, tonnage or construction of the vessels dumped or, in some case, whether the permits were ever used. In the first decade or so of the LC, few permits were reported for vessel dumping each year, with a widely scattered trend towards increasing numbers of permits through the 1990s up until 2010 (IMO 2016a). In the most recent year for which a finalized report on permits is available, 2016, four countries reported on dumping permits for vessels; Australia for a vessel of unspecified size in the Coral Sea, Canada for a vessel of 42,000 tonnes in the West Atlantic Ocean, Mexico with three permits covering disposal of vessels with a total weight of over 100,000 tonnes in an unspecified location and the United States, which issued a permit covering five vessels (in the West Atlantic, Eastern Pacific and Bering Sea) but with no indication of weights or other information provided (IMO 2019a).

An issue that has come to prominence in recent years is that of the management of end-of-life fibre-reinforced plastic (FRP) vessels, commonly referred to as fibreglass vessels, and the extent to which they may currently be disposed of by abandonment in harbours or deliberate sinking at sea (effectively dumping in both cases). Although Norway has in the past reported issuance of permits for the disposal at sea of a number of small plastic vessels in 1997 (IMO 1999) and again in 2003 (IMO 2007a), for example, it is not known whether this was unusual at the time or if it was a practice common to more countries that was simply not being regulated through any permitting process and therefore not reported. What is clear, however, is that specific guidance developed under LC/LP for the assessment of vessels proposed for dumping (examined further) explicitly does not include specific consideration of FRP vessels, focusing instead on larger, predominantly steel vessels. Norway ceased the dumping at sea of all vessels in 2004 (IMO 2007a). Nonetheless, given the very large number of FRP craft in current use around the world (e.g. an estimated 6 million recreational craft in Europe alone), and the significant proportion of those anticipated to be decommissioned and scrapped each year (estimated at 140,000 across Europe) (IMO 2017c), the question of their management and ultimate disposal remains an issue of direct relevance for the protection of the marine environment. A recent review of end-of-life management practices for FRP vessels, commissioned through IMO in response to concerns raised within the LC/LP (IMO 2019c), concludes that no figures are immediately available on the extent to which FRP vessels are being disposed of at sea, whether in small island states, in Europe or in North America, but that the potential existed for any such dumping to be a significant contributor to inputs of plastic material to the sea. The problems relating to FRP vessels are explored further later in this chapter.

The category of platforms or other man-made structures at sea has been used to report the dumping of a diverse range of materials including, in recent years, a steel wave generator, a riser turret mooring and associated mid-water buoys (Australia), the man-made components of an ice pier (United States) and a carbon steel well head from offshore oil and gas operations (New Zealand) (IMO 2016b, 2017a, 2018a, 2019a). Again, in the majority of cases reported over decades, very little information has been provided by the Parties to date, such that no retrospective determination of the plastic content of such wastes can be made.

5.2.5 *"Bulky items"*

Relatively few permits have ever been reported under the rather obscure category of "bulky items" (none in more recent years), which was conceived in order to address some specific difficulties in relation to isolated small island states. Just as with other waste categories, however, it is not clear whether such wastes have continued to be dumped by any states, whether non-parties or parties that do not regularly report. Given that at the time that this category was fully defined in the 1990s it was envisaged that it may include inter alia the casings of household "white goods", concern that such wastes may contain residual plastic components is justified. Moreover, just as for vessels, platforms and other man-made structures, Annex 1 of the LP requires that, for bulky wastes, "material capable of creating floating debris or otherwise contributing to pollution of the marine environment has been removed to the maximum extent". Again, however, just as for vessels and man-made structures, the extent to which such inspection for and removal of plastics was ever carried out in practice in those cases in which bulky items have historically been dumped at sea has never been documented.

5.2.6 *Spoilt cargoes*

As noted earlier, in addition to the eight categories of waste specified in Annex 1 of the LP, a small number of permits are commonly issued each year to authorize the dumping at sea of a diversity of cargoes that have become spoilt in transit and for which offloading for processing on land is deemed to have become impracticable. For example, in 2016 Greece issued a permit for the disposal into the Arabian Sea of almost 2,000 tonnes of "seawater-damaged bulk yellow corn", and the USA for 318 tonnes of "distillers dried grains" in international waters of the East Atlantic Ocean (IMO 2019a). Other spoilt cargoes permitted for dumping in recent years include 1,000 tonnes of "damaged corn in bulk" by Malta (also in the Arabian Sea) and 1,500 tonnes of "damaged granulated sulphur" authorized by the Marshall Islands (IMO 2016b). In both 2013 and 2014, South Africa issued permits for the disposal to the India Ocean of cargoes of coal (10,000 tonnes and 26,000 tonnes respectively) (IMO 2016b, 2017a). On both those occasions, the emergency provisions under Article 8 of the London Protocol were invoked, i.e. under so-called "force majeure" conditions, where dumping of cargo has been assessed as a necessary measure to secure the safety of a vessel and/or of human life at sea. The London Protocol provides additional procedures and criteria to help ensure that any such decisions are based on as thorough consideration as possible of all the information available, while recognizing the urgency of the situation that is unfolding (IMO 2006a).

The revised joint LC/LP-IMO *Guidance for management of spoilt cargoes* requests parties to give consideration to "how the spoilt cargo is packaged and how it would be released" (IMO 2013a). This builds on specific concerns expressed by parties in the early part of the last decade over reports that some proportion of consignments of bananas that were rejected due to spoilage in transit may then have been dumped at sea along with their plastic packaging (IMO 2005a). The guidance also provides an illustrative list of some of the spoilt cargoes that have historically been considered for sea disposal after seawater ingress, including "cement packed in bags", "bagged sugar" and even "bagged garlic", though it is not specified in any of these cases what sort of material the bags were made from or, therefore, whether any of the packaging was plastic. In the examples listed earlier (bulk corn, distillers' grains, coal, etc.), it seems unlikely that packaging materials would have formed part of the material dumped. In fact, in the case of a spoilt cargo disposal of rice in the north-western Indian Ocean by a United Kingdom flagged vessel, bags were retained onboard the ship after the rice was discharged overboard. That said, the discharge of packaging materials during spoilt cargo discharges cannot be entirely excluded as a possibility.

5.2.7 *Other materials, including historical and illegal dumping*

In addition to the general permits for the waste streams on the "reverse list", and any special permits for spoilt cargoes or for other materials that may be dumped under conditions of force majeure, the LC/LP also provides a mechanism by which suspected illegal dumping of wastes or other matter can be reported (IMO 2012). It is unclear, however, how frequently this reporting mechanism has been used in practice. It also appears that there is almost no publicly available information relating to any such reports and how they may have been addressed, let alone how many illegal dumping incidents may have occurred involving plastics or wastes likely to contain significant quantities of plastics. In one higher profile case in the United States in the late 1990s, a defendant was reportedly prosecuted after pleading guilty to instructing employees under his supervision to dump "hundreds" of plastic bags containing asbestos into the ocean (NOAA 2008). There are, however, no other details available in the public domain regarding the total quantities dumped (of asbestos or plastics), the disposal locations or the ultimate fate and impacts of those materials, or whether this was a "one-off" or a more widespread illegal practice at that time.

Incidentally, while it is possible, perhaps even likely, that plastics formed a part of some of the consignments of industrial and/or radioactive wastes that were legally disposed of at sea before the practices were prohibited in the 1990s, it appears that there is no information in the public domain regarding that issue.

5.3 Ocean dumping and plastics

In addition to setting out the categories of waste that can or cannot be considered for disposal at sea by dumping, the mechanisms of LC and LP also provide detailed frameworks to guide the assessment of candidate wastes in order to determine the justification and suitability for dumping, as well as to assist in the selection of an appropriate disposal site and requirements for monitoring and permit review. Application of those assessment frameworks, set out as Generic Guidelines under LC (IMO 2014a) and incorporated as Annex 2 of the LP (LP 2006), requires initial conduct of a waste prevention audit, followed by consideration of whether there are alternatives to sea disposal further up the waste management hierarchy (as part of the general obligation to minimize reliance on disposal at sea for all wastes). If disposal at sea is still considered an acceptable option, the assessment then proceeds through characterization of the waste (which may include physical, chemical and biological aspects), selection of dump site and assessment of potential impacts on the marine environment, before considering permitting and monitoring conditions.

Integral to the waste characterization step is a comparison of selected contaminant concentrations against an action list. Although guidance on the setting of action lists and action levels (i.e. the levels at which certain management decisions are triggered) has been developed under the LC/LP, in order to assist parties in their development (IMO 2017d), it is ultimately for national authorities to determine the lists of contaminants and the trigger levels they consider applicable in their own jurisdiction. Those lists and levels are therefore set on the basis of a combination of considerations, including which contaminants are deemed to be of greatest concern, concentrations likely to cause impacts at the dumpsite and surrounding area and, more pragmatically, the feasibility for those contaminants to be detected and quantified through routine sampling and analysis without excessive cost or time constraints.

As a result, action lists for any particular waste category can vary considerably from party to party, in terms of the range of contaminants included and the action levels associated with them. Most focus on a limited range of toxic metals and commonly recognized persistent organic pollutants (IMO 2007b). Some include a handful of what might be considered "emerging" chemical pollutants, though many of those are in effect also now long-standing issues.

To date, no country has set specific action levels either for litter or for microplastics in any waste stream, despite the growing recognition of the scale of the problem. One possible exception is the qualitative but seemingly absolute requirement set within the Republic of Korea that "dredged material to be disposed of at sea shall not contain any other material including synthetic rope, used fishing gear, rag debris, rubber products, packing material" (IMO 2007b). The otherwise apparent absence of litter or plastic-based action levels may be in part a reflection of the time required for technical changes to be introduced and accepted within the legal mechanisms governing national permitting decisions but is largely a consequence of the ongoing challenges and limitations to the separation, detection, identification and quantification of plastic litter and microplastics in waste streams, especially in high volume wastes such as dredged materials. These challenges and their implications are explored further later in this chapter.

Complementing the generic assessment guidelines is a series of waste-specific assessment guidelines (WAGs), addressing each of the eight waste streams identified in Annex 1 to the LP, but applicable under both the LC and the LP. These WAGs are intended to assist in the interpretation of the overarching assessment frameworks, and not to provide for either a more or less stringent assessment *per se*. They are set out in the same format and describe the same iterative processes while guiding permitting authorities to what are considered to be the key considerations in relation to each waste category.

In the case of dredged materials, for example (IMO 2013b), it is explicitly recognized under the waste prevention audit that the primary goal must be to identify and control the sources of contamination (both local and upstream), since the demands for safe navigation will always require the dredging of harbours, channels and other waterways and, therefore, the *de facto* creation of dredged material. Although there is an increasing focus on identifying options to reuse dredged material in, for example, coastal management applications, and therefore to reduce the reliance on disposal at sea (e.g. IMO 2017e, 2017f), such applications also require the sediments to be as free from contamination as possible. To date, the priority has very much been on chemical contaminants, though the same principle need to identify and control upstream sources applies equally to marine litter and microplastics. This was explicitly recognized by the meeting of parties to the LC/LP as *Recommendation to encourage action to combat marine litter*, agreed at their thirty-eighth meeting in 2016:

"The Contracting Parties to the London Protocol and the London Convention express concern around the issue of plastic litter and microplastics in the marine environment and encourage Member States to make every effort to combat marine litter, including through the identification and control of marine litter at source and to encourage monitoring, additional study and knowledge-sharing on this issue." (IMO 2016d)

The same meeting also agreed to encourage parties "to take into account the issue of plastics and marine litter when applying the dredged material waste assessment guidance" and "noted that the issue of plastics may be revisited in the next revision of the waste assessment guidance, as appropriate".

The same principles can, of course, be seen to apply to sewage sludge, even if reliance on disposal at sea of that waste stream is in decline, as the failure to identify and control contaminants (chemicals and plastics) at source can also place strict limits on land-based options for treatment and reuse. Indeed, at the thirty-ninth meeting of LC/LP in October 2017, there was further agreement "that Parties should redouble efforts to share knowledge and technical expertise with regard to the analysis of plastics, including microplastics, in dredged material and sewage sludge (in particular), with a view to developing methods to enable routine, reliable monitoring, assessment and reporting of microplastic contaminant levels in such waste streams as soon as possible" (IMO 2017b). It is nonetheless expected to be some time before such information sharing can lead to standardization and widespread availability of such assessment techniques and, therefore, to a sufficient accumulation of comparable data to enable quantitative estimates of aggregated amounts dumped at sea as components of dredged materials.

In parallel, parties to the OSPAR Convention (the Regional Seas Convention for the North-East Atlantic) are in the process of developing suitable indicators for microplastics in marine sediment (OSPAR 2019), in part to fulfil requirements arising from the European Union's Marine Strategy Framework Directive (MSFD 2008). This Directive requires "Good Environmental Status" (GES) for marine litter, i.e. that "properties and quantities of marine litter do not cause harm to the coastal and marine environment"; criteria and methodological standards for GES determination have also been set.

In the case of waste categories such as vessels, platforms and other man-made structures, and bulky items, the more relevant concern in relation to marine litter and microplastics is likely to be the identification and, where possible, removal of plastics and similar materials that are integral to those waste categories (i.e. as structural or furnishing components), rather than being more incidental to the wastes (as is the case for dredged material and sewage sludge). For example, the specific WAG for vessels (IMO 2016e) highlights the need to develop a pollution prevention plan, with the aim "to assure that wastes (or other matter and materials capable of creating floating debris) potentially contributing to pollution of the marine environment have been removed [from the vessel] to the maximum extent possible", mirroring the obligation under Annex 1 of the LP. The WAG goes on to identify plastics and "styrofoam" insulation as examples of "floatable materials" with the potential to cause pollution and which therefore should be removed where possible. Similarly, the WAG for platforms and other man-made structures (IMO 2014b, 2019d) requires that "floatable materials that could adversely impact safety, human health or the ecological or aesthetic value of the marine environment shall be removed", at least "within technical and economic feasibility and taking into consideration the safety of workers, platforms or structures to be disposed of at sea".

Given the very limited information available for those vessels and man-made structures that have actually been dumped at sea, as summarized in LC/LP annual reports of permits issued, it is not possible to determine how strictly or consistently the requirements for waste assessment and the drawing up and implementation of pollution prevention plans are being adhered to in practice, nor therefore how much residual plastic may remain on those vessels or structures at the time of dumping. Some additional information on the application of the guidelines for vessels has been provided in the past by Canada, in the context of permitting decisions for vessels in British Columbia (BC; IMO 2005b), and with particular regard to the former 125 m naval vessel *Cape Breton*, sunk under a dumping permit in 30 m of water in the Fairway Channel, BC. Under that approach, the Canadian authorities determined that "plastic, other synthetic materials and soft furnishings may be left *in situ* if they are part of the structure of the vessel and are securely attached to the structure of the vessel, subject to any tests that the responsible Environment Canada official may specify". There were also specific requirements for plastic foam insulation, which was to be removed entirely from the vessel prior to disposal unless it met all of four criteria, relating to its condition, knowledge of its chemical composition, integrity of covering material and security of attachment to the structure of the vessel. Despite the descriptive detail contained in the paper, and the overview it provided of the complexity of the operation to prepare the *Cape Breton* for dumping, it did not provide information on quantities of each assessed material (including plastics) that were removed, nor the amounts remaining on the vessel at the time of dumping.

In the case of FRP vessels, the entire structure of the vessel itself is of concern with regard to the potential for contribution to plastic litter and, as that structure is abraded or degrades, also as a source of microplastics (IMO 2019c). Although there is a paucity of data regarding the number of FRP vessels that are dumped at sea each year, there are legitimate concerns that the lack of access to other more sustainable options (e.g. abandonment or dumping on land, or open burning) may well be driving some level of essentially unregulated and unreported sea disposal, especially in small island developing states. Although most FRP vessels are small craft relative to the vessels for which the WAG under LC/LP was developed, the fact that much of their weight is plastic resin, combined with the sheer number of individual vessels reaching or at their end of life, makes it an issue of high potential significance in relation to plastic litter and microplastic pollution. At their fortieth meeting in November 2018, parties to LC/LP endorsed a statement prepared by their scientific groups in May of the same year that expressed "serious concerns that the disposal at sea of fibre-reinforced plastic vessels may represent a significant additional source of plastic litter and microplastics in the marine environment" (IMO 2018b). This statement of concern went on to stress that "such vessels are not good candidates for disposal at sea, or appropriate for use as artificial reefs in the marine environment, as they may float or drift, also posing a hazard to navigation".

5.4 Quantity and impact of marine litter from ocean dumping

5.4.1 *Background and introduction*

It is evident that, despite the likely occurrence of plastic litter and/or microplastics in a number of the waste categories that may be considered for dumping at sea, remarkably few studies have so far attempted to characterize those wastes for plastics in quantitative terms. This inevitably places limitations on comparative evaluation of the absolute or relative significance of waste dumping as a contributor to overall inputs of plastic litter and microplastics to the marine environment. The following section summarizes those data and assessments that are available to date, and also serves as an illustration of the substantial gaps in, and in many cases near total absence of, quantitative information.

5.4.2 *Dredged materials and sewage sludge*

Worm *et al.* (2017) noted that microplastics are often found to be four or five orders of magnitude more abundant in sediments when compared to overlying waters, suggesting that whatever their origin, sediments may represent an inevitable sink for most plastics, including microplastics. Although some commonly used polymers, such as polyethylene and polypropylene, are inherently less dense than seawater and may be expected to remain buoyant, in practice even these materials can be found in marine sediments, perhaps as a result of increases in density over time through biofouling or aggregation with other materials. Koelmans *et al.* (2017) use output from a whole ocean mass balance model to suggest that as much as 99.8% of the plastics that have entered the marine environment since the 1950s may already have sunk below the surface layers of seawater, with a significant proportion therefore expected to be resting on the sea floor or incorporated into sediments.

Both macro- and microplastics are found even in some of the remotest and deepest parts of the ocean. There is some evidence to suggest that both macro- and microplastics are present in higher abundances in sediments in coastal regions, especially in ports and harbours and other areas with strong spatial association to human activities (Eerkes-Medrano *et al.* 2015). For example, Claessens *et al.* (2011) found microplastics to be common contaminants in sediments from coastal waters of Belgium, with average abundances significantly higher within harbour sediments (166.7 ± 92.1 particles per kg dry weight) than in beach sediment (92.8 ± 37.2 particles per kg) or in other shallow water sediments in the region (97.2 ± 18.6 particles per kg). The highest level of microplastic contamination, at 390.7 ± 32.6 particles per kg dry sediment, was found in a confined area within Nieuwpoort Harbour, which is understood to receive discharges and run-off from a range of industrial and urban sources. Laglbaeur *et al.* (2014) found even higher levels in some Slovenian sediments, especially close to the coast, while Willis *et al.* (2017) reported values higher still (up to 4,300 microplastics per kg) in sediments from a harbour in Tasmania.

A survey of sediments from 11 waterways in the United States, conducted by the US Army Corps of Engineers, found microplastics to be present in 100% of the samples collected, with an average abundance of 1,611 ± 1,372 particles per kg of dry sediment (range 217-5,019) (IMO 2019e). As part of the same survey, a desktop review of 30 additional studies yielded similar averages in excess of 1,000 particles per kg dry weight for sediments collected from both inland and shallow marine waters.

Microplastics may accumulate to higher densities in sediments in areas of relatively low flow compared to those that are subject to stronger currents, as may be expected (e.g. Vianello *et al.* 2013; in the Venice Lagoon). This may also be of relevance in relation to likelihood of accumulation in relatively sheltered, low energy environments, such as in ports and harbours (e.g. Claessens *et al.* 2011), which may also be subject to more concentrated localized inputs of plastics, as well as perhaps being more likely to be subject to periodic dredging. Other studies have suggested that microplastics may accumulate to higher abundances in sediment in down current locations within estuarine environments, and that fragments of denser polymers may have more patchy and localized distributions than less dense polymers (e.g. Browne *et al.* 2010). There are, however, complexities in the pattern of distribution of plastics in sediments which make it difficult and potentially misleading to draw too many generalizations. These include the high heterogeneity of distribution and abundance (GESAMP 2019; Worm *et al.* 2017) and the apparent lack of correlation between abundance of microplastics and either the presence of macro-plastic litter at the same locations (Dekiff *et al.* 2014, based on analysis of beach sediments in the North Sea) or the grain size of sediments (Alomar *et al.* 2016). Furthermore, Law and Thompson (2014) noted that it will likely remain difficult to link most plastic litter and microplastics to specific sources because of the complexity of the pathways by which these contaminants are distributed and sorted once they reach the marine environment.

