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SEA-BASED SOURCES OF MARINE LITTER – A REVIEW OF CURRENT KNOWLEDGE AND ASSESSMENT OF DATA GAPS (SECOND INTERIM REPORT OF GESAMP WORKING GROUP 43, 4 JUNE 2020)

SEA-BASED SOURCES OF MARINE LITTER – A REVIEW OF CURRENT KNOWLEDGE AND ASSESSMENT OF DATA GAPS

Second Interim Report of GESAMP Working Group 43

4 June 2020

Notes:

GESAMP is an advisory body consisting of specialized experts nominated by the Sponsoring Agencies (IMO, FAO, UNESCO-IOC, UNIDO, WMO, IAEA, UN, UNEP, UNDP and ISA). Its principal task is to provide scientific advice concerning the prevention, reduction and control of the degradation of the marine environment to the Sponsoring Organizations.

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Authors:

Kirsten V.K. Gilardi (WG 43 Chair), Kyle Antonelis, Francois Galgani, Emily Grilly, Pingguo He, Olof Linden, Rafaella Piermarini, Kelsey Richardson, David Santillo, Saly N. Thomas, Pieter Van den Dries, and Lumin Wang

Background to this report:

In early 2019, GESAMP established Working Group 43 under the co-lead of FAO and IMO, with co-sponsorship from UNEP. Later in the year a first, interim report was prepared and is submitted to IMO's Marine Environment Protection Committee (MEPC), as IMO document MEPC 75/INF.23. The report is available from the IMO DOCS website (http://docs.imo.org).

Attached at annext to this document, is the second interim report. **It should be noted that this report outlines the initial, interim findings regarding the state of knowledge of the sea-based sources of marine litter. It has been peer-reviewed and approved for circulation by GESAMP, but should still be regarded as work in progress.**

The first full, technical report of the Group is expected by the end of 2020.

Executive Summary

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'[1], 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, given its inherent strength and durability, which allows it to persist in the marine environment for prolonged periods of time (e.g. decades), compounded by the sheer quantity of plastic that has been manufactured, used and discarded globally since its commercial advent in the 1950s.

While it is generally assumed that the majority of plastic waste entering the world's ocean comes from land-based sources, yet marine litter resulting from sea-based activities, such as fishing, aquaculture, shipping, ocean dumping and other ocean-based activities, has not been specifically quantified on any scale, and its contribution to the global burden of plastic debris in the world's ocean is poorly understood. Furthermore, certain forms of sea-based marine litter, such as abandoned, lost or otherwise discarded fishing gear (ALDFG) that is largely comprised of a variety of manufactured, synthetic materials that do not degrade in seawater, may not only be significant sources of marine plastic litter, but may well have greater impacts on marine biota and habitats than do other forms of marine litter.

The overall objective of the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) Working Group 43 on Sea-based Sources of Marine Litter is 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. 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 the Food and Agriculture Organization of the United Nations (FAO), the International Maritime Organization (IMO), the United Nations Environment Programme (UNEP) and other relevant organizations and research institutions.

This second interim report builds on content initially presented in a first interim report on progress made by WG 43 from June – December 2019. Herein, WG43 fully addresses Term of Reference (ToR) 1, Identify sources of marine litter from sea-based sources, including but not limited to fishing operations, aquaculture, shipping, dumping of waste and other matter at sea and other sea-based sources (e.g. recreation). This second interim report also presents new and further work on: ToR 2, Estimate the relative contribution and impacts of different sea-based sources of marine litter; ToR 4, Assess data gaps as identified under ToRs 1 to 3 and prioritize for further work; and ToR 6, Quantify the environmental, social and economic impacts of ALDFG. Terms of Reference 3, 5, and 7 (see Section 1.2.2 for detail) will be addressed in the final technical report.

Principal findings to date are that sea-based activities and industries contribute to the global burden of marine litter, and that this warrants concern largely because synthetic materials comprise significant portions and components of litter entering the world's oceans from fishing, aquaculture, shipping, ocean dumping and other maritime activities and sources. Furthermore, certain types of sea-based marine litter, such as ALDFG, are known to impact marine resources, wildlife and habitats. 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] Galgani et al. 2013. Guidance on Monitoring of Marine Litter in European Seas. Report of the EU/ MSFD Technical Group on Marine Litter, Joint Research Center, EUR 26113 EN, doi:10.2788/99475

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 marine litter inputs exists in the scientific, peer-reviewed and grey literature. An effort to update global estimations for inputs will be a priority of the Working Group going forward. The Working Group intends to further explore and refine its findings, with intent to derive a scientifically defensible estimate of the relative contribution of sea-based sources of marine litter, further analyze the quantity and category of plastics produced and used by the fishing and shipping industries, identify ALDFG hotspots, further quantify the environmental, social and economic impacts of ALDFG, and review and compare options for mitigating the problem of sea-based sources of marine litter.

Lastly, in the time since we drafted our first Interim Report, 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 very 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 next couple of 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 produced pre-COVID-19, so the pandemic is not expected to impact our analyses presented herein. However, in the coming months, Working Group 43 will be mindful of 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.

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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's oceans started to expand in the 1970s, prompting international regulations to prevent inputs of marine litter, most notably the London Convention (LC), London Protocol (LP) and the International Convention for the Prevention of Pollution from Ships (MARPOL), and serving as the focus of several international scientific conferences held since the mid-1980s. The United Nations 2030 Agenda for Sustainable Development includes Sustainable Development Goal 14.1 to significantly reduce marine pollution of all kinds, including marine debris, by 2025 (UNSDG 2030).

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 has produced several reports on the ocean plastic, 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's ocean comes from land-based sources – an estimated 275 million metric tonnes generated by 192 coastal nations in 2010 alone (Jambeck *et al*. 2015). Research compiled from observations in all European seas suggest 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 2011-2017 with estimations that 60% of the litter was from local and regional sea-based sources (Schaeffer 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's ocean is poorly understood. Furthermore, certain forms of sea-based marine litter, such as abandoned, lost or otherwise discarded fishing gear (ALDFG) that are largely comprised of 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. Recent 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 (UNEP OSPAR 2009; UNEP/MAP 2015; Eunomia 2016).

While reference is commonly made to the “fact” that 80% of litter in the world’s oceans 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). Unfortunately, since that time 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