Because of the wide diversity in sizes, forms and types of microplastic that are encountered in sediments, as well as the current lack of standardization of methods across different studies (including size ranges and counting techniques) (van Cauwenberghe *et al.* 2015), substantial caution must be exercised when attempting to make quantitative comparisons between different studies, especially as most data are reported simply as counts or abundances of individual microplastic fragments and fibres per unit weight of sediment. Note that there are efforts underway to improve standardization for measuring microplastics in the marine environment, e.g. GESAMP (2019). That said, only one study has been identified to date which reports levels of microplastic contamination of sediment in terms of mass of plastic per unit dry weight of sediment (Reddy *et al.* 2006), which would be necessary to enable even rudimentary estimation of the comparative contribution of microplastic loadings arising from sediments that are dredged and disposed of at sea, compared to other sea-based sources of plastics.

With the growing body of data on the presence of plastic litter and microplastics in shallow water sediments, it is reasonable to speculate that most (if not all) dredged materials destined for disposal at sea will also contain some measurable presence of these contaminants. However, that is where the confidence ends. A literature review conducted by the US Army Corps of Engineers in 2015 concluded that, as of that time, "research focused specifically on dredging and plastics is almost non-existent" (IMO 2015b). Although the authors of that review were able to identify two technical papers prepared for the Army Corps of Engineers that addressed the presence of macro-plastic litter in dredged material, these largely dealt with descriptions of mechanical mechanisms to screen out a proportion of that debris prior to consideration for disposal at sea. No research could be found at that time that addressed the presence or impacts of microplastics in relation to dredging operations, nor on the implications of dredging and subsequent dumping of sediments on the resuspension and redistribution of microplastic contaminants (IMO 2015b).

In 2014, in recognition of the need for greater understanding of the issue for purposes of protection of the marine environment from dumping activities, IMO (on request from the scientific groups to LC/LP) commissioned a review of the information available at the time on the presence of litter and microplastics in waste streams of relevance to LC/LP. The resulting report, published in 2016, highlighted many of the same issues summarized earlier, and concluded in particular that:

> "it is presently impossible to generalize regarding the litter content of either sewage sludge or dredged materials, in terms of litter types, properties or quantities. The main reasons for this are an overall shortage of data, differences in methodology and reporting, and the lack of systematic sampling in space and time. Nevertheless, it seems probable that various types of small and micro-sized plastics present the greatest hazards and warrant most concern. It is premature to speculate, however, on the specific materials that present the greatest risks for marine life or to focus on any particular line of experimental research that would enable actual effects to be evaluated." (IMO 2016f)

Overall, the report provides a useful overview of the presence of litter and microplastics in marine sediments, and of the potential exposure and effects with regard to marine life, which complements the reports and studies of GESAMP (2015, 2016). For understandable reasons, however, the authors were unable to draw any direct links at this stage between observed distribution and impacts and the contribution from the sea-based activity of dumping *per se*:

> "Clearly then, until more data can be gathered and evaluated it would not be appropriate to form conclusions about the environmental effects of plastics, or other types of litter, introduced to the sea in sewage sludge and dredged material, or the relative impacts of these and other litter sources. To advance understanding of this issue, far more extensive investigations will be required." (IMO 2016f)

One possible line of evidence that could begin to fill this gap would be the study of the behaviour and accumulation of marine litter and microplastics at and within the vicinity of disposal sites, either for dredged material or sewage sludge. In this area also, however, data remain extremely limited, in part because, unlike the situation for chemicals on the action lists, there have been no systematic requirements to date for monitoring of dump sites or the material disposed of to them for plastics. In a survey of microplastics in sediments beneath Continental Shelf waters of Rio de Janeiro State (Brazil), Neto *et al.* (2019) noted that samples collected within or close to dredged material dump sites were among those yielding the highest abundance of microplastics, especially for plastic fragments and films. However, plastic fibres,[9] which accounted for almost half of the 2,400 microplastics isolated and investigated in this study, were more widely dispersed across the study area, and the authors note that, given the heavy urbanization and industrialization of the adjacent coastal region, there are many potential sources of plastic pollution to sediments in the region, including substantial sub-sea sewage outfalls. In an earlier survey of microplastics in shallow water sediments from 18 locations around the world, Browne *et al.* (2011) noted that, whereas it was undoubtedly the case that the disposal at sea of sewage sludge over decades had contributed to the presence of microplastics (especially fibres) in marine sediments, this was one of many sources of plastic pollution to coastal waters.

5.4.3 *Other dumped waste*

If the information available on plastics in dredged material and sewage sludge dumped at sea is extremely limited, that relating to the presence of plastics associated with other of the waste streams that may be considered for dumping is almost non-existent. It is only possible to provide some illustrative examples of the types of concerns that exist, without drawing any more generic conclusions as to how representative they may be or, therefore, their relative contribution as sources of marine litter and microplastics.

In the case of scuttled vessels, for example, while there is a clear potential for some residual plastics to remain on board at the time of disposal at sea, in the vast majority of cases the information made public in the form of annual dumping reports is generally limited only to the number of permits issued and the ocean region they were issued for. This is accompanied sometimes (though not always) with an indication of the tonnage of the vessels dumped.

A rare exception (aside from the information provided by Canada in relation to the *Cape Breton* discussed earlier in this chapter) relates to the sinking (scuttling) off the coast of Florida of the former United States Navy aircraft carrier *USS Oriskany* in May 2006. At the time at which this was discussed within the scientific groups and meeting of the governing bodies of LC/LP in the same year, the key concern related to the residual presence on the vessel (after preparation for reefing) of considerable quantities of polychlorinated biphenyls (PCBs) (estimated at approximately 300 kg in total), contained primarily in electrical cables and bulkhead insulation in locations considered to be inaccessible during decommissioning operations (IMO 2006b). The ecological risk assessment prepared for the US Navy at the time, however (PEO Ships 2006), indicates that the quantities of plastics and other polymers themselves (i.e. in which the PCBs were contained) also represented a substantial burden of potentially polluting materials, if only in the longer term as the steel structure of the vessel itself corrodes. By the time the vessel was sunk, those materials still constituted an estimated 228 tonnes of plastic-coated cabling, 14 tonnes of bulkhead insulation material, 5 tonnes of black rubber and more than a tonne of ventilation gaskets. Although a sampling programme was subsequently instigated to monitor for PCB contamination of a number of fish species in the vicinity of the vessel, which showed initial elevated levels followed by a gradual decline (FFWCC 2011), it is not clear whether there has been, or will in the future be, targeted efforts to monitor the degradation of the vessel itself and any consequent redistribution of plastics or other debris.

As noted previously, the sinking of the *USS Oriskany* is a very specific case, and one not officially classed as dumping or disposal. While it cannot therefore be used as a basis for extrapolation, given that every large vessel dumped at sea is likely to present unique aspects and have been subject to differing levels of clean-up prior to disposal, it does nonetheless serve to illustrate the complexity of obsolete vessels as wastes and the potential for them to act as sources of plastic litter and microplastic pollution (at least in the long term) if they are dumped at sea.

There is, of course, the possibility that FRP vessels may also be dumped at sea in some regions, perhaps as a largely unregulated and therefore unreported activity. The IMO review on this issue concluded that although there are some indications that disposal at sea may be used “as a last resort action or deliberate, and perhaps irresponsible approach” there are currently no data available on how many FRP vessels may have been disposed of at sea so far, nor on how widespread the practice might be in different regions (IMO 2019c). What is clear, however, is that even a single FRP craft dumped at sea could represent a substantial local source of plastic debris and microplastics over time as the vessel degrades and breaks up on the seabed. There is an urgent need for further sharing of information among states not only on the availability of alternatives to abandonment, disposal or open burning of FRP vessels, but also on the extent to which such vessels have in the past and continue to be disposed of at sea, insofar as this information may be available. Without those details, this will remain another real but largely unquantifiable concern in relation to its contribution to marine plastic litter and microplastics.

Another of the concerns introduced earlier in this chapter, unrelated to vessels, is the possibility that at least some spoilt cargoes may have been dumped along with their packaging, some of which may have been plastic. Once again, while this is clearly a possibility, perhaps even a likelihood in some instances, there

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[9] As defined in GESAMP Reports and Studies No. 90: *Microplastics in the Ocean*, 2015, Particles in the size range 1 nm to <5 mm were considered microplastics for the purposes of this assessment.

is almost no published information available on the issue. Review of reports to LC/LP on permits issued between 1990 and 2010 reveals two instances in which specific reference has been made by parties to plastic packaging in relation to spoilt cargoes authorized for disposal at sea, namely a cargo of 280 tonnes of spoilt bananas, permitted for dumping in the Mediterranean Sea by Panama in 1997 (IMO 1999), and another 700 tonnes of spoilt wheat, permitted for disposal by Cyprus in 2004 (IMO 2007a). In the latter case, the footnote provided to the report states indicates that the plastic bags in which the wheat was packaged were subsequently burned (at an unspecified location) and the residues disposed of on land rather than being disposed of at sea with the spoilt product.

In the case of the bananas, the equivalent footnote states “cardboard cartons and plastic inserts retained for safe disposal on land”, suggesting once again that it was only the organic component that was disposed of at sea. However, a separate report received by the Secretariat of the London Convention in 2004, submitted by the private company Steamship Maritime Co. Ltd (contracted by the shipping industry to advise on the dumping of wastes and compliance issues), highlighted the potential scale of unregulated sea disposal of spoilt and rejected cargo, with a focus on bananas and their packaging (IMO 2004). In the case of the spoilt banana cargoes handled by the company itself, it had been possible to verify that all packaging materials, including cardboard crates and plastic wrapping, had been “properly disposed of on land”. However, the company also estimated that, given the overall scale of the international trade in pre-packaged bananas, even assuming a relatively low spoilage and rejection rate of 5% at receiving ports, somewhere in the region of 250,000 tonnes of bananas may have been dumped at sea each year, creating somewhere in the region of 19,000 tonnes of associated cardboard and plastic packaging waste. The company went on to offer its opinion that, although some of that packaging will have been dealt with at the receiving port prior to disposal, the greater portion might have been dumped at sea (to an estimated total of over 100,000 tonnes of packaging in the period 1997-2004). These are estimates only, based on generic assumptions and clearly unverifiable in practice, and the estimates cover combined quantities of both cardboard and plastic, with the cardboard most probably accounting for the majority of the estimated weight. This information was noted by the parties to LC in 2004 and contributed at the time to a renewed incentive to review guidance on management of spoilt cargoes.

5.4.4 *Debris from space vehicle launches – An emerging issue?*

A further issue of concern, though one that has yet to be assessed in any detail by the parties to LC/LP, is the potential impact on the marine environment from the jettisoning over the sea of rocket stages and other components of space launch vehicles, with the expectation that such debris will be deposited in the ocean. Space stations and larger spacecraft in low orbit are eventually decommissioned and brought back to Earth; however, unlike satellites, they do not always burn up in the atmosphere before reaching the ground. Therefore, aeronautical operators will direct spacecraft to an isolated area at sea, called Point Nemo, or the Oceanic Pole of Inaccessibility, which is one of the most isolated places on Earth located at 48°52’.6 S, 123°23’.6 W (Mosher 2017). Over 263 spacecraft have been purposefully crashed here since 1971, with the number continually growing. Russian spacecraft outnumber craft from other space agencies, with over 190 Russian space objects, followed by the United States with 52 objects (Stirone 2016). The impact of decommissioned space craft on marine debris levels is unknown and has not been widely studied, and whether this would be considered as an at-sea source of marine debris is uncertain; however, this may be considered as an emerging issue. Several corporations globally involved in space launches are known to launch over the sea, with impacts on coastal marine debris levels largely unknown or not studied (IMO 2018c). Debris items from rocket launches include fuel tanks, fairings, engine components, batteries and unburned fuel (IMO 2018d). Disposal activities or regulations relating to these items fall outside any effective regulatory system, with no requirements for reporting.

A preliminary overview of the practice of the disposal at sea of space launch vehicle components, and their potential to contribute to marine debris on the seabed and at the sea surface, was presented to the meetings of the scientific groups to LC/LP in 2018 (IMO 2018c), following outline discussions in the previous year. This overview noted that the practice of allowing launch vehicle components to fall into the sea in an essentially uncontrolled manner was common to many national and private launch facilities, and that the practice was set to rise markedly in the future given the expected increase in frequency of satellite launches.

In almost all cases, however, no information is currently available in the public domain on the nature of jettisoned components, nor therefore on their final fate in the marine environment or potential for effects on the marine environment. One exception is the case of the launch facility operated by the private company Rocket Lab in New Zealand, operating under license from the United States Federal Aviation Administration (US FAA 2019), which has been subject to a relatively detailed ecological risk assessment by the New Zealand Ministry for the Environment (NIWA 2017; NZ MoE 2016). This assessment acknowledged that debris from such launches, from approximately 1 tonne per launch for the smallest rockets up to an assumed maximum of 40 tonnes of debris per launch for the largest which may be launched from that site, will fall into the sea in an uncontrolled manner over a wide area, and that debris will include inter alia some elements of carbon-fibre reinforced polymer and unspecified “foam” (though with no reliable indication of actual quantities of such materials). This debris, including the likely plastic components, is expected to have broken up into smaller pieces during its transit through the atmosphere and back down to the sea surface, but again in ways that are unpredictable and difficult to model with any precision.

The NIWA 2017 assessment examined seven areas of threat that could arise from such operations, including direct strike causing mortality of marine species, toxic contaminants, ingestion of debris, smothering of seafloor organisms (especially in the case of the denser carbon-fibre reinforced composites), provision of surfaces for attachment of biota and the creation of floating debris (especially for the polymer foam components, as well as natural cork) (NIWA 2017). Despite the limitations to quantitative data and information, the assessment concluded that operation of the facility up to 100 launches in total would nonetheless be expected to present only low to moderate risks to the marine environment, though data gaps and uncertainties are understandably very large. The scale and significance of debris inputs, including plastics, arising from other space vehicle launch sites around the world remains unknown.

In response to the issues, the parties to LC/LP convened a Correspondence Group on the Marine Environmental Effects of Jettisoned Waste from Commercial Spaceflight Activities, which provided an initial report to the annual meeting of the governing bodies in 2019 (IMO 2019f). This includes some additional information from a number of parties regarding the operation of such launch facilities within their territories, though this currently does not provide sufficient basis for a detailed quantitative assessment of the significance of the practice of jettisoning launch vehicle components over the sea as a contribution to marine debris, including marine plastic litter.

5.5 Chapter summary

- Of wastes that may be disposed of at sea, dredged materials are by far the most significant in terms of volumes and tonnages, as dredging is common in all countries with a significant level of sea-based commerce. These are primarily sediments dredged from estuaries, ports, harbours and other coastal locations, either for maintenance of navigation channels or for capital projects.
- Although reports of wastes and other materials dumped at sea by many countries have been compiled over the past several decades, under the auspices of LC/LP and by some regional seas conventions, information on the quantities of plastics or other litter contained in those wastes remains extremely limited.
- There is enough evidence that several of the waste streams that may be considered for dumping, including dredged materials, can contain significant amounts marine litter and microplastics, but the lack of routine monitoring and overall paucity of quantitative data to date makes it difficult to estimate their contribution either in absolute terms or relative to other sea-based sources.
- There is an urgent need for states to share data on the extent to which FRP or fibreglass vessels have been disposed of at sea, as well as information on the availability of alternatives to disposal at sea for such craft.
- Despite the likely occurrence of plastic litter and/or microplastics in a number of the waste categories that may be considered for dumping at sea, remarkably few peer-reviewed studies have so far attempted to characterize those wastes for plastics in quantitative terms.
- Spacecraft as a source of plastic marine litter is an emerging issue. Space stations and larger spacecraft are eventually decommissioned and brought back to Earth; aerospace missions/operations routinely direct spacecraft to an isolated area at sea, called Point Nemo, or the Oceanic Pole of Inaccessibility, where more than 263 spacecraft have been purposefully crashed since 1971, with the number continually growing.
- To date, no country with the possible exception of the Republic of Korea has set specific action levels either for litter or for microplastics in any waste stream, despite the growing recognition of the scale of the problem.

6 OTHER OCEAN USES AS A MARINE LITTER SOURCE

6.1 Other ocean uses

6.1.1 *Offshore oil and gas exploration*

Offshore oil rigs enable producers to explore, extract and process oil and natural gas through drilled wells, and to store the extracted products before being transported to land for refining and marketing (Statista 2019). Different types of offshore rigs are used, including fixed platforms anchored directly onto the seabed by concrete or steel legs, and tension-leg platforms that float and are tethered to the seabed. A typical platform is self-sufficient in energy and water needs, and houses all of the equipment required to process oil and gas for delivery directly onshore by pipeline or via a floating platform and or tanker loading facility. The platforms also have room for housing workforce, with platform supply vessels supporting personnel and equipment requirements. As of early 2018, the global rig fleet comprised over 1,300 offshore oil rigs, including stacked and under construction rigs (Statista 2019). The highest concentration of offshore oil is in the North Sea, with 184 rigs, followed by the Gulf of Mexico, with 175 rigs (Figure 6.1).

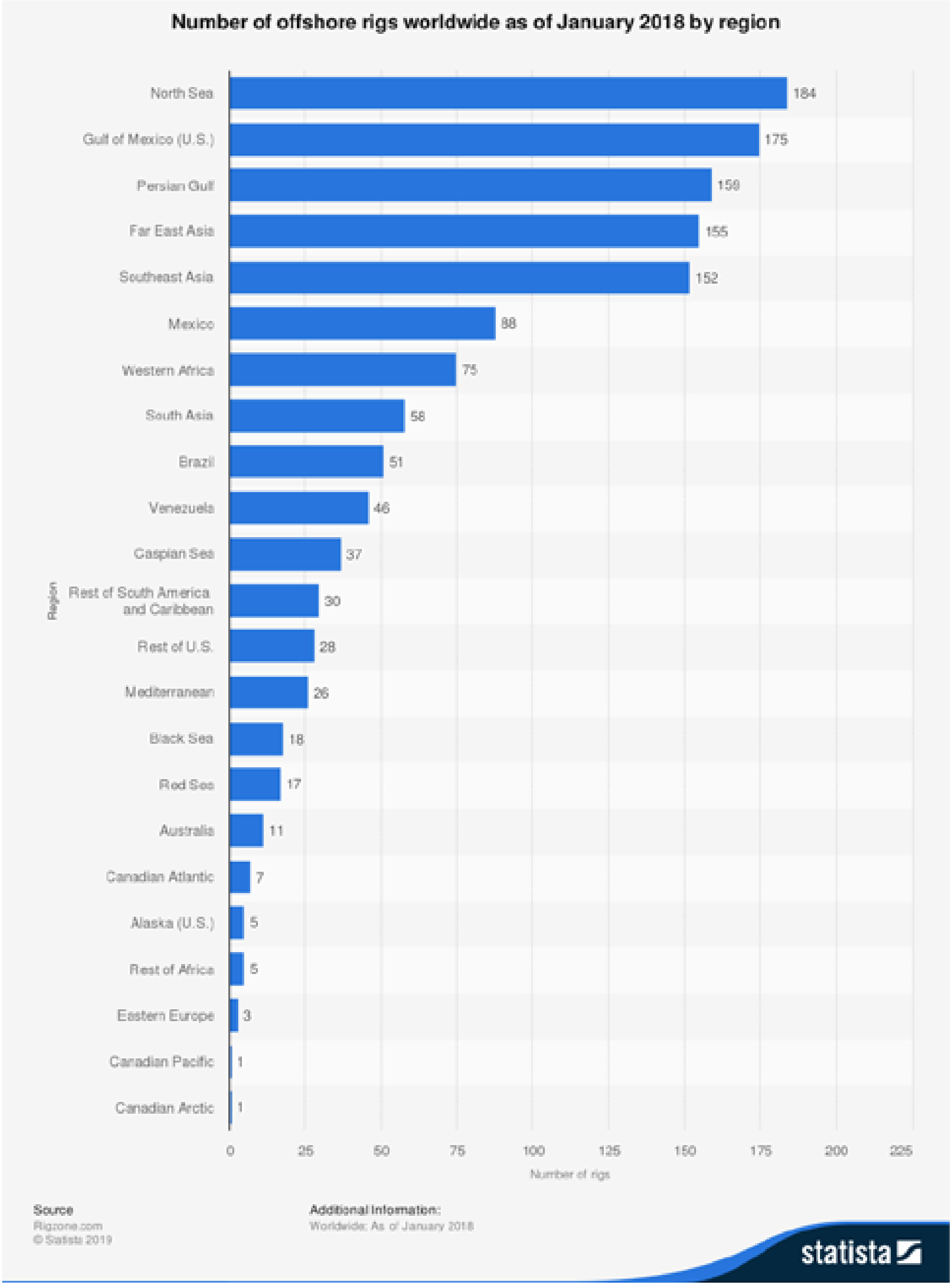

Figure 6.1: *Number of offshore oil rigs as of January 2018 by region (Statista 2019).*

A number of legal provisions dealing with pollution from offshore installations are stipulated in international conventions; however, the provisions are limited. United Nations Convention on Law of the Sea (UNCLOS) contains a number of provisions aiming to minimize any harmful effects of offshore activities related to the construction, operation, and maintenance of platforms (Kashubsky 2006). UNCLOS does not set any definite or specific standards, but instead, encourages coastal states to develop national laws. London Convention (LC) covers dumping from offshore platforms and other man-made structures including any deliberate disposal of decommissioned platforms but does not cover disposal during normal operations. International Convention for the Prevention of Pollution from Ships (MARPOL) primarily concerns ships but also applies to fixed and floating offshore platforms when they are mobile, and requires offshore structures to be equipped with the same pollution control devices required for ships of 400+ gross tonnes. The International Convention on Oil Spill Prevention (OPRC) contains specific and detailed provisions that deal with the prevention of marine pollution from offshore installations, including setting out the requirements related to emergency discharges and requiring state parties to report discharges. The Convention for the Protection of the Marine Environment of the North-East Atlantic (OSPAR) covers the North-East Atlantic region and requires “best practice” in relation to discharge and regulation of marine pollution from offshore oil and gas operations.

In many drilling regions, operators are required to report their use and emissions of chemicals and substances to national authorities on an annual basis. In Norwegian waters, discharge from oil production and exploration is regulated by national policies based on OSPAR Convention (Mepex 2016). Regulation of discharges into the sea are based on a substance classification system, with substances classified as either green, yellow, red or black (in order of least to most harmful) based on ecotoxicological properties, including biodegradability, bioaccumulation potential, toxicity, and harmfulness to organisms’ reproductive systems (Mepex 2016). In principle, any substances containing microplastics should be classified as red owing to their properties, which would subject them to strict discharge regulations. However, a lack of knowledge and awareness in the offshore industry concerning use and definition of microplastics means an absence of appropriate reporting and regulations, and that potential discharge of microplastics into the ocean environment is likely occurring through a few discharge channels (Mepex 2016).

Some evidence suggests that the use of microplastics in offshore oil and gas activities could be substantial (AFWEI 2017). Microplastics are known to be used in production and drilling processes in oil and gas activities (Mepex 2016). Microplastics are used in drilling fluids for oil and gas exploration and in industrial abrasives, i.e. for air-blasting to remove paint from metal surfaces and for cleaning different types of engines (Thompson 2015). Industrial abrasives can include acrylic, polystyrene (PS), melamine, polyester (PES) and poly allyl diglycol carbonate microplastics (Eriksen *et al.* 2013). During the drilling process, microplastics are often used in cement additives and drilling fluids; there are two types of drilling fluids, water-based and non-aqueous based, both of which have been known to contain synthetic polymers (IOGP 2016). Cement additives can include synthetic polymers such as polyethylene (PE) and polyvinyl alcohol (PVA), as well as alpine drill beads (a co-polymer bead designed to act as a mechanical lubricant) (Anonymous 2017).

Other potential discharge sources include proppants and loss circulation materials (LCMs). Proppants are designed to keep a hydraulic fracture open, and lightweight proppants can be composed of plastics (Liang *et al.* 2016). The presence of plastic substances has often been found in LCMs, which are drilling fluid additives that are designed to make sure drilling fluid remains in circulation (AFWEI 2017; OSPAR 2018). In the offshore industry, microplastics can only be discharged intentionally only either as cement additives used in metal linings, well bores and when wells are capped off (however the risk of discharge is considered low), or in the production phase, when synthetic chemicals are used in fluids that can potentially be discharged overboard (Buxton 2018). In the production phase, polymeric corrosion inhibitors have been used, and water content with the added inhibitors was found to be allowed in certain cases to be discharged into the sea as long as the oil content was below 30 ppm (AFWEI 2017; Anonymous 2017). However, the level of use and potential discharge of these polymer inhibitors is not well known and considered to be low. It has been reported that the drilling operations in offshore oil and gas may have some of the largest discharge frequency of plastics into the environment from an at-sea source (Anonymous 2017).

Offshore oil and gas exploration is subject to the MARPOL Convention; the disposal of any garbage from offshore platforms is prohibited and typically sorted on board (with the exception of food waste) for disposal onshore (National Oceans Office 2003). However, there is a risk with any ship or structure in the ocean that items are lost overboard, if either not properly secured or disposed of (BSEE 2015). Offshore industrial activities may generate items which are deliberately or accidentally released into the marine environment, including hard hats, gloves, storage drums, survey materials and personal waste (Allsopp *et al.* 2006; Sheavly 2005). Debris can fall, blow or wash off structures into the water, and there have also been events recorded where items have deliberately been thrown overboard, primarily when there is limited storage onboard, with those responsible potentially unaware of the environmental impact (US EPA 2002). In the North-East Atlantic and Caribbean, galley waste such as containers, cleaner bottles, spray cans, metal food cans, plastics gloves and crates, and operational waste such as strapping bands, industrial packaging, hard hats, wooden pallets, oil drums, light bulbs/tubes, and injection gun containers have all been reported as marine debris with likely origins from offshore industrial activities, as well as from shipping (UNEP 2009).

Abandoned equipment from offshore oil exploration activities has also been reported as debris. Following the drilling of hundreds of exploratory oil wells off the coast of California, well heads, seafloor completions, pipeline segments and other assorted offshore drilling equipment were found abandoned on the seafloor

(Caselle *et al.* 2002). It is likely that similar events to the one reported in California have occurred in other areas of the ocean, particularly in regions with a high density of oil and gas exploration activities.

6.1.2 *Shark and "stinger" nets*

Shark nets are submerged mesh netting placed near popular swimming beaches with the aim to reduce swimmer-shark encounters. While the nets may deter some sharks by preventing them from swimming to the bathing area, they are often intended to lethally intercept sharks as a method to control local shark populations. The longest running lethal shark net programme was initiated in 1937 in New South Wales (NSW), Australia, with nets still used at over 100 beaches along the coast of NSW and Queensland (Department of Environment and Energy 2005). Use of mesh nets is controversial as they often capture non-target species; thus, alternatives to both shark nets and drum lines have been trialled and considered (e.g. O'Connell *et al.* 2014), with varying degrees of success.

Shark nets are made of polyester or nylon mesh, plastic rope, buoys and floats, as well as other plastic materials. Standard nets used in Australia are typically 186 metres long and 6 metres wide, with a mesh size of 500 mm (Department of Agriculture and Fisheries 2019). There have been reports of shark net disintergration, with parts of nets breaking away and becoming debris (Mackenzie 2016).

Drum lines consist of baited shark hooks suspended from a large plastic buoy, and anchored to the seabed by metal chains (Department of Agriculture and Fisheries 2019). There is limited information on dispersal of drum-line debris, however it is likely that drum lines have been displaced by cyclones and storms previously.

"Stinger" nets are enclosures used at beaches to designate a safe swimming area and to provide a barrier to prevent jellyfish from entering. Stinger nets are used globally, primarily in tropical areas where venomous jellyfish species are distributed. Stinger nets are typically made of nylon marine mesh, plastic floats and buoys, and galvanized chain ballast (Ecocoast 2019). There have also been reports of stinger nets being displaced and broken up due to rough seas, specifically around Italy, Spain and Tunisia during trialling programmes of stinger nets for use in the Mediterranean (Project Jellyrisk 2015).

Developing non-lethal alternatives to shark nets and drum lines has involved some unsuccessful trials using equipment that has been lost or abandoned. Shark barriers were trialled in NSW, Australia; however, they were unsuccessful due to the inability to withstand rough sea conditions (Department of Primary Industries 2016). Barriers made from plastic and nylon, attached to pylons and anchored to the ocean floor with metal chains have been abandoned in trials or halfway through construction, and have contributed to local levels of marine debris.

6.1.3 *Weather monitoring*

Weather balloons are used by meteorological institutes worldwide to collect and transmit information on atmospheric pressure, temperature, humidity and wind speed using a small, expendable measuring device called a radiosonde (a plastic box containing powered sensors used to take measurements) (Bamford 2019). Each weather balloon typically consists of a large, helium-filled latex balloon, a foil-covered PS base, batteries for powering the GPS and sensors, and often rope.

Given the importance of measuring vertical profiles of the troposphere for accurate reporting and forecasting of weather events, it is becoming more common for ships to operate onboard meteorological stations. Since 2003, a network of 26 European meteorological institutes has engaged a fleet of 18 ships to participate in the Eumetnet-Automated Shipboard Aerological Programme (E-ASAP). E-ASAP is a unique observation programme, and involves merchant ships in the North Atlantic and Mediterranean Sea to regularly launch weather balloons while at sea (Krockauer 2009). Each ship typically launches two to three balloons a day, about 75 nautical miles from mainland Europe; a total of approximately 5,000 balloons per year. Weather balloons are also routinely used by scientific researchers at sea to collect atmospheric data in support of research initiatives (CSIRO 2019).

Weather balloons consist of acidic batteries, plastic components and latex rubber, that when deployed and not retrieved, contribute to plastic and rubber pollution levels, as well as toxins, in the ocean. Weather balloons have been demonstrated to travel up to 250 km from the initial deployment location, where it is unlikely to be retrieved. The balloons break up into smaller pieces of plastic and PS foam over time, eventually becoming microplastic material. Meteorological institutes, such as the Australian Bureau of Meteorology, have been making small design improvements to weather balloons over the years to minimize impact on the environment when balloons are lost, including replacement of a PS radar target with cardboard, and using smaller lithium batteries (Bamford 2019). There are ongoing discussions and consideration by meteorological institutes regarding ways to improve weather monitoring equipment to reduce the environmental impact.

6.1.4 *Artificial reefs*

The construction of artificial reefs has long been a human activity. The practice of reef building for a variety of objectives (e.g. fishing, ecological conservation) has evolved both in its material consideration and complexity (e.g. see Bortone *et al.* 2011; Ladd 2012). Because coral reefs are threatened by a collection of issues, including human activities, agricultural run-off, and climate change, the construction of artificial reefs is an approach to develop and restore coral reef ecosystems on a global scale. Many national projects focusing on the restoration of coral ecosystems were initiated in the 1970s, including establishing areas for artificial reefs and dumping readily available structures into the ocean to serve as the foundation. Countries began dumping old boats, train cars, vehicles, decommissioned military ships, and many other types of structures with the objective of supporting coral growth and settlement (New Heaven Reef Conservation 2018).

Some countries initially considered artificial reef initiatives to have the added benefit of disposing waste easily, at low cost, and there were many incidences recorded of dumping materials, often toxic, that were not suitable to support coral growth. One example is Osborne Reef off the coast of Florida, USA (Figure 6.2), where up to two million unballasted tyres tied together with nylon straps were dumped two kilometres offshore in 20 metres of water in the 1970s (Morley *et al.* 2008; Sherman and Spieler 2006). Thirty years later, several studies have shown that the tires did not significantly increase any fish habitats, that the tires were leaching toxic chemicals, the nylon straps had degraded, and that the tires were being transported by storms. Ultimately, the location of the proposed artificial reef and the materiality used for the foundation prevented any significant reef formation (Morley *et al.* 2008). Projects aimed at removing tires have been ongoing, using diving and naval resources, with the cost of removing the tires estimated at over USD 30 million (Sherman and Spieler 2006). Similar events also occurred in Indonesia, the Philippines, and Australia. In the Gulf of St. Vincent in South Australia, two reefs constructed of tires bundled together with polypropylene rope and tape were deployed in the early 1970s, with poor construction consequentially leading to the bundles breaking and the tires being dispersed (Branden *et al.* 1994).

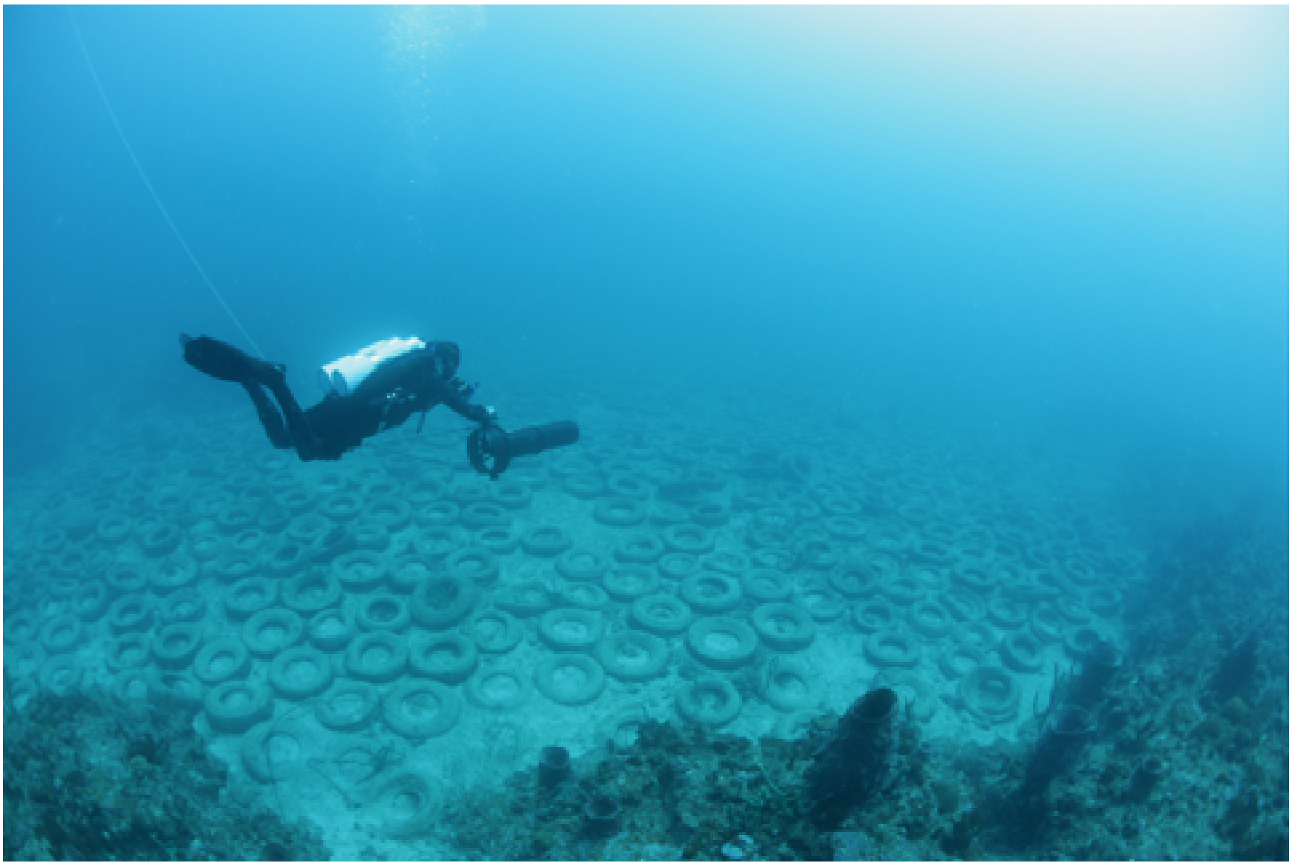

Figure 6.2: *Osborne Reef off the Florida coast, USA. (Photograph reprinted with permission of Mikkel Pitzner).*

In response to such issues, LC/LP-UNEP produced guidelines for the placement of artificial reefs (LC/LP 2009) with the explicit intents “to prevent pollution or degradation of the marine environment as a consequence of the placement of artificial reefs” and “to ensure that placement of artificial reefs is not used as a mechanism to circumvent the provisions of the London Convention on the ‘dumping’ of waste”.

Currently, a range of materials is used to construct artificial reefs. For example, polyvinyl (PVC) pipes are frequently used throughout Southeast Asia, as they are easy to construct and economical, with projects often sponsored by PVC manufacturing companies (New Heaven Reef Conservation 2018). However, this material is at risk of becoming debris, as PVC artificial reefs have been shown to be overturned easily and displaced in light storms, and thus may break apart easily, and eventually start to degrade. The main causes of artificial reef disintegration and dispersal of materials are seasonal storms and hurricanes, prevailing ocean currents, poor consideration for placement (i.e. inappropriate depth or substrate) and use of poor materials.

6.1.5 *Scientific research equipment and activities*

Scientific research often requires the use of equipment made of polymer materials, in sometimes harsh or remote environments where the equipment may be lost. Long oceanographic observation campaigns often employ disposable equipment that is designed for single use (Barbier and Pabortsava 2018). Single-use plastics used by research scientists include tools such as expendable bathythermographs (XBTs) for measuring vertical temperature of the upper ocean, passive drifters for measuring water currents, tags and GPS devices for marking and tracking animals, and robotic instruments for accessing hostile or remote areas (GESAMP 2016). Other lightweight items such as tags will float at the surface if displaced from the targeted tag species. Reports of fish tags used in the Southern Ocean and discovered in beach clean-ups on the west coast of Australia demonstrate the distances that these lightweight materials can be transported (CCAMLR 2019).

The Intergovernmental Oceanographic Commission of UNESCO (IOC-UNESCO) plays an important role in providing a code of conduct for marine scientific research vessels in relation to minimizing the impact of scientific operations in the ocean environment (Barbier and Pabortsava 2018). Several areas have been identified for improvement in order to minimize pollution as a result from scientific activities, including the use of floats designed using more environmentally sustainable materials, developing new battery technology with less risk of impact, developing strategies for better recovery at sea of deployed equipment, and minimizing deployment of equipment by maximizing use of existing floats and drifters (Barbier *et al.* 2016).

There are also many incidences of lost equipment, either accidental or abandoned. Equipment may be lost due to weather displacing items such as moorings and sensors, or if items that require GPS relocation break or reach the end of their lifetime prematurely. Moorings are long anchored lines of scientific equipment and floats which are deployed to collect a range of ocean data over long periods of time, and are often serviced for continued use; however, there is a risk of losing plastic floats and chains used in mooring construction (CSIRO 2019). Equipment may also be abandoned due to safety concerns or harsh weather, as research campaigns often operate in remote environments with rapidly changing weather conditions, such as in polar regions.

6.1.6 *Fireworks*

Firework displays are a tradition in many cultures for significant events and holidays. They are used in high concentrations at specific times of the year, such as celebrations during Chinese New Year, Indian Diwali, or Fourth of July in the USA. Aerial fireworks generally have five main components: (i) a stick or “tail”, usually a wooden, plastic or cardboard stick that is used for placement and is left on the base when launched; (ii) a fuse made of cardboard or fabric that does not always completely burn up; (iii) a charge, ignited by the fuse, which launches the firework; (iv) the effect which causes the explosion, with modern day fireworks using nitrogen compounds as the base for the effect composition; and (v) the nose cone made of cardboard or plastic and essential for the aerodynamic features, which is often lost or left behind following launch (NOAA 2019; Palaneeswari and Muthulakshmi 2012). Firework displays are often land-based, however worldwide there are displays launched from barges over the ocean, with the majority of debris falling into the surrounding marine environment. Charred fuses, plastic and cardboard pieces have all been reported as marine debris originating from firework displays (NOAA 2018) (Figure 6.3). Additionally, firework packaging is often left behind, and is also at risk of being dumped overboard either accidentally or intentionally when launching from barges.

Spent Plastics in Consumer Aerial Fireworks

A guide to what plastic debris remains after the party

Plastic battery shells from Saturn Battery Missiles. The most environmentally offensive plastics due to their sheer numbers (1 plastic battery shell PER battery). Sizes vary from 25 to 1000 shells in ONE missile.

Plastic plugs from many fireworks varieties, mostly from Rockets.

Plastic tubes used in many aerial fireworks

Plastic Propellers from Satellites.

Whole plastic bodies from Space Fighters, Grenades, Lady Bugs, Artillery Shells, Poppers, etc.

Plastic wings from propeller types such as Rocket Launchers.

Plastic tip caps used in Rocket types

Plastic body parts from novelty types

Plastic bases from various Rocket types

Figure 6.3: *Marine debris originating from consumer aerial fireworks (adapted from Anderson, 2015).*

6.1.7 *Other sources*

Military and war activities – Militaries have conducted training and combat operations at sea for centuries, depositing munitions such as aerial bombs, mine floats, projectiles, depth charges, torpedoes, rifle grenades etc., as well as shipwrecks and plane wrecks. Munitions dumped at sea during or as a part of military operations, especially during the First and the Second World Wars, have been known to occur in every basin of the global ocean. To this point little is known about the severity of impacts, although this is an active area of inquiry (see GESAMP 46th Session, 2019, Correspondence Group on Impact of Armed Conflict on the Marine Environment and Sustainable Development[10]).

6.2 Quantity and impact of marine litter from other ocean sources

6.2.1 *Background and introduction*

Quantifying litter and microplastics from "other" sources outside of the fishing, aquaculture, ocean dumping, and shipping operations is a challenge due to the limited availability of information, lack of regulations regarding reporting of debris events, and lack of knowledge surrounding particular operations and industries. This puts limitations on the ability to evaluate absolute or relative significance of these "other" sources as contributors to overall marine debris levels, and in particular plastic pollution levels. General impacts of debris on the marine environment, including entanglement and ingestion, are similar to impacts of debris originating from other at-sea industries and operations and thus are only briefly covered in this section.

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[10] http://www.gesamp.org/work/scoping-activities

6.2.2 *Quantity and impact of marine litter from other sources*

There are several reports available produced by specific industrial regions that provide estimates of plastic input by offshore oil operations, including an estimate of the total discharge of plastic materials contained in offshore chemical products at approximately 159 tonnes in the United Kingdom during 2013 (Mepex 2016); an estimated 102 tonnes of small plastic particles dumped into the North Sea in 2016 (AFWEI 2017); a reported two tonnes of microplastic released in offshore oil drilling in Norwegian waters (Mepex 2016); and estimates that offshore oil and gas contribute 1%-2% of total marine pollution (Kashubsky 2006). Most estimates are likely underreporting the actual level of plastic discharge, particularly when considering that the offshore oil and gas industry as a whole is largely uncertain about the definition of microplastic, and that there are reports of high levels of discharge labelled as “possible plastics” (OSPAR 2019). The types and frequency of chemicals used is also highly variable across the industry. Thirty-one substances considered to contain plastic materials were reported in chemical discharges in 2013 in the UK, but the quantity of the plastics was described as relatively small (OSPAR 2018). Additionally, it is not possible to quantify the amount of general waste lost overboard, as it is either not reported or not publicly available information. The effects of chemical discharge with plastic additives are similar to those of microplastic impacts, which are further considered by GESAMP WG 40.

Shark and “stinger” nets are used globally, especially in places such as Australia, Hong Kong, South Africa and various other countries where shark attacks are of concern. Along the east coast of Australia, shark nets are used at over 100 beaches, and nets are present at over 30 beaches in Hong Kong. The quantity of shark and stinger nets in the water at any given time is unknown, and, as species distributions shift as a response to climate change (particularly for jellyfish), such types of nets are being trialled in new locations. The frequency of loss of nets, either partial or complete, is either not reported or not publicly available information, and the impact on debris levels has not been studied. The Australian Department of Environment and Energy (2005) has reported that 932 sharks and 107 non-target species on average are killed per year in shark nets along the east coast of Australia, and large numbers of turtles are still reported as caught on drum lines. Entanglement is the biggest impact on local marine species; however, it is important to consider that this is the primary objective of shark nets. Sustainable alternatives to minimize impacts include drones, sonar Clever Buoys™, and electromagnetic fields.

Artificial reefs as contributors to marine debris levels may be considered substantial in some areas, with consideration that debris levels are cumulative. Artificial reefs that have or are currently using plastic or rubber components, particularly light weight ones, are at risk of degradation, leaching of toxic chemicals into the surrounding environment, break up into microplastics, and dispersal. Dispersal can be an issue as currents and storms can move debris items into adjacent reef habitats. For example, tyres from Osborne Reef have destroyed nearby coral reef structures, with an estimated 350,000 tyres resting on or near the reef tract alone (FDEP 2009). Additionally, reefs made from metal structures could potentially leak toxins into the ocean, affecting and accumulating in reef species.

The quantity and frequency by which single-use plastics are used in scientific research is not documented nor reported by national research programmes. Equipment deployed by researchers to monitor the ocean has minimal impacts on the marine ecosystem in comparison to shipping, drilling, oil platforms etc. (Bernal and Simcock 2016). While the relative input of marine litter from research vessels may be low, the impact would likely be concentrated at a local scale around highly researched areas, such as the Northern Antarctic Peninsula in the Southern Ocean (Waller *et al.* 2017).

O’Shea *et al.* (2014) found that 65%-70% of weather balloons released on land by meteorological services end up in the ocean, and it is reasonable to assume that the majority of balloons released at sea contribute to marine debris. Programmes such as E-ASAP are useful in terms of quantifying weather balloons released at sea in particular regions and providing a source for determining levels of impact. It is difficult to know whether there are additional programmes similar to E-ASAP operating in other regions of the world whereby merchant ships are launching weather balloons, as at-sea deployment is not a widely covered issue. Impacts from weather balloons as marine debris include disintegration of rubber and plastic particles into smaller microplastics that may be ingested, leaching of toxic acidic chemicals from battery components, as well as entanglements on ropes and in the balloon by marine species.

Lastly, coastal clean-up initiatives have reported high levels of plastic debris originating from fireworks, particularly following significant events. The Mississippi Coastal Cleanup removed 7,897 pieces of fireworks and sparklers at ten beaches in 2018, and the Ocean Blue Project removed over 4,200 lbs of plastic firework debris from beaches in one county during July 2019 (following Fourth of July activities) (NOAA 2019; Ocean Blue Project 2019). The overall input of fireworks launched at sea has not been studied and there is little information available on this subject. Impacts include introducing toxic chemicals used as part of the effect of the firework entering the local environment, disintergration and subsequent ingestion by marine species of fuses, plastic and cardboard pieces, and there have also been reports of launches and relative sound pollution impacting local wildlife through observed behavioural changes, specifically with sea lion species (NMFS 2006).

6.3 Chapter summary

- Quantifying litter and microplastics from sources other than fishing, aquaculture, dumping, and shipping operations is a challenge due to the limited availability of information, lack of regulations regarding reporting of debris events, and lack of knowledge surrounding particular operations and industries.

- Offshore oil and gas contribute to total marine plastic pollution. There is evidence that the use of microplastics in offshore oil and gas activities could be substantial, as they are known to be used in production and drilling processes in oil and gas activities. Most estimates are likely underreporting the actual level of plastic discharge, particularly when considering that the offshore oil and gas industry as a whole is largely uncertain about the definition of microplastic, and that there are reports of high levels of discharge labelled as "possible plastics".
- The frequency of loss of shark and stinger beach protection nets, either partial or complete, is either not reported or not publicly available information, and the impact on debris levels has not been studied. Typically made of polyester or nylon mesh, plastic rope, buoys and floats, as well as other various plastic materials, there have been reports of shark net break ups, with parts of nets breaking away and becoming debris.
- Weather balloons, partly comprising plastic components, are deployed worldwide and can travel up to 250 km from the initial deployment location. An estimated 65%-70% of weather balloons released on land by meteorological services end up in the ocean, and it is reasonable to assume that most of balloons released at-sea contribute to global marine litter burdens.
- Artificial reefs that have or are currently using plastic (especially polyvinyl chloride) or rubber components, particularly light weight ones, are at risk of degradation, leaching of toxic chemicals into the surrounding environment, break up into microplastics, and dispersal.
- The quantity of single-use plastics and frequency by which they are used in scientific research are not documented nor reported by national research programmes. The quantity of equipment deployed to date by researchers to monitor various properties in the ocean is relatively small in comparison to other sources (e.g. shipping, drilling, oil platforms etc.)

7 SOLUTIONS FOR REDUCING SEA-BASED SOURCES OF MARINE LITTER

Given the nature and scale of the problem and the diversity of sources evident from the preceding chapters, it is clear that efforts to reduce the quantities of litter that reach the marine environment from sea-based sources will demand a wide array of actions and approaches. Such approaches could include, for example: improved designs and material substitutions; improvements to collection, segregation and recycling; collection of lost fishing gear and other litter where feasible; improved practices for hull cleaning; greater awareness raising and education regarding sources and impacts; capacity-building to increase understanding of good practices; and the enhancement of measures to prevent deliberate and accidental loss to the marine environment. In the case of litter that arises as incidental contamination in wastes dumped at sea, there will need to be a strengthened emphasis on the prior auditing of wastes and, in the case of dredged material in particular, a strong focus on controlling upstream sources.

The London Convention/London Protocol (LC/LP) in 2016 called upon states "to make every effort to combat marine litter, including through the identification and control of marine litter at source and to encourage monitoring, additional study and knowledge-sharing on this issue." (IMO 2016). This has as much relevance to sea-based sources of marine litter as it has to land-based sources.

The following sections focus on measures that can be taken to address the specific problems of abandoned, lost or otherwise discarded fishing gear (ALDFG) and marine litter arising from shipping, in order to illustrate the range of measures available to begin addressing some of the most significant sources. While the focus is on marine litter from ALDFG and shipping, it is important to note that this is not to say that other sea-based industries are not also working towards solutions, e.g. as a result of a roundtable organized by the World Aquaculture Society Institute for Marine Engineering, Science and Technology (IMarEST), 21 participating organizations suggested categorizing the volume, location and use of plastics on a farm to identify where plastics could be replaced, and suggested that plastic management policies and post storm checklists be developed to track potential inputs into the marine environments (Drillet 2020).

Readers are also referred to Annex I for a summary of detail on studies evaluating solutions to ALDFG as a source of marine litter.

7.1 Reducing or preventing ALDFG

Solutions to ALDFG include prevention, mitigation and remediative measures, which are available to fishers, gear manufacturers and designers, fishery managers and regulators, non-profit organizations, port authorities, researchers and seafood companies (GGGI 2017). ALDFG-prevention measures aim to avoid the introduction of ALDFG to the marine environment and include changes to gear and vessel design, improvements in fisheries management (e.g. requirements for gear-marking and spatial and temporal management measures), implementation of best practices and education and awareness raising initiatives. Mitigation measures focus on reducing the impacts from ALDFG once it is in the ocean and include changes to gear design that reduce ghost fishing and impacts to marine habitats. Remediative measures focus on removing ALDFG from the environment and include lost gear reporting, identification and recovery. Implementation of ALDFG solutions requires collaboration among stakeholders and sectors. Interventions are most effective if they are targeted, adaptive and based on a thorough understanding around sources and causes of ALDFG (Figure 7.1).

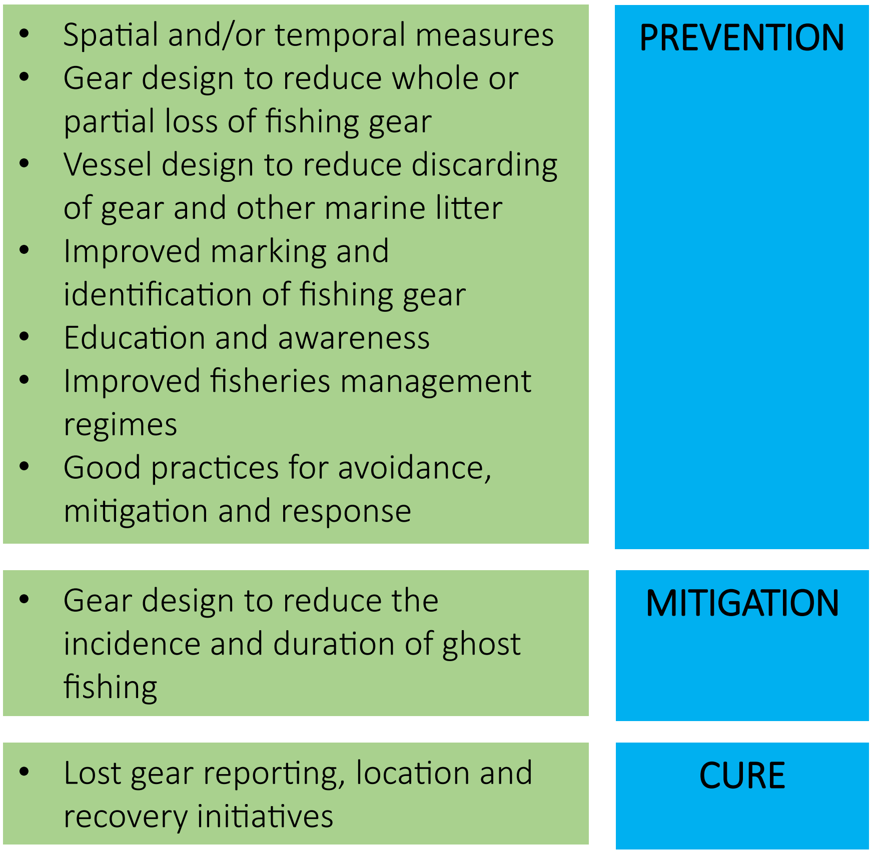

Figure 7.1: *ALDFG prevention, mitigation and curative measures (from GGGI 2017)*

7.1.1 *Management and regulations*

Fisheries management and regulatory measures provide an important suite of solutions that can effectively prevent and reduce ALDFG at its source (Gilman 2015; Huntington 2019; Richardson *et al.* 2018). With significant positive correlations demonstrated between fishing effort and gear loss, reductions in fishing effort and capacity control are sometimes proposed to prevent and reduce gear losses – the less gear that is being used, the less gear there is to lose (Richardson *et al.* 2018; Yildiz and Karakulak 2016). In output-controlled fisheries, increasing fishing efficiency can reduce fishing effort and gear loss. Spatial and temporal management measures are especially useful for preventing gear losses due to gear conflict (e.g. interaction between towed and static gears, competition among fishers, vandalism, theft) (FAO 2016; Gilman 2015; Macfadyen *et al.* 2009; Thomas *et al.* 2020). Fishing gear marking and tracking requirements, if linked to a centralized gear loss reporting system, can prevent gear losses by ensuring greater gear accountability and better knowledge of gear locations (FAO 2019). Gear-marking also enables fishers to more readily recover gear when it is lost, and facilitates gear to be returned to fishers should it be identified by a third party (FAO 2019). Mandatory and no-fault gear loss and ALDFG reporting requirements for both vessels that lose gear and for others that observe ALDFG at sea ensure that loss events are recorded and reported, which contributes to knowledge around total gear losses for a given fishery and/or location, and facilitates lost gear recovery, as well as location of gear that may present a navigational hazard (Macfadyen *et al.* 2009; Richardson *et al.* 2019a). Rewards for gear stewardship, such as financial incentives for returning end-of-life gear, provision of gear recycling initiatives and engagement in ALDFG cleanup programs can motivate fishers to take greater precautions and initiative around ALDFG prevention, reduction and recovery (Cho 2009; Macfadyen *et al.* 2009; Nelms *et al.* 2021; Wyles *et al.* 2019). Efforts to reduce illegal, unreported and unregulated (IUU) fishing activities often additionally result in decreased overall gear losses and abandonment (see section 2.2.3) (FAO 2016; Masompour *et al.* 2018; Richardson *et al.* 2018). Enforcement, including community-supported enforcement (Pomeroy et. al. 2015) is critical to the success of fisheries management and regulatory measures, to ensure that required measures are effectively implemented and followed.

7.1.2 *Best Practices and Codes of Conduct*

Best practices and codes of conduct guidelines serve as valuable references, principles and standards for stakeholders to employ behaviours and strategies that prevent and minimize ALDFG. FAO's Code of conduct for responsible fisheries, which supports conservation, management and development of fisheries globally, encourages Member States and fisheries management organizations to minimize lost or abandoned gear and ghost fishing, including through the development and use of selective and environmentally safe gears and techniques (FAO 1995). FAO's Voluntary guidelines for the marking of fishing gear additionally provides guidelines for States and regional fisheries bodies on the marking of fishing gear to prevent and assist in the identification and recovery of ALDFG (FAO 2019). Global Ghost Gear Initiative (GGGI) published Best practice framework for the management of fishing gear, which outlines a diversity of prevention, mitigation and remediative practices available to a variety of stakeholders to develop policies and practices that reduce ghost gear, including encouraging best practices in industry and fisheries management to influence supply chains and consumers (Figure 7.1) (GGGI 2017).

In 2019, FAO and the GGGI conducted a series of regional workshops around the world on best practices to prevent and reduce ALDFG that resulted in a series of recommendations to inform next steps toward the development of regional and national action plans and strategies around ALDFG (FAO 2020). Best practice guidelines around ALDFG have also been developed in the Northwest Pacific (NOWPAP MERRAC 2015) and the Adriatic Sea (Da Ros *et al.* 2016) and are currently under development for the Asia-Pacific region[11]. Seafood sustainability certifiers can also require that best practices be implemented, with some ALDFG best practice standards currently required by the Marine Stewardship Council (MSC 2014, 2020), and commitments by the Aquaculture Stewardship Council to integrate ALDFG best practices into their certification schemes (Huntington 2019).

Stakeholder Group	Role	Best Practice Areas
Gear designers and manufacturers	Design, production and sale of fishing gear	Embedded traceability; research into, and use of/integration of, biodegradable materials for use in the marine environment; incentives to return redundant/used gear
Fishers	Individuals and crew catching seafood at sea	Reduced soak times; gear use limits in high-risk areas and during high-risk times; marking and identification of fishing gear; responsible storage of gear; reporting of lost gear; guidance on location and retrieval of lost/abandoned gear
Fisheries organizations	Non-statutory organizations representing fishers	Code of practices specific to fisheries; spatio-temporal agreements with other metiers; monitoring of fishing gear losses; communication protocols
Port Operators	Bodies operating and managing fishing ports	Accessible, low-cost gear and litter disposal facilities; integration into recycling initiatives; better awareness of responsible disposal opportunities; implement "check out-check in" gear inventories where appropriate.
Fisheries managers and regulators	Management bodies setting policy, plans and regulations for fishing activities	Designation of spatio-temporal restrictions in high-risk areas; development of appropriate gear marking and identification regulations; development of technical regulations to reduce ghost fishing potential in high-risk areas; conducting impact assessment to gauge unintended consequences of management actions on gear loss and ghost fishing
Fisheries control agencies	Body or agency responsible for enforcing fisheries regulations	Establish registry and database of lost/abandoned gear; enforcement of gear-marking and identification regulations
Fisheries and marine environment research	Research and development	Development of biodegradable materials acceptable to fishers but effective at reducing gear-catching ability after control is lost
Seafood ecolabel standards and certifications holders	Setting and maintaining standards for responsible sourcing of seafood	Gear loss and its consequences (e.g. ghost fishing) is included in all seafood sustainability standards, with supporting guidance provided where necessary

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[11] https://aimp2.apec.org/sites/PDB/Lists/Proposals/DispForm.aspx?ID=2665

Stakeholder Group	Role	Best Practice Areas
Seafood companies	Fleet operators, processors, wholesalers and retailers	Encouraged to ensure that their seafood sourcing avoids high risk fisheries and that they participate in relevant initiatives, e.g. gear recycling.
Non-governmental organizations	Advocates for sustainability and good practices	Coordination of advocacy, actions and information gathering; contribution to a centralized lost gear/ghost fishing information hub/forum; organizing ghost gear recovery in vulnerable areas.

Table 7.1. Summary of ALDFG best practices across a variety of stakeholders (GGGI 2017).

7.1.3 *Improvement of port facilities for end-of-life gear*

Availability of port reception facilities available to fishers for end-of-life gear that are adequately sized, convenient, affordable and safe can prevent ALDFG by providing appropriate and accessible alternatives to discarding gear at sea (Huntington 2017; Macfadyen *et al.* 2009). Ports authorities can additionally prevent ALDFG by minimizing port disposal fees and administrative burdens, further reducing barriers to fishers for proper unwanted gear disposal (Brodbeck 2016). Port authorities can also work with government officials and administrators, private industry, non-governmental organizations (NGOs), researchers and/or local waste disposal infrastructure managers to support reception facilities appropriate to the specific types of fishing gear received at a particular facility, as well as create and promote gear buyback and recycling programmes (Brodbeck 2016; Huntington 2017). Steveston Harbour in Canada is a successful model for a net recycling programme.[12]

Another example is the *Suchitva Sagaram* ("clean ocean") project in Kerala, India, in which plastic that is collected during trawling is recycled by turning into a material for road surfacing, and which has broad support from boat owners.[13] To ensure that these facilities are known and available to fishers, port authorities can also report the status of their facilities to the Port Reception Facilities Database of IMO, allowing for later communication with relevant fishing industries via Global Integrated Ship Information System of IMO (Huntington 2017).

7.1.4 *Modification and improvements in gear design*

Since fishing gear design plays a role in causing ALDFG (see section 2.2), modifying and innovating gear designs can prevent the generation of ALDFG. Gear modifications to prevent gear loss may be purposeful, or may be an unintended positive result of innovations developed to improve fisheries in other ways, such as bycatch avoidance, conflict reduction, and stock conservation. Gear modifications to prevent ALDFG are often initiated by regulatory requirements or by voluntary, industry-driven initiatives that typically involve collaborations with NGOs or consulting firms. While ALDFG prevention is generally considered to be more cost effective than mitigation or remediative efforts (Gilman 2015; Macfadyen *et al.* 2009), gear designs introduced specifically to prevent gear loss may impact efficacy or effectiveness of fishing operations, such as catch per unit effort (CPUE) of target species, and therefore may be difficult to introduce into a fishery without thorough testing and cost–benefit analyses.

There is no "one size fits all" solution, as some gear modifications for the purpose of ALDFG prevention are designed expressly for specific causes for gear loss that are more predominant in specific locations. For example, rather than using a vertical line and marker buoy for each pot, fishers working near busy ports may choose to connect multiple pots together with a groundline with marker buoys at one or both ends of the line, to minimize the number of vertical lines and buoys, so as to reduce the risk a passing vessel will entangle or cut a vertical line. Where vessel traffic is less heavy, this practice could result in more gear loss as a result of entanglement with other fishing gear, particularly if the longlined gear is not detectable due to inadequate gear marking.

In many fisheries, crustacean and fish pots are legally required to be equipped with a biodegradable material that disables the capture function of the pot should it become abandoned or lost. The biodegradable material provides larger openings for entrapped animals to escape once it has degraded. Biodegradable cotton twine (aka: rot cord, escape cord, biotwine) is a common material used to hold escape panels in place (CNO 2019; WAC 2012). Research has shown that effectiveness in allowing entrapped animals to escape the pot once it is disabled can vary greatly depending on gear design and escape panel placement (NRC 2015). Fully biodegradable panels made of polymer material are also used on the US East Coast in crab and lobster pot fisheries (Bilkovic *et al.* 2012), and the use of biodegradable resin, made of polybutylene succinate (PBS) and polybutylene adipate-co-terephthalate (PBAT) for the funnel of the conger eel pot has been successfully tested in South Korea (Kim *et al.* 2014). The PBS/PBAT material is reported to biodegrade into CO_2 and H_2O in seawater within two years.

The amount of time between gear loss and gear disablement that prevents ghost fishing is a key variable in determining the severity of ghost fishing caused by ALDFG. Therefore, degradation rates of biodegradable or sacrificial gear components are important to identify and understand. In Puget Sound, USA, Antonelis *et*

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[12] https://static1.squarespace.com/static/5b987b8689c172e29293593f/t/5bd6e6374785d30272a69ffb/ 1540810312113/Approaches+to+the+Collection+andand+Recycling+of+End-of-Life+Fishing+Gear.pdf

[13] https://www.indiatoday.in/magazine/states/story/20171106-kerala-fishermer-new-cleaning-initiative-fishing-waste-out-of-sea-1070715-2017-10-28

al. (2011) observed that the commonly used legal-size cotton escape cord in simulated derelict crab pots deteriorated, on average, in 126 days. This study determined that the average time from capture to mortality of a Dungeness crab in a lost crab pot was 51.5 days, suggesting that ghost fishing in Dungeness crab pots could be significantly reduced if the gear was disabled faster (e.g. within 50 days of placement in the ocean).

In Alaska, following a gear loss event in Cook Inlet in 1988 that was responsible for the loss of an estimated 15,000 Tanner crab (*Chionoecetes bairdi*), state regulators reduced the maximum thread count (thickness) from 120 to 30 count for escape cords to reduce the amount of time until the cord degraded, thereby reducing the time during which the pot is ghost fishing (Barnard 2008).

Biodegradable monofilament gillnets made from PBS and PBAT were tested in the drift gillnet fishery for yellow croaker (*Larimichthys polyactis*) off southwest South Korea, with very positive results showing no significant difference in CPUE of target species between the biodegradable net and the standard control net (Kim *et al.* 2016). The study also showed that biodegradable netting began to degrade after 24 months in seawater. Research conducted in the coastal cod fishery in Norway showed lower CPUE efficiency in biodegradable netting compared to the standard nylon net (Grimaldo *et al.* 2019), and the CPUE progressively lowered over time (Grimaldo et al, 2020). In both studies, authors noted greater wear and tear on biodegradable netting from day-to-day fishing operations, which increases gear failure and associated repairs and replacement.

Biodegradable ropes and twines are also being used to test fish aggregating devices (FADS) in tropical tuna fisheries with much success (Lopez *et al.* 2019; Moreno *et al.* 2018), with the goal to reduce plastic materials used as FAD components and entanglement hazards.

7.1.5 *Education and awareness-raising*

Education and awareness-raising around ALDFG sources, causes and impacts is an essential ALDFG prevention and reduction strategy that can be employed by all fisheries stakeholders. ALDFG education and awareness-raising initiatives can take many forms depending upon the stakeholder group, fishery and geographic location. NGOs and cross-sectoral intiatives (e.g. GGGI) are often the most proactive groups engaged in awareness raising activities, and can advocate for sustainability and best practices through information gathering and dissemination, capacity-building workshops and activities, lobbying managers and policy makers around ALDFG interventions, and organizing ALDFG identification, monitoring and recovery efforts (Huntington 2017; Richardson *et al.* 2019b). Researchers and academics are also important for ALDFG education and awareness, as the communication of their research findings can inform policy making, along with later dissemination of research results more widely by media and NGOs. Fisheries bodies including associations, managers and regulators, fisheries observers and the seafood industry can raise awareness, educate about and communicate ALDFG impacts and prevention and reduction strategies directly with their fishers (Huntington 2017; Richardson *et al.* 2017). Fisher education and awareness around ALDFG is particularly important as it can result in increased gear and environmental stewardship. For example, UK fishers voluntarily participating in an at-sea marine litter clean-up programme[14] reported care and responsibility for marine litter and its environmental impacts, as well as engagement in less environmentally harmful waste management behaviours, compared to fishers not involved in the programme (Wyles *et al.* 2019).

That said, small-scale and artisanal fishers in developing countries often have less access to these resources and training. In many ways, the success of any ALDFG solution relies upon basic education and awareness of this issue in the first place.

7.1.6 *Removal of ALDFG*

Retrieval of ALDFG from the marine environment is a remediative solution to the problem. That said, it is important to acknowledge that even if quantity of removed gear is significant, quantities represent just a fraction of the gear that is lost. Various methods are employed for gear recovery. The most direct method is hoisting floating ALDFG aboard a vessel. However, these hoisting options are only available when gear is visible and retrievable at the sea surface. Dragging heavy grapnels, also called "creeps", through fishing grounds where ALDFG is known or suspected to occur is a simple form of recovery that can be and is often executed by fishing vessels immediately after gear loss. These dragging methods are also most amenable to post-season or closed-season gear sweeps, are conducted by fishing vessels and/or management or enforcement vessels and do not require expensive equipment or technically complicated skills beyond those already present. Dungeness crab fisheries along the North American West Coast (California, Oregon, Washington and British Columbia) each have their own form of post/closed-season gear sweeps, targeting abandoned, lost or otherwise discarded (ALD) pots that are detected via visual surveys for marker buoys (NRC 2018). To recover crab pots that become buried in the sand following storm events, vessels are often equipped with a probe-like nozzle connected to a hose and high-pressure water pump that is used to jet seawater into sediment around a buried pot until it becomes free and liftable via the standard crab block (NRC 2018). Additionally, in situations where stuck gear cannot be freed by pressure from the vessel hydraulics or the pot pump, a line-cutter is sometimes used to send down the buoy line and sever the line where it meets the sea floor, foregoing the buried pot, but removing the line entanglement and other hazards associated with the buoyed vertical line (NRC 2018).

Lost pot gear sweeps targeting relatively lightweight gears deployed by recreational and small commercial vessels occur in the USA throughout the coastal Gulf of Mexico and East Coast, primarily where blue crab and lobster fisheries occur (Bilkovic *et al.* 2016;

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[14] Fishing for Litter: https://fishingforlitter.org; see also KIMO International, https://www.kimointernational.org/fishing-for-litter/

GOMLF 2020; Hallas 2018; Heiser 2018; Louisiana Wildlife and Fisheries 2019; TPWD 2019). Some of these operations, especially in Chesapeake Bay, and operations utilizing larger vessels and equipment, such as those in the Bay of Fundy between Canada and the USA, use a variety of grapnels and grapnel arrays, often with multiple hooks attached to a beam or a length of chain.

In Norway, the Directorate of Fisheries has conducted annual ALDFG surveys and recovery with large grapnels since 1980. In 2020 alone, recovery efforts resulted in removal of 2,669 pots, 700 nets, thousands of meters of ropes and lines, and hundreds of floats and anchors, totalling 100 tonnes of ALDFG removed (Martinussen 2020). Gear recovery from the seafloor using large grapnels from trawl vessels has also been successful in South Korea (Cho 2011).

The use of grapnels for ALDFG recovery is often attractive due to the relatively low cost when compared to using other methods such as divers or remotely operated vehicles (ROVs). However, most grapnel-based ALDFG removal operations include dragging hooks along the seabed, which can be harmful to seafloor habitats and marine wildlife. For this and other reasons, diving via SCUBA or surface supplied air is also a popular method for ALDFG removal, particularly in shallow waters less than 30 m depth. Diver-based gear recovery is particularly useful in sensitive habitats and in highly dynamic seafloor topography such as pinnacles, reefs, areas with known shipwrecks and other locations where the use of grapnels would be damaging and dangerous, posing a high risk for snagging and equipment loss. One of the primary advantages of diver-based removals as opposed to grapnel operations is that divers can ensure the complete recovery of a gear item, or the complete clearing of ALDFG in a given area. Diving, by professional divers, is almost exclusively employed as the gear recovery method in the Puget Sound Derelict Fishing Gear Program and in the California Lost Fishing Gear Recovery Project.

ROVs are employed for ALDFG recovery in select situations, including for research purposes and gear retrieval at depth. ROV-based gear recovery is not common due to relatively high-costs for ROV deployment and operational challenges (e.g. dynamic seafloor and ocean conditions, particularly tidal currents). In Puget Sound, USA, ROVs have been used to investigate rockfish bycatch and remove abandoned, lost or otherwise discarded (ALD) shellfish pots in water depths beyond maximum diver safety depths (> 30 m; see NRC 2019), and ROV-based derelict net removals were successfully conducted to test the feasibility of this method in deep water derelict net removals (NRC 2015). Nevertheless, cost of operating a working class ROV, which is powerful enough to maintain position during tidal cycles, limits its wider application.

7.1.7 *Research*

Research is critical to informing strategic ALDFG solutions. This includes research around amounts, sources, causes and drivers of ALDFG and effective prevention strategies (Huntington 2017; Richardson *et al.* 2018, 2019b). By understanding how much ALDFG is entering the ocean in a given location and the causes for gear abandonment, loss and discard, fishers, managers and policy makers are better positioned to implement solutions accordingly. Research on gear marking, identification and tracking technologies including cost-effectiveness, practicality and likelihood of uptake by gear manufacturers and fishers, would likely facilitate improved gear stewardship (FAO 2019; Huntington 2017). Similarly research around improved vessel technologies that can contribute to gear loss prevention, such as navigation, positioning, seabed mapping and communications technologies can assist with better vessel preparedness and safety behaviours that reduce likelihood of losses (Huntington 2017; Richardson *et al.* 2018).

Continued research into ALDFG identification and retrieval methods is especially important to inform the development of affordable, cost-effective gear-retrieval programmes, including improving knowledge around ALDFG sources, amounts and hot-spots. Interviews with and gear loss reporting by fishers are helpful in obtaining information from fishers themselves around where and when they lose gear, with the potential to return to the locations where gear losses occurred for retrieval efforts. Diver surveys are commonly used to identify and in many cases also recover ALDFG (Richardson *et al.* 2019b). Video surveys can also provide detailed information around the locations and amounts of ALDFG, including the opportunity to return for retrieval efforts. More expensive but often highly detailed survey approaches to identify ALDFG include the use of sidescan sonar and ROV surveys, which are often able to provide information around the presence of ALDFG in areas otherwise inaccessible to dive and other visual surveys.

Research should also be carried out to establish a framework for conducting ALDFG risk assessments for gear types and fisheries to inform fisheries managers on priority actions to reduce its impact. Factors may include the risk that gear may become ALDFG, the amount of gear being used, impacts of ALDFG on fisheries resources and protected species, risks to the ecosystem and marine environment, and risks to navigation.

7.2 Reducing or preventing marine litter from shipping

For almost every type of ship-generated waste there are various onboard management methods. For plastic waste specifically: (1) it is either sorted or held separately (compacted or otherwise) from other forms of waste and delivered to a port reception facility (PRF); or (2) it is incinerated (EMSA 2016). Incineration is constrained by MARPOL VI, Regulation 16, which prohibits shipboard incineration of polyvinyl chlorides (PVC) except in a shipboard incinerator for which an IMO Type Approval Certificate has been issued in accordance with MEPC.244(66) (MEPC 2014). Incineration of plastics containing polychlorinated biphenyls (PCBs) is always prohibited. The remainder of this section is focused on reducing shipping as a marine litter source through improved handling on-and-off vessels.

7.2.1 *Standardization of waste management protocols at ports*

A standardized approach to waste management reduces marine litter inputs to the ocean from shipping by minimizing the risk of illegal dumping. Several useful guidelines have already been developed by IMO. Waste management protocols at ports as a "best practice" have been demonstrated by many ports having waste management protocols in place. In EU ports (e.g. Antwerp, Rotterdam, Hamburg), many of which are operating with specified tariffs for receiving waste as per implementation of EU Directive 2000/59/EC on PRFs for ship-generated waste and cargo residues. An added benefit of standardization of protocols is that it allows for collection of data on quantities of solid waste being brought to port, and thereby allows for examination of temporal and geographic trends. For example, in 2007 the three major seaports in Belgium (Ports of Antwerp, Ghent and Zeebrugge) initiated a mandatory reporting requirement for waste collection from ships (Figure 7.2), and determined that a significant portion of off-loaded waste was plastic (Figure 7.3).

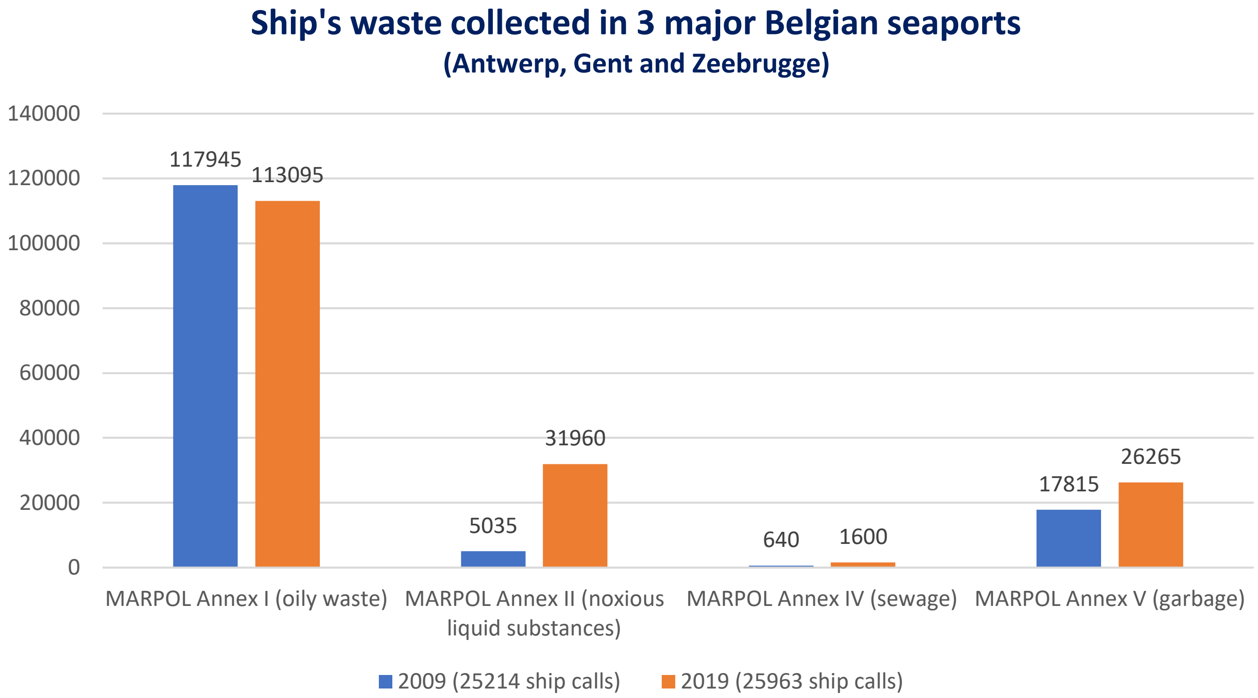

Figure 7.2: *Ship waste collected in the three major Belgian seaports (based on unpublished data collected by Flemish Waste Agency OVAM, Belgium, for ports in Antwerp, Ghent and Zeebrugge).*

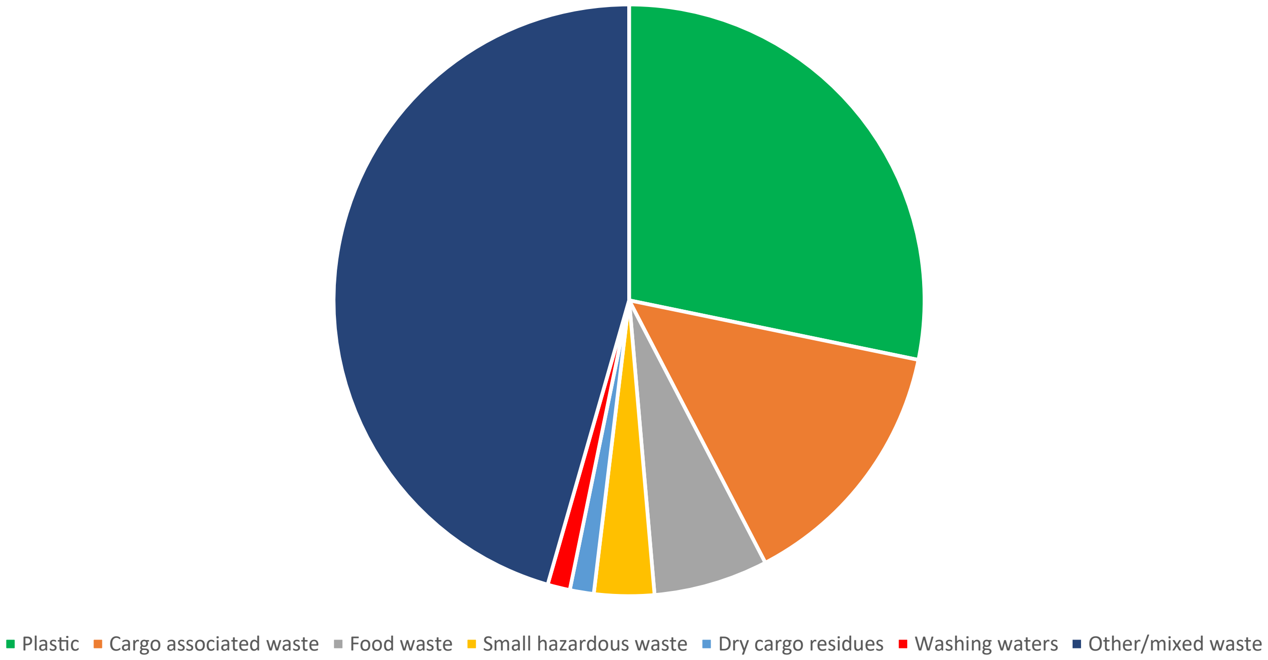

Figure 7.3: *Composition of MARPOL Annex V waste collected in 2019 in the port of (based on unpublished data collected by Flemish Waste Agency OVAM, Belgium, for ports in Antwerp, Ghent and Zeebrugge).*

More recently, Euroshore surveyed its members in Europe and Africa for data on ship waste collection and found that in one year alone (Euroshore 2019), Euroshore member ships generated 2.5 million tonnes of waste (Figure 7.4), the majority of which was oil and oily waste, with a not insignificant portion comprised garbage (Figure 7.5).

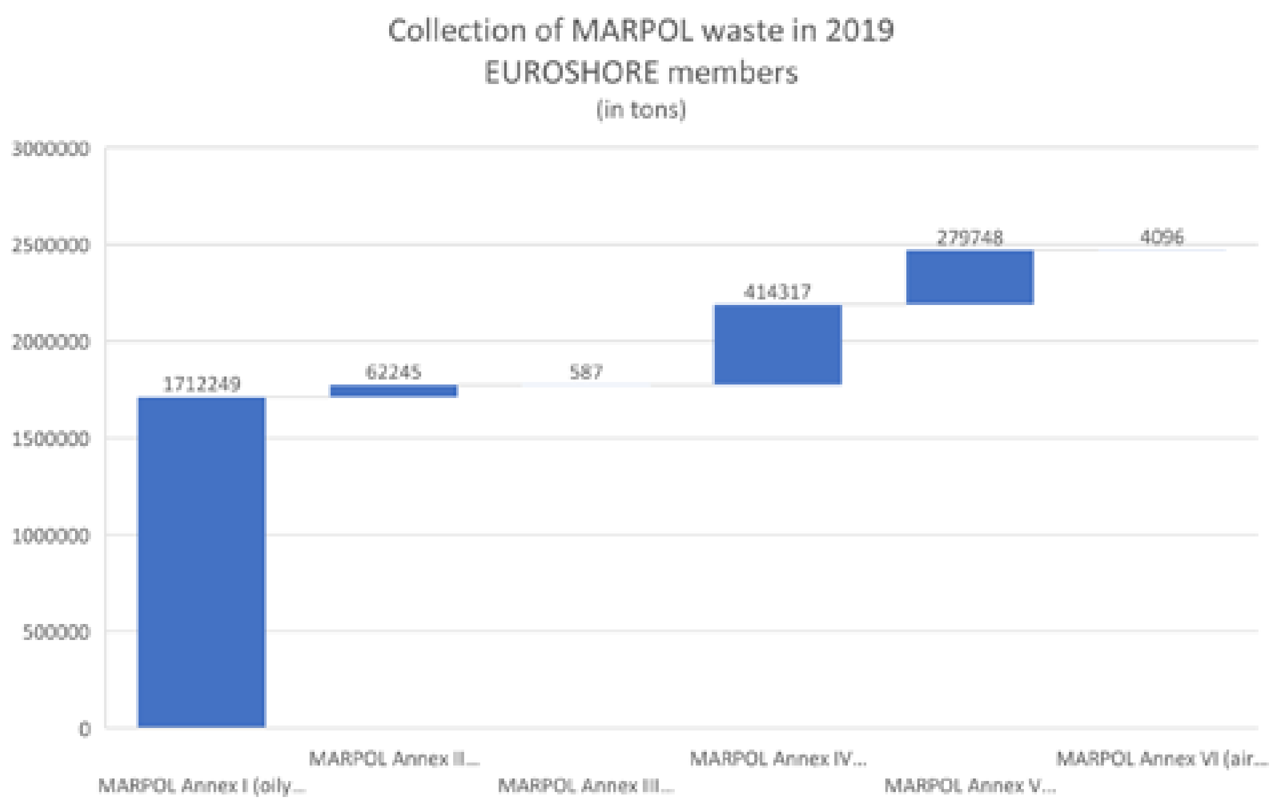

Figure 7.4: *Volumes of waste collected by Euroshore members in 2019 (Euroshore 2019)*

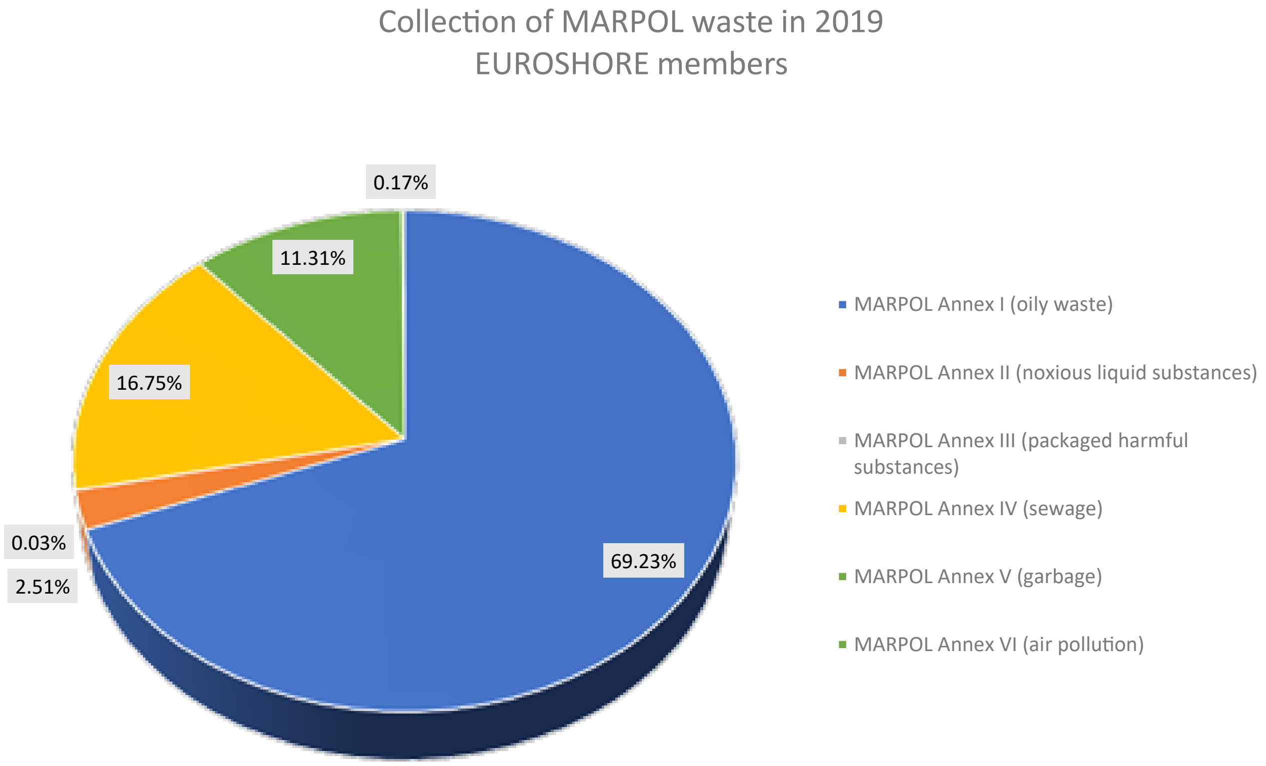

Figure 7.5: *Composition of waste collected by Euroshore members in 2019 (Euroshore 2019)*

Variable tariffs placed on off-loaded waste cause vessels to "port hop" or resort to illegal dumping of waste to cut costs. Port-hopping is a tactic used by illegal operators exporting waste from the European Union to developing countries, and is particularly difficult to detect because operators give other, more logistical reasons for switching ports, such as demurrage, storage, handling, etc. (Rucevska *et al.* 2015). It is difficult to measure the extent to which vessels may currently practice "port hopping", especially in Asia where there are a higher number of ports (e.g. China has 34 major ports and more than 2,000 minor ports, of which most are sea ports; Rucevska *et al.* 2015).

Provision of, and standardization of protocols for use of, adequate PRFs, especially in developing and island nations, would greatly reduce ship-sourced marine pollution. A good example of this is the development of waste reception hubs in the South Pacific (within the framework of the Regional Reception Facilities Plan for the SIDS in the Pacific Region). Options for PRFs are discussed further.

7.2.2 *Improvements of port reception facilities*

The collection of plastic waste from ships is conducted by PRFs, of which there are many types (REMPEC 2019). Unfortunately, waste management, plastic treatment and recycling options at PRFs vary throughout the world, and in some regions there are no PRFs. This is a particular challenge for developing and island nations, where port management of shipping waste is difficult for both technical and economic reasons – including a lack of land for disposal sites and other infrastructure problems (e.g. roads). For example, simply the layout of many Pacific Island ports creates waste management problems because they often comprise a simple sheltered anchorage in which containers or cargoes are transferred to or from smaller vessels and barges to the shore. This is especially true for cruise liners that come into key regional and island ports that operate as ferry bases (SPREP 2015). Inadequate PRFs also promote "port-hopping" or illegal dumping of waste at sea by vessels. Improving PRFs for waste from ships, including its onshore downstream management, is the single, most effective solution to preventing discarding of waste at sea. Fortunately, there are a number of PRF options that can be tailored to the size, needs and available infrastructure of ports worldwide.

7.2.2.1 Floating reception facilities

Barges (either towed or self-propelled) can serve as floating reception facilities and provide several advantages for management of ship-based waste. Barges in most cases have limited draught requirements, enabling their use in shallow waters. In some cases, barges can be used for the simultaneous collection of both solid and liquid ship-generated waste, assuming that the tanker barge also has sufficient free space to allow for safe storage of solid ship-generated waste. Sufficient calm weather berthing space or suitable docking facilities must be made available for the delivery of the wastes. Floating PRFs (Figure 7.6) can often use berthing facilities that were built for other purposes; in ports where berths have become obsolete due to increased ship size, the old berths may be converted into docking port reception facilities for barges. Floating PRFs can off-load waste directly from the delivering ships, but care must be taken to prevent garbage from accidentally ending up in the water (e.g. nets, coverings, chutes). By this same token, when ship-generated wastes and cargo residues are being collected by a barge or other floating collection device (e.g. a towed pontoon), the waste needs to be off-loaded to shore for hauling to a storage and/or disposal facility: provisions must be made for off-loading the waste barge either in the port, at the disposal site (if it is accessible to the barge), or at another port if the wastes and residues are being transported by water to another port.

Figure 7.6: *A floating port reception facility (photo credit: Bek and Verburg, Rotterdam, NL)*

7.2.2.2 Mobile reception facilities

Vehicles can be used for receiving ship-generated waste, and they confer a high level of both site and time flexibility for ports. However, the loading capacity of vehicles is usually smaller than the capacity of barges, and terrain and road surfacing in the port might not always be suitable for a safe and swift transport. Trucks or other vehicles that are used to collect solid ship-generated waste directly off-loaded from ships require easy access to get close to the ships, and therefore depend on an adequate road system within the port area and terminals. Protocols for preventing the loss of waste into surrounding waters during transfer are essential. In case of collection of segregated waste streams, it is also necessary to use multiple vehicles in order to prevent the waste streams from mixing (e.g. hazardous with non-hazardous).

Receptacles, such as skips (bins) and other containers, can easily be transported to a berthing area where ships intend to deliver solid wastes (e.g. garbage) (Figure 7.7). An advantage is that in those cases a truck can transport the receptacle to the berthing place in the port, leave it there for the period of time the ship needs for delivering the waste, and return afterwards for collection when the receptacles are filled with the garbage. For this method to be effective, communication between the ship and the port reception facility is necessary in order to ensure that the receptacles being used have sufficient collection capacity and are adequate (e.g. in case of delivery of food waste) for the ship's use.

Figure 7.7: *Skips for waste from fishing vessels in port of Tromsø, Norway (photo credit: Peter Van den dries)*

7.2.2.3 Fixed reception facilities

An alternative to the mobile collection of ship-generated waste for transport off-site is to have one or more centrally located fixed PRFs, or fixed collection points within the ports equipped with containers or skips. For smaller ports this might be a suitable option, especially when the fixed PRF is located strategically within the port (e.g. at a lock providing the main access to the port). A specific advantage of a fixed PRF is that its operations can be extended and combined with waste (pre-)treatment. For large ports the main disadvantage of a fixed PRF is that a ship will likely have to shift berths because the fixed PRF is located somewhere else in the port, and shifting berths is a time-consuming and expensive operation that may lead to undue delays or ships not motivated to use the PRF. If PRFs are located in a less suitable place, it could result in delays, congestion and an increased risk of accidents and collisions. Appropriate sites for fixed PRFs therefore include wharves adjacent to moorages, access points to docks, fuel stations and boat launching ramps (Figure 7.8).

Figure 7.8: *A fixed PRF in Antwerp, Belgium (photo credit: Peter Van den dries)*

Depending on the size of the port, stationary receptacles can be placed either in one central location or at multiple sites within the port area. The space required depends on the number and type of receptacles to be placed together, and on the types and volumes of ship-generated waste to be collected at a single site. For example, some countries have strict requirements regarding the collection and disposal of international catering waste, often referred to as quarantine waste. In these cases, waste contractors have to provide separate bins in order to collect the ship-generated waste of concern.

Figure 7.9: *PRF in Favignana, Italy (photo credits: Peter Van den dries)*

In smaller ports such as fishing ports and marinas, limited types of fixed PRFs can be used when only limited amounts and types of ship-generated wastes will be delivered in those ports (Figure 7.9). In marinas it is not always necessary to provide large and differentiated reception facilities, as the main type of ship-generated waste delivered will be garbage and household waste, general receptacles designed for the collection of the most common fractions of household waste will be sufficient.

7.3 Chapter summary

- Given the nature and scale of the problem and the diversity of sources evident from the preceding chapters, it is clear that efforts to reduce sea-based sources of marine litter will demand a wide array of actions and approaches
- Preventing and reducing ALDFG as a major sea-based source of marine litter will require a combination of fisheries management and regulatory measures, best practices and codes of conduct guidelines, modifications and innovations in gear design and operation, and increased availability of port reception facilities for end-of-life gear. While retrieval of ALDFG is an important curative measure, but there must be an equal and concomitant effort to prevent its abandonment, loss and discarding in the first place is critical.
- A standardized approach to waste management by the global shipping sector is necessary to inform broad-scale adoption of best practices, and to generate data that will elucidate temporal and geographic trends. Improved availability and use of PRFs are also key to reducing shipping as a source of marine litter.
- All efforts to reduce sea-based sources of marine litter will require targeted and effective education and awareness-raising among stakeholders across all sectors – government, industry, academia, NGOs, and communities – in order to build consensus and will for effecting change.
- Research into causes, quantities, impacts, and solutions for sea-based sources of marine litter is required to generate the evidence necessary to inform management and policy change recommendations at all scales.

8 ASSESSMENT OF DATA and KNOWLEDGE GAPS

It is clear that despite a very significant body of scientific work on marine litter and its sources, quantities and impacts has been produced and with new scientific papers every month from investigators around the world, but certain gaps in our knowledge and understanding remain. These gaps warrant further investigation to inform prevention and mitigation strategies that can be applied locally, regionally and globally.

8.1 General data and knowledge gaps

Fundamental, cross-cutting data and knowledge gaps that apply to all potential sea-based sources of marine litter include the following:

- **Global geographic data gaps**: There is a great need to better understand the type, quantity and impact of sea-based sources of marine litter in most areas of the world, and to further develop capacity for data analysis and quality assurance in all regions, using common approaches. Global monitoring will need a much greater degree of spatial coverage and resolution sufficient to describe large-scale patterns of debris distribution at a global scale. This must be designed for multi-year functionality, with gradual enhancement driven by national and regional monitoring capacities, developing technologies, gained knowledge, changes in the ocean circulation, and trends in ocean usage.
- **Appropriate methodologies to quantify and compare data**: It is essential that common methodologies are developed to collect scientific, social and economic data on sea-based sources of marine litter across all sectors and across geographic areas. Anthropogenic inputs may change over time, and the level of input of marine litter from sea-based sources may shift. A quantitative comparative assessment of the relative contribution to marine plastic pollution of all sea-based sources of marine litter would

presumably need to be carried out on a mass basis, and this can be achieved only by developing and applying both standardized data collection protocols as well as tools for metadata analysis and machine learning.

- **Distinguishing sea-based sources from land-based sources of marine litter**: Common types of plastic marine litter such as water bottles, plastic gloves, plastic balloons, food packagings and other plastic food waste are often attributed to land-based sources. But these same types of litter also arise from sea-based sources. Distinguishing sea-based from land-based sources of plastic litter is important for a better understanding of the relative contribution of sea-based versus land-based sources of marine litter, and also to inform waste management strategies for on-board vessels.
- **Assessing risk of sea-based sources of marine litter**: With regard to the potential impact of sea-based sources of marine litter across all potential sources, there is a need to establish the risk of impact, with consideration to whom, to which compartment of the environment, where and when. Risk assessment requires (1) the assessment of the potential consequences after exposure at a particular level (hazard identification/characterization); (2) the assessment of the exposure (probability that a hazard will occur); (3) the characterization of the risk, combining hazard and exposure; and (4) the evaluation of uncertainties. This is critical because risk assessment applied to sea-based sources of marine litter will enable and inform broader investigations of where and how species, sectors and habitats may suffer from the presence of marine litter, and the ability to focus mitigation strategies on areas of high risk.
- **Understanding pathways and transport**: Generally speaking, there is a paucity of information on pathways taken by litter generated at sea. While some efforts have been made to model sources of, for example, abandoned, lost or otherwise discarded fishing gear (ALDFG), in certain regions around the world, significant challenges remain in being able to predicting/modelling marine litter movement at sea. This is important because ocean transport likely contributes to geospatial "hotspots" – areas of the ocean that are disproportionately impacted by sea-based sources of marine litter that is being generated at distant locations. Understanding geographical sources and fates of marine litter, including marine habitats most affected, is key to informing mitigation strategies.
- **Socio-economic impacts of marine litter generated at sea**: Few local, regional or global estimates exist for direct and indirect costs arising from sea-based marine litter on ocean users, industries and coastal communities. It is especially important to understand socio-economic impacts of marine litter on developing and rapidly developing economies, including many small island developing states, because these nations are largely dependent upon ocean-based industries (e.g. fisheries, aquaculture, tourism) for livelihoods, food security, and local and national economies, and for whom adverse impacts arising from sea-based sources of marine litter might be disproportionate.
- **Health impacts of marine litter**: Generally speaking, while the potential impact of marine litter on human and animal health is not specific to any one source of marine litter, some specific types of litter from sea-based sources warrant investigation. For example, the toxicity of, and injuries from, items collected during cleaning operations in harbours needs to be better evaluated. Possible health risks associated with cargo items lost at sea that contain chemicals, drugs, or other dangerous goods should be addressed. More generally, the potential hazards to human and animal health of the polymers that comprise the structural backbone of marine plastics have not been adequately studied and are less well understood than the hazards of plastic chemical additives. This is a focus of investigation by GESAMP WG 40, but bears repeating here as well.

8.2 Fishing and aquaculture data and knowledge gaps

Data and knowledge gaps in our understanding of fishing and aquaculture as sea-based sources of marine litter include the following:

- **Portion of global marine litter burden comprising ALDFG**: At the time of this report, there are insufficient data in the published and grey literature to allow for an update of the oft-cited statistics that 640,000 tonnes of ALDFG end up in the global ocean every year. A more current and accurate estimate of the ALDFG portion of marine is urgently needed. Undertaking this estimation will require proactive steps to collecting data directly from fishers and other stakeholders (including gear suppliers with sales data), especially in parts of the world where data are scant, and to apply statistical modelling to published and unpublished data on fishing effort and location, quantities of gear deployed, and rates of loss (and replacement). This would likely begin as an iterative "living" estimate, based on a mix of coarse- and fine-scale data, with periodic extrapolations and interpretations and further refinement as data of greater precision and reliability become available and are incorporated.
- **ALDFG categories and differentiation among sub-gear types**: Future studies need to more clearly distinguish across sub-gear types, because sub-gears classified under the same overarching gear category may have

very different impacts following loss. Future research that aims to better understand losses from both high-risk sub-gear types (e.g. gillnets), as well as to provide evidence for likely lower risk sub-gear types (e.g. hook-and-line gear) is important because it will allow for a more nuanced and informed discussion across fisheries.

- **Distinguishing between actively deployed gear and ALDFG as causes of wildlife entanglements**: At present it is extremely difficult to distinguish marine wildlife entanglements caused by actively deployed gear compared to entanglements caused by ALDFG. Very often, marine animals (especially cetaceans) entangled in actively deployed gear are reported as marine litter entanglement events, because by the time the animal is observed and entangled, it has torn and damaged the gear. Entanglement rates in ALDFG may be exaggerated if it is assumed that all entanglements, including those in actively deployed fishing gear, are all due to ALDFG. Better data around this question is important because management and fishery interventions to prevent entanglements will necessarily vary depending on the status of the gear causing the entanglement.
- **Population-scale impacts of ALDFG on target and non-target species**: Population-scale impacts of ALDFG on both target and non-target resources are largely unknown and understudied. Research on impacts of ALDFG to specific fisheries and related target species are limited. There is almost no information on ALDFG impacts on major fisheries. As well, ALDFG wildlife entanglement is circumstantial and opportunistic, precluding any kind of global assessment of impact.
- **Geographic gaps**: Future research on quantities and impacts of ALDFG should focus on geographic areas for which there is very little to no information, especially in Africa, Asia, South America and Antarctica. Research should focus on developing countries where large numbers of small-scale fishing vessels and large-scale artisanal fisheries operate. Research should also be undertaken in regions where large-scale/industrial fishing vessels deploy large volumes of gear, such as purse seine fisheries using drifting fish aggregating devices (dFADs) and some pelagic longline fisheries, and where there may be greater chances for the introduction and accumulation of ALDFG.
- **Quantifying ALDFG contributions from recreational fisheries**: A lack of quantitative information exists on the amount of ALDFG from the recreational fishing sector. The primary challenge in gaining ALDFG related information from recreational fisheries globally lies in the general paucity of oversight, reporting, and documentation of participation and effort when compared to commercial fisheries. This is important because recreational gear has been documented as the dominant type of ALDFG present in some water bodies, compared to ALDFG from commercial fisheries. At present, it is unknown if this is the case in other parts of the world where there is a high level of recreational fishing.
- **Fish aggregating devices (FADs) as sources of marine litter**: Quantities, degradation and impacts from anchored and drifting FADs are documented but limited. Further research for this gear type should be prioritized to better identify the scale and scope of the degree to which FADS contribute to marine litter.
- **Aquaculture operations as sources of marine litter**: Available information on aquaculture operations as a source of marine litter comes from countries with relatively highly industrialized aquaculture where few farms dominate the major market, but most aquaculture productions is in Asia where the data is very limited. Globally speaking, the aquaculture industry is akin to small scale fishing, wherein small businesses dominate, and from which we have verhy little to no information. This data gap must be addressed, as should the lack of reporting on loss, abandonment or discard of plastic materials from aquaculture operations by the majority of producing countries, which prevents conducting comprehensive assessments of the scope and scale of marine litter generated by aquaculture. This is critical to address with future studies given the growth of aquaculture worldwide.

8.3 Shipping and boating

Data and knowledge gaps in our understanding of shipping and boating as sea-based sources of marine litter include the following:

- **Mapping and modelling shipping-related litter sources and distribution**: Further development and improvement of modelling and mapping tools are needed to better evaluate when, how and why litter is disposed of from all different categories of shipping (e.g. merchant, navy, fishing, artisanal, recreational etc.), and if/where legal or illegal discharge of bulk solid and liquid cargoes is occurring. Such tools would support quantitative estimates of marine litter inputs, pathways of movement and accumulation of litter from ships, and would help elucidate where and why some regions are particularly exposed to litter from shipping. Mapping and modelling tools would also reveal accumulation areas of importance (e.g. closed bays, gyres, and specific deep-sea zones) as they are related to shipping routes.
- **Microplastics in ship surface coatings**: Little mention exists of marine coatings as a source of microplastics in the scientific and grey literature on marine litter. It is important to better understand how activities such as hull cleaning, replacement of hull coatings, and

the normal wear of antifouling hull coatings contribute to the presence of microplastics in the ocean. With the hull-cleaning industry growing in some geographic areas, the individual contributions from normal use, maintenance, and cleaning of coatings remain to be determined as the first step in further research efforts. Closing data gaps and limited knowledge on antifouling substances and marine paints will help inform future management and/or policy development. This is critical as the shipping industry addresses overall imperatives to minimize environmental impacts. For example, in-water cleaning is a recent innovation that addresses a significant market need to reduce ship fuel consumption that can also directly help address the prevention of transport of invasive species. But the contribution of in-water cleaning to the global burden of plastics in the ocean is unknown.

- **Socio-economic impacts of litter from shipping**: Further research is needed to evaluate the potential loss of income due to litter from shipping in relation to tourism, fishing and more generally, ecosystems services.

8.4 Ocean dumping data and knowledge gaps

Data and knowledge gaps in our understanding of ocean dumping as a sea-based source of marine litter include the following:

- **Geographic Gaps**: Even with the current list of 100 parties to either or both London Convention (LC) or London Protocol (LP), there remains an almost equal number of countries (some of them large, rapidly industrializing countries) that are not party to either instrument and for those any dumping activities are therefore not currently captured within the globally available reporting mechanism. There is no simple way to gain insights into the extent of dumping in such countries, and therefore the types and quantities of plastic materials dumped and how they may be assessed.
- **Characterization of plastics in material dumped at sea**: Analytical techniques necessary to enable reliable characterization and quantification of plastics, especially microplastics, in wastes considered for dumping at sea are still currently complex, time-consuming and expensive, suitable for research-level studies but not yet routinely applicable or affordable in support of timely decision-making on permit issuance. While both the LC and LP contain the obligation to characterize all candidate wastes for contaminants of concern – a term that should evidently include at least some components of marine litter and microplastics – the development and consistent application of accessible methods to do so remains an aspiration.
- **Dredged materials as sources of marine litter**: It is almost undeniably the case that the dumping at sea of dredged materials, especially those drawn from busy harbours or urbanized coastal areas, will act as a significant source of plastic contaminants within the area of a dumpsite and, perhaps, further afield. Nevertheless, it seems inevitable also that, other than for some highly traceable forms of litter or microplastics, those contaminants will be largely indistinguishable in character from plastics that may have been deposited in the same area through a completely different pathway (e.g. local land-based discharges, long-distance transport by currents and winds, resuspension from adjacent sediments, loss or disposal from shipping etc.).

8.5 Other sources data and knowledge gaps

Data and knowledge gaps in our understanding of ocean uses other than fishing, aquaculture, shipping and boating, and ocean dumping as sea-based sources of marine litter include the following:

- **Contributions of plastics from offshore oil and gas exploration and extraction**: Quantifying levels and frequency of marine litter discharged from the offshore oil and gas industry requires further in-depth study to accurately assess the types and channels for discharge into the marine environment. The most comprehensive data available is for North Sea operations, where there is the highest concentration of offshore oil and gas activity exploration; however, different materials and chemicals may be used in different regions and thus further global studies on marine debris originating from at-sea industrial activities is required.
- **Shark and stinger net loss**: While the use of shark and stinger nets is fairly regionally circumscribed, the quantity or frequency of loss, either partial or complete, is not reported, and there are little to no obligations to report loss to national authorities. Additionally, losses of equipment through field trials have not been quantified. Reporting of net loss events to relevant authorities, with information publicly available, would assist in estimating shark and stinger net contributions to marine debris.
- **Quantity of weather balloons lost at sea**: Most weather balloons released at sea will not be retrieved and the majority become marine debris. There is a need to quantify the number of balloons launched globally each year, and to assess the relative contribution of this form of marine litter to the global ocean plastic burden.
- **Global estimates of fireworks as sources of marine litter**: Understanding contributions to marine debris from at-sea fireworks displays is challenging. It is nearly impossible to attribute particular type of debris to either at-sea or

land-based fireworks displays. Research on the number of fireworks launched on barges and the average weight and types of plastic lost per firework item would assist in developing estimates.

- **Quantity of abandoned scientific research equipment:** While not a significant contributor of global marine plastic litter in comparison to other sources (e.g. oil and gas exploration and drilling), it should be noted that there is very little published data on locations, quantity and impacts of abandoned scientific research equipment.

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Chapter 3. Aquaculture as a marine litter source

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ACRONYMS

ABS	acrylonitrile butadiene styrene
aFAD	anchored fish aggregating device
ALD	abandoned, lost, or otherwise discarded
ALDFG	abandoned, lost or otherwise discarded fishing gear
COFI	Committee on Fisheries (FAO)
CPUE	catch per unit effort
dFAD	drifting fish aggregating device
DFG	derelict fishing gear
EEA	European Economic Area
EPS	expanded polystyrene
EVA	ethyl vinyl acetate
FRP	fibre-reinforced plastic (fibreglass)
GPS	global positioning system
HDPE	high-density polyethylene
ISSCFG	International Standard Statistical Classification of Fishing Gear
IUU	illegal, unreported, unregulated
LC	London Convention
LDPE	low-density polyethylene
LLDPE	linear low-density polyethylene
LP	London Protocol
MARPOL	International Convention for the Prevention of Pollution from Ships
OPRC	International Convention on Oil Pollution Preparedness, Response and Cooperation
OSPAR	The Convention for the Protection of the Marine Environment of the North-East Atlantic
PA	polyamide
PBAT	polybutylene adipate-co-terephthalate
PBS	polybutylene succinate
PCB	polychlorinated biphenyl
PE	polyethylene
PES	polyester
PET	polyethylene terphthalate
PMMA	Poly (methyl methacrylate) (plexiglass, or acrylic)
PP	polypropylene
PRF	port reception facility
PS	polystyrtene
PUR	polyurethane
PVC	polyvinyl chloride
RFMA	regional fisheries management authority
RFMO	regional fisheries management organization
ROV	remotely operated vehicle
SCUBA	self-contained underwater breathing apparatus
SSF	small-scale fishery
TBT	tributyl tin
ToR	Term of Reference
UHMWPE	ultra-high molecular-weight polyethylene
UNCLOS	UN Convention on the Law of the Sea

USD	United States dollars
VGMFG	Voluntary Guidelines for the Marking of Fishing Gear (FAO)
WAG	waste assessment guidelines
XBT	expendable bathythermograph

ANNEX I – ABANDONED, LOST OR OTHERWISE DISCARDED FISHING GEAR (ALDFG) – GLOBAL LITERATURE REVIEW

In order to fully address Terms of Reference (ToRs), Working Group 43 initially undertook an extensive literature review of all publications available as of December 2019 on sources, levels, impacts, preventative measures, knowledge gaps and research priorities for ALDFG from artisanal, commercial and recreational fishing operations. The Working Group utilized the Web of Science, Scopus, Google Scholar and Google, and reviewed scientific publications and grey literature, including technical reports. Wherever possible, attempts were made to recover the primary sources for data cited from studies reviewed.

Literature was included in this review if it contained information about sources (including causes for loss), levels (i.e. quantitative amounts of documented as lost and/or found/recovered/retrieved), impacts and/or preventative measures for ALDFG:

- Information collected for ALDFG sources included geographic location, associated fishery and target species, time of loss, scale of loss (i.e. from an individual vessel or across an entire fleet) and causes of the ALDFG.
- Information collected for causes of ALDFG was broadly categorized into those arising from environmental conditions; due to conflicts and interactions with other gear types, vessels, fishers and/or marine users; resulted from fisheries management and regulations (either lack of or responsible for); and attributable to operational causes and operators.
- Information collected for levels focused on quantitative amounts of ALDFG over specific time intervals (e.g. lost annually, seasonally, on a set) and where available and required, associated effort information (e.g. fleet size, number of sets per trip, trip length). This information is minimally required for any analysis surrounding gear loss rates. For discussion purposes, and to further inform more qualitatively the scope and scale of the issue, information was also collected about the amounts of ALDFG found, recovered and/or retrieved even if this information was not time-bound.
- Information collected for impacts was broadly categorized into economic (e.g. direct and indirect costs to fishers, fisheries), environmental (e.g. habitats, invasive species, wildlife) and social impacts (e.g. aesthetic, hazards to navigation/safety, health).
- Information about preventative measures included a wide variety of measures that can be broadly categorized into awareness raising/education; improvements in gear design (including biodegradable gears and components); management interventions (including effort regulation, best practices/code of conduct, combatting illegal, unreported, unregulated (IUU), enforcement, gear-marking, monitoring, reporting, and spatial and temporal management); infrastructure availability and improvements (notably port reception facilities); technological investments (e.g. navigation technologies, use of side-scan sonar); ALDFG removal and retrieval efforts and ALDFG research.

Search terms were designed to capture terminology commonly used in ALDFG research/reports/literature, common fishing gear types, target species, fisheries operations, impacts, and, in the case of levels, terms for quantitative amounts of ALDFG. These categories and terms were then used in a variety of combinations in different literature searches, depending upon the gear type, and impact or level of interest.

List of search terms (key themes and terms are presented in alphabetical order):

- ALDFG-related terms: “abandoned, lost or otherwise discarded fishing gear (ALDFG)”; “ALDFG”; “derelict fishing gear (DFG)”; “DFG”; “gear retrieval”; “ghost”; “ghost gear”; “loss*”; “unintended fishing”
- Fishery/gear type terms: “anchored fish aggregating device”, “bag net”, “beacons”, “buoys”, “cast net”, “dip net”, “drag net”, “dredge*”, “drifting fish aggregating device”, “drift net”, “FAD*”, “fish aggregating device”, “floats”, “gear”, “gillnet”, “handline”, “hook”, “jig”, “lift net”, “line”, “longline”, “net”, “pole”, “pot”, “purse seine”, “raft”, “ring net”, “rope”, “seine”, “set net”, “sinker”, “trammel”, “trawl”, “trap”, “troll”
- Fisheries operations terms: “active”, “anchor”, “artisanal”, “bait”, “bait boxes”, “boat”, “cable”, “commercial”, “deep sea”, “drum*”, “crew”, “fish*”, “fishing line”, “fleet”, “foam”, “industrial”, “light bulbs”, “light sticks”, “monofilament”, “net*”, “observer”, “offshore”, “operation*”, “passive”, “small-scale”, “strapping bands”, “subsistence”, “thermocole”, “traditional”, “vessel”
- Impacts terms: “benthic”, “economic”, “ecosystem”, “endangered”, “entangle”, “environment*”, “ghost fishing”, “habitat”, “hazard”, “impact”, “ingest”, “navigation”, “non-target”, “recreation”, “safety”, “social”, “tourism”, “wildlife”
- Target species terms: “cod”, “crab”, “lobster”, “octopus”, “salmon”, “shrimp”, “tuna”
- Quantitative loss terms (also to identify levels of gear losses): “amount”, “estimat*”, “length”, “los*”, “number”, “rate”, “percent”, “weight”

Summary findings

A total of 233 publications that included information about sources, levels, impacts and prevention measures for ALDFG from artisanal, commercial and recreational fisheries was identified and reviewed. The literature review encompassed papers and reports produced from 1970 to December 2019, with most of the studies undertaken in the last decade (61%, N = 141). The studies reviewed employed a range of methodologies that varied depending upon the topic/subject matter of the paper. Broad categories of methodologies employed by the studies reviewed included:

- reviews, commentaries and syntheses of existing literature around a specified topic;
- interviews and/or surveys with fishers, often with the aim to identify amounts, causes, impacts and/or prevention mechanisms for ALDFG;
- removal/retrieval surveys, often with the aim to identify amounts of ALDFG for a specified location and/or identify impacts from the recovered ALDFG;
- underwater surveys, often conducted either by divers and/or remotely operated vehicles (ROVs), with the aim to identify amounts of ALDFG for a specified location, and/or identify impacts from the recovered ALDFG;
- beach/coastal surveys, often conducted either by researchers, and/or in coordination/collaboration with citizen science groups, with the aim to identify amounts of ALDFG for a specified location and/or identify impacts from the recovered ALDFG;
- wildlife surveys, often documenting information about ALDFG entanglement in and/or ingestion by marine wildlife. Studies are commonly conducted for birds, marine mammals and turtles;
- fishery management plans/reports with information documented by management agencies about amounts and impacts of gear losses (sometimes required reporting by fishers and/or fishery observers). Information is often included about prevention/mitigation measures the agency is engaged in, in response to the ALDFG issues;
- simulation studies for ghost fishing impacts, often at sea although sometimes in the lab. These studies frequently involve intentionally setting a piece of ghost gear in an at-sea environment that resembles where normal fishing and losses might occur, and observing ghost fishing impacts over time; and
- simulation studies for biodegradable gear designs, at sea and in the lab. These studies frequently involve testing biodegradable gear types or components of a gear. They frequently aim to determine overall effectiveness in catch, minimization of bycatch and/or ghost fishing, durability and lifespan for gear, and how these gear types compare to their conventional plastic-based counterparts.

Most of the studies reviewed reported data on abandoned, lost, or otherwise discarded (ALD) traps (including pots) (51% of all studies reviewed, N = 121) and nets (49% of all studies reviewed, N = 115), with a little more than a quarter of the studies reporting data around ALD hooks and lines (26% of all studies reviewed, N = 62).[15] Many studies reported information about sources, levels, impacts and prevention measures for ALDFG for multiple gear types. Within the pots and traps category, studies reviewed reported data on pots (mostly crab and lobster pots, as well as cuttlefish, eel, fish, octopus, shrimp and whelk), fyke, hoop and pound nets. Within the net category, studies reviewed reported data on gillnets and entangling nets (including set, drifting, and fixed gillnets; and trammel nets); purse seine nets (including the use of anchored and drifting fish aggregating device [FADs]); seine nets (including beach and boat seines); trawl nets (including bottom otter trawls, midwater otter trawls and midwater pair trawls); cast and other miscellaneous nets. Other miscellaneous net types reviewed included scoop nets and a variety of unidentified net types. Within the hooks and lines category, studies reviewed reported data on handlines and pole-lines (both hand-operated and mechanized), longlines (set and drifting) and trolling lines.

Studies were distributed globally, with the greatest number of studies from North America, notably the United States of America. A quarter of the studies reviewed originated from the United States of America (26%, N = 61), followed by "Global" (studies designated as global studies, so for a variety of countries around the world or all countries) (9%, N = 20), South Korea (7%, N = 16), Australia (6%, N = 14), Canada (4%, N = 10), Italy (4%, N = 9), Turkey (4%, N = 9), UK (4%, N = 9), Japan (3%, N = 8), Norway (3%, N = 8), the Portugal (3%, N = 7), Maldives (3%, N = 6), Spain (2%, N = 5), Brazil (2%, N = 4), the Pacific Ocean (broadly as a region) (2%, N = 4), Antarctica (1%, N = 3), France (1%, N = 3), India (1%, N = 3), the Indian Ocean (broadly as a region) (1%, N = 3), Thailand (1%, N = 3), the Sultanate of Oman (1%, N = 3), Sweden (1%, N = 3), the US Virgin Islands (1%, N = 3) the Baltic Sea (broadly as a region) (1%, N = 2), China (1%, N = 2), Iceland (1%, N = 2), Indonesia (1%, N = 2), the Atlantic Ocean (broadly as a region) (1%, N = 2), the Mediterranean Sea (1%, N = 2), Sri Lanka (1%, N = 2), and Uruguay (1%, N = 2). The review also included a handful of individual studies for a variety of countries and regions including Albania, the Arctic Ocean, Barbados, the Caribbean islands (broadly as a region), Chile, Commonwealth of the Northern Mariana Islands, Costa Rica, French Polynesia, Guam, Greenland, Iran, Macedonia, Mexico, Morocco, New Caledonia, Russia, Samoa, Sweden, India and the United Arab Emirates.

A little more than half of the studies reviewed reported causes for the ALDFG (52%, N = 115). The most common causes of losses reported included gear loss due to some type of conflict (66% of all studies reporting causes of loss, N = 76), poor weather

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[15] Percentages listed above represent the gear types across all studies reviewed. Because many studies examined multiple gear types, the percentages total to more than 100% as they represent the proportion of gear represented across all studies.

conditions (57%, N = 65) and gear becoming ensnared or entangled on a bottom obstruction (31%, N = 36). Other commonly reported causes of loss included currents (18%, N = 21), operator error (15%, N = 17), illegal, unreported or unregulated (IUU) fishing activities (15%, N = 17); intentional discard (13%, N = 15) and gear abandonment (12%, N = 14). Less common causes of gear loss reported by these studies (10% and less) included: loss of a buoy and/or other gear marker (10%, N = 12); wildlife interfering with gear (10%, N = 12); tide (9%, N = 10); improper design or use of gear for conditions (7%, N = 8); too much fishing efforts/ too many vessels (7%, N = 8); fishing in excessively deep water (6%, N = 7); unavailable or inadequate port waste reception facilities (5%, N = 6); catching too much fish for the gear to hold (3%, N = 4); inadequate onboard navigation technologies (4%, N = 4) and gear in need of maintenance, repair and/or replacement (3%, N = 4). Of the studies reporting conflict, the most common types of conflict reported across these studies included conflict between towed and static gears (68% of studies reporting conflict as a cause of loss, N = 52); gear conflicts between other merchant vessels such as ships running over static gears (63%, N = 48); vandalism (34%, N = 23); theft (34%, N = 23); and IUU fishing activities (IUU) (22%, N = 17).

Less than half of all studies reviewed reported some form of quantitative assessment of ALDFG (42%, N = 99). Studies reported levels of gear loss in a wide variety of units that included percentages of gear lost, counts of gear lost, lengths and weights of gear lost, pieces of gear lost and percentages of fishers losing gear, most often on both fleet and vessel levels. Of the studies reporting levels of gear lost, most reported amounts of ALDFG in percentages (68%, N = 67), ranging from 0% to 88.2% for both fleets and vessels; followed by counts/numbers of items of gear lost (57%, N = 56) , which ranged from 0 to 500,000 items of gear lost for both fleets and vessels; total lengths of gear lost (km) (12%, N = 12), which ranged from 0 to 1,028.37 km of gear lost for both fleets and vessels; counts/numbers of pieces of gear lost (9%, N = 9), which ranged from 0 to 5,540 pieces of gear lost for both fleets and vessels; weights of gear lost (tonnes), on the fleet level (7%, N = 7), which ranged from 0.2 to 135,400 tonnes of gear; and the percentage of fishers losing a piece of gear, on the fleet level (1%, N = 1), which ranged between 2% and 4%.

Most of the studies reviewed (80%, N = 187) reported some type of economic, environmental and/or social impact associated with ALDFG. Of the studies reviewed reporting impacts, almost all studies reported some type of environmental impact (97%, N = 182), with a little more than a third of the studies reporting economic impacts (38%, N = 71) and 13% of the studies reporting social impacts (N = 24). Many studies reported multiple types of impacts (i.e. some combination of economic, environmental and/or social impacts).

The most common types of environmental impacts reported included ghost fishing (71% of all studies reporting impacts, N = 133); impacts to marine wildlife (34%, N = 64), with many reports including impacts to birds, marine mammals and/or turtles; specifically entanglement impacts to marine wildlife (28%, N = 52); impacts to marine habitats, often benthic habitats (27%, N = 51); impacts to non-target, bycatch species (16%, N = 30); specifically ingestion impacts to marine wildlife (7%, N = 13); the introduction and/or spread of invasive species (5%, N = 10) and impacts to an entire species population (2%, N = 3). The most common types of economic impacts reported included economic impacts resulting from loss specifically of the target species (27% of all studies reporting impacts, N = 50); economic impacts from losses of fish stocks more generally (21%, N = 39); direct and/ or indirect economic impacts to fishers (17%, N = 31) and costs associated with ALDFG disposal (3%, N = 5). The most common types of social impacts reported included impacts to human health, often through food safety concerns from seafood ingestion of ALDFG (8% of all studies reporting impacts, N = 15); hazards to navigation (7%, N = 13); aesthetic impacts, such as the ALDFG being washed ashore on communities' beaches and coastlines (7%, N = 14); impacts to safety at sea, often through vessel interactions with ALDFG (4%, N = 8) and tourism impacts (2%, N = 4).

While it was not originally a focal area of this literature review, prevention and mitigation measures for ALDFG were noted. More than half of the studies reviewed included some type of recommendation for prevention and/or mitigation of ALDFG (66%, N = 153). Almost half of the studies recommended a broad suite of fisheries management measures to prevent and mitigate ALDFG (45% of all studies providing prevention recommendations, N = 69), which are outlined in further detail in the following paragraph. The next most common prevention recommendations included gear removal/retrieval (43%, N = 66); improvements in overall gear design (which could also include the use of biodegradable gears) (35%, N = 54); specifically, the use of biodegradable gears and/or biodegradable gear components (29%, N = 45) and awareness raising/education (24%, N = 37). Other less common prevention and mitigation recommendations broadly included improvements in the availability of port reception facilities, both physically and financially (16%, N = 24); ALDFG research (11%, N = 17); improvements in onboard navigation technologies (10%, N = 15); communication and collaboration across relevant stakeholders (5%, N = 7); the use of side scan sonar to identify and recover lost gear (4%, N = 6) and seabed mapping (1%, N = 2).

Of the management recommendations, the most common areas for management included spatial management measures (40% of the management recommended studies, N = 28); enforcement (39%, N = 27); effort regulation (33%, N = 23); gear marking (33%, N = 23); gear loss reporting (30%, N = 21); monitoring (28%, N = 19); retrieval and return at end of life (25%, N = 17); financial incentives by management agencies for a variety of ALDFG efforts (25%, N = 17) and temporal management measures (19%, N = 13). Other less commonly recommended management measures included measures that effectively prevent IUU fishing activities (9% of the management recommended studies, N = 6) and the need for industry best practices/a code of conduct (6%, N = 4).

ANNEX II – GESAMP REPORTS AND STUDIES

The following reports and studies have been published so far. They are available from the GESAMP website: http://gesamp.org

1. Report of the seventh session, London, 24-30 April 1975. (1975). Rep. Stud. GESAMP, (1):pag.var. Available also in French, Spanish and Russian

2. Review of harmful substances. (1976). Rep. Stud. GESAMP, (2):80 p.

3. Scientific criteria for the selection of sites for dumping of wastes into the sea. (1975). Rep. Stud. GESAMP, (3):21 p. Available also in French, Spanish and Russian

4. Report of the eighth session, Rome, 21-27 April 1976. (1976). Rep. Stud. GESAMP, (4):pag.var. Available also in French and Russian

5. Principles for developing coastal water quality criteria. (1976). Rep. Stud. GESAMP, (5):23 p.

6. Impact of oil on the marine environment. (1977). Rep. Stud. GESAMP, (6):250 p.

7. Scientific aspects of pollution arising from the exploration and exploitation of the sea-bed. (1977). Rep. Stud. GESAMP, (7):37 p.

8. Report of the ninth session, New York, 7-11 March 1977. (1977). Rep. Stud. GESAMP, (8):33 p. Available also in French and Russian

9. Report of the tenth session, Paris, 29 May - 2 June 1978. (1978). Rep. Stud. GESAMP, (9):pag.var. Available also in French, Spanish and Russian

10. Report of the eleventh session, Dubrovnik, 25-29 February 1980. (1980). Rep. Stud. GESAMP, (10):pag.var. Available also in French and Spanish

11. Marine Pollution implications of coastal area development. (1980). Rep. Stud. GESAMP, (11):114 p.

12. Monitoring biological variables related to marine pollution. (1980). Rep. Stud. GESAMP, (12):22 p. Available also in Russian

13. Interchange of pollutants between the atmosphere and the oceans. (1980). Rep. Stud. GESAMP, (13):55 p.

14. Report of the twelfth session, Geneva, 22-29 October 1981. (1981). Rep. Stud. GESAMP, (14):pag.var. Available also in French, Spanish and Russian

15. The review of the health of the oceans.(1982). Rep. Stud. GESAMP, (15):108 p.

16. Scientific criteria for the selection of waste disposal sites at sea. (1982). Rep. Stud. GESAMP, (16):60 p.

17. The evaluation of the hazards of harmful substances carried by ships. (1982). Rep. Stud. GESAMP, (17):pag.var.

18. Report of the thirteenth session, Geneva, 28 February - 4 March 1983. (1983). Rep. Stud. GESAMP, (18):50 p. Available also in French, Spanish and Russian

19. An oceanographic model for the dispersion of wastes disposed of in the deep sea. (1983). Rep. Stud. GESAMP, (19):182 p.

20. Marine pollution implications of ocean energy development. (1984). Rep. Stud. GESAMP, (20):44 p.

21. Report of the fourteenth session, Vienna, 26-30 March 1984. (1984). Rep. Stud. GESAMP, (21):42 p. Available also in French, Spanish and Russian

22. Review of potentially harmful substances. Cadmium, lead and tin. (1985). Rep. Stud. GESAMP, (22):114 p.

23. Interchange of pollutants between the atmosphere and the oceans (part II). (1985). Rep. Stud. GESAMP, (23):55 p.

24. Thermal discharges in the marine Environment. (1984). Rep. Stud. GESAMP, (24):44 p.

25. Report of the fifteenth session, New York, 25-29 March 1985. (1985). Rep. Stud. GESAMP, (25):49 p. Available also in French, Spanish and Russian

26. Atmospheric transport of contaminants into the Mediterranean region. (1985). Rep. Stud. GESAMP, (26):53 p.

27. Report of the sixteenth session, London, 17-21 March 1986. (1986). Rep. Stud. GESAMP, (27):74 p. Available also in French, Spanish and Russian

28. Review of potentially harmful substances. Arsenic, mercury and selenium. (1986). Rep. Stud. GESAMP, (28):172 p.

29. Review of potentially harmful substances. Organosilicon compounds (silanes and siloxanes). (1986). Published as UNEP Reg. Seas Rep. Stud., (78):24 p.

30. Environmental capacity. An approach to marine pollution prevention. (1986). Rep. Stud. GESAMP, (30):49 p.

31. Report of the seventeenth session, Rome, 30 March - 3 April 1987. (1987). Rep. Stud. GESAMP, (31):36 p. Available also in French, Spanish and Russian

32. Land-sea boundary flux of contaminants: contributions from rivers. (1987). Rep. Stud. GESAMP, (32):172 p.

33. Report on the eighteenth session, Paris, 11-15 April 1988. (1988). Rep. Stud. GESAMP, (33):56 p. Available also in French, Spanish and Russian

34. Review of potentially harmful substances. Nutrients. (1990). Rep. Stud. GESAMP, (34):40 p.

35. The evaluation of the hazards of harmful substances carried by ships: Revision of GESAMP Reports and Studies No. 17. (1989). Rep. Stud. GESAMP, (35):pag.var.

36. Pollutant modification of atmospheric and oceanic processes and climate: some aspects of the problem. (1989). Rep. Stud. GESAMP, (36):35 p.

37. Report of the nineteenth session, Athens, 8-12 May 1989. (1989). Rep. Stud. GESAMP, (37):47 p. Available also in French, Spanish and Russian

38. Atmospheric input of trace species to the world ocean. (1989). Rep. Stud. GESAMP, (38):111 p.

39. The state of the marine environment. (1990). Rep. Stud. GESAMP, (39):111 p. Available also in Spanish as Inf. Estud.Progr.Mar.Reg.PNUMA, (115):87 p.

40. Long-term consequences of low-level marine contamination: An analytical approach. (1989). Rep. Stud. GESAMP, (40):14 p.

41. Report of the twentieth session, Geneva, 7-11 May 1990. (1990). Rep. Stud. GESAMP, (41):32 p. Available also in French, Spanish and Russian

42. Review of potentially harmful substances. Choosing priority organochlorines for marine hazard assessment. (1990). Rep. Stud. GESAMP, (42):10 p.

43. Coastal modelling. (1991). Rep. Stud.GESAMP, (43):187 p.

44. Report of the twenty-first session, London, 18-22 February 1991. (1991). Rep. Stud. GESAMP, (44):53 p. Available also in French, Spanish and Russian

45. Global strategies for marine environmental protection. (1991). Rep. Stud. GESAMP, (45):34 p.

46. Review of potentially harmful substances. Carcinogens: their significance as marine pollutants. (1991). Rep. Stud. GESAMP, (46):56 p.

47. Reducing environmental impacts of coastal aquaculture. (1991). Rep. Stud. GESAMP, (47):35 p.

48. Global changes and the air-sea exchange of chemicals. (1991). Rep. Stud. GESAMP, (48):69 p.

49. Report of the twenty-second session, Vienna, 9-13 February 1992. (1992). Rep. Stud. GESAMP, (49):56 p. Available also in French, Spanish and Russian

50. Impact of oil, individual hydrocarbons and related chemicals on the marine environment, including used lubricant oils, oil spill control agents and chemicals used offshore. (1993). Rep. Stud. GESAMP, (50):178 p.

51. Report of the twenty-third session, London, 19-23 April 1993. (1993). Rep. Stud. GESAMP, (51):41 p. Available also in French, Spanish and Russian

52. Anthropogenic influences on sediment discharge to the coastal zone and environmental consequences. (1994). Rep. Stud. GESAMP, (52):67 p.

53. Report of the twenty-fourth session, New York, 21-25 March 1994. (1994). Rep. Stud. GESAMP, (53):56 p. Available also in French, Spanish and Russian

54. Guidelines for marine environmental assessment. (1994). Rep. Stud. GESAMP, (54):28 p.

55. Biological indicators and their use in the measurement of the condition of the marine environment. (1995). Rep. Stud. GESAMP, (55):56 p. Available also in Russian

56. Report of the twenty-fifth session, Rome, 24-28 April 1995. (1995). Rep. Stud. GESAMP, (56):54 p. Available also in French, Spanish and Russian

57. Monitoring of ecological effects of coastal aquaculture wastes. (1996). Rep. Stud. GESAMP, (57):45 p.

58. The invasion of the ctenophore Mnemiopsis leidyi in the Black Sea. (1997). Rep. Stud. GESAMP, (58):84 p.

59. The sea-surface microlayer and its role in global change. (1995). Rep. Stud. GESAMP, (59):76 p.

60. Report of the twenty-sixth session, Paris, 25-29 March 1996. (1996). Rep. Stud. GESAMP, (60):29 p. Available also in French, Spanish and Russian

61. The contributions of science to integrated coastal management. (1996). Rep. Stud. GESAMP, (61):66 p.

62. Marine biodiversity: patterns, threats and development of a strategy for conservation. (1997). Rep. Stud. GESAMP, (62):24 p.

63. Report of the twenty-seventh session, Nairobi, 14-18 April 1997. (1997). Rep. Stud. GESAMP, (63):45 p. Available also in French, Spanish and Russian

64. The revised GESAMP hazard evaluation procedure for chemical substances carried by ships. (2002). Rep. Stud. GESAMP, (64):121 p.

65. Towards safe and effective use of chemicals in coastal aquaculture. (1997). Rep. Stud. GESAMP, (65):40 p.

66. Report of the twenty-eighth session, Geneva, 20-24 April 1998. (1998). Rep. Stud. GESAMP, (66):44 p.

67. Report of the twenty-ninth session, London, 23-26 August 1999. (1999). Rep. Stud. GESAMP, (67):44 p.

68. Planning and management for sustainable coastal aquaculture development. (2001). Rep. Stud. GESAMP, (68):90 p.

69. Report of the thirtieth session, Monaco, 22-26 May 2000. (2000). Rep. Stud. GESAMP, (69):52 p.

70. A sea of troubles. (2001). Rep. Stud. GESAMP, (70):35 p.

71. Protecting the oceans from land-based activities - Land-based sources and activities affecting the quality and uses of the marine, coastal and associated freshwater environment. (2001). Rep. Stud. GESAMP, (71):162p.

72. Report of the thirty-first session, New York, 13-17 August 2001. (2002). Rep. Stud. GESAMP, (72):41 p.

73. Report of the thirty-second session, London, 6-10 May 2002. Rep. Stud. GESAMP, (73)

74. Report of the thirty-third session, Rome, 5-9 May 2003 (2003) Rep. Stud. GESAMP, (74):36 p.

75. Estimations of oil entering the marine environment from sea-based activities (2007), Rep. Stud. GESAMP, (75):96 p.

76. Assessment and communication of risks in coastal aquaculture (2008). Rep. Stud. GESAMP, (76):198 p.

77. Report of the thirty-fourth session, Paris, 8-11 May 2007 (2008), Rep. Stud. GESAMP, (77):83 p.

78. Report of the thirty-fifth session, Accra, 13-16 May 2008 (2009), Rep. Stud. GESAMP, (78):73 p.

79. Pollution in the open oceans: a review of assessments and related studies (2009). Rep. Stud. GESAMP, (79):64 p.

80. Report of the thirty-sixth session, Geneva, 28 April - 1 May 2009 (2011), Rep. Stud. GESAMP, (80):83 p.

81. Report of the thirty-seventh session, Bangkok, 15 - 19 February 2010 (2010), Rep. Stud. GESAMP, (81):74 p.

82. Proceedings of the GESAMP International Workshop on Micro-plastic Particles as a Vector in Transporting Persistent, Bio-accumulating and Toxic Substances in the Oceans (2010). Rep. Stud. GESAMP, (82):36 p.

83. Establishing Equivalency in the Performance Testing and Compliance Monitoring of Emerging Alternative Ballast Water Management Systems (EABWMS). A Technical Review. Rep. Stud. GESAMP, (83):63 p, GloBallast Monographs No. 20.

84. The Atmospheric Input of Chemicals to the Ocean (2012). Rep. Stud. GESAMP, (84) GAW Report No. 203.

85. Report of the 38th Session, Monaco, 9 to 13 May 2011 (pre-publication copy), Rep. Stud. GESAMP, (85): 118 p.

86. Report of the Working Group 37: Mercury in the Marine Environment (in prep.). Rep. Stud. GESAMP, (86).

87. Report of the 39th Session, New York, 15 to 20 April 2012 (pre-publication copy), Rep. Stud. GESAMP, (87):92 p.

88. Report of the 40th Session, Vienna, 9 to 13 September 2013, Rep. Stud. GESAMP, (88):86p.

89. Report of the 41st Session, Malmö, Sweden 1 to 4 September 2014, Rep. Stud. GESAMP, (89) :90p.

90. Report of Working Group 40: Sources, fate and effects of microplastics in the marine environment: a global assessment. Rep. Stud. GESAMP (90) :96 p.

91. Pollution in the Open Ocean 2009-2013: A Report by a GESAMP Task Team, (2015) Rep. Stud. GESAMP (91):85 p.

92. Report of the forty-second session, Paris, 31 August to 3 September 2015. Rep. Stud. GESAMP, (2015): 58 p.

93. Sources, fate and effects of microplastics in the marine environment: part two of a global assessment (2016). Rep. Stud. GESAMP, (93): 220 p.

94. Proceedings of the GESAMP international workshop on the impacts of mine tailings in the marine environment (2016). Rep. Stud. GESAMP (94): 83 p.

95. Report of the forty-third session, Nairobi, 14 17 November 2016. Rep. Stud. GESAMP, (2017): 72 p.

96. Report of the forty-fourth session, Geneva, 4-7 September 2017. Rep. Stud GESAMP (2018): 66 p.

97. The magnitude and impacts of anthropogenic atmospheric nitrogen inputs to the ocean (2018). Rep. Stud. GESAMP (97): 47 p.

98. High level review of a wide range of proposed marine geoengineering techniques (2019). Rep. Stud. GESAMP (98):143 p.

99. Guidelines for the monitoring and assessment of plastic litter in the ocean (2019). Rep. Stud. GESAMP (99):123 p.

100. Report of the forty-fifth session, Rome, 17-20 September 2018. Rep. Stud. GESAMP (2019): 70p.

101. Methodology for the evaluation of ballast water management systems using Active Substances (2019). Rep. Stud. GESAMP (101):110 p.

102. GESAMP Hazard Evaluation Procedure for Chemicals carried by Ships, 2019. Rep. Stud. GESAMP (102): 97p.

103. Proceedings of the GESAMP international workshop on assessing the risks associated with plastics and microplastics in the marine environment (2020) Rep. Stud. GESAMP (2020): 60p.

104. Report of the forty-sixth session, New York, 9-13 September 2019. Rep. Stud. GESAMP (104):

105. Impacts of wastes and other matter in the marine environment from mining operations including deep sea mining, (in preparation) Rep. Stud. GESAMP (105).

106. Global Pollution Trends: Coastal Ecosystem Assessment for the Past Century (2020) Rep. Stud. GESAMP (106): 103 p.

107. Report of the forty-seventh session, 8 to 11 September 2020. Rep. Stud. GESAMP (107):

108. Sea-based sources of marine litter (2021). Rep. Stud. GESAMP (108): 109 p

Science for Sustainable Oceans

ISSN 1020–4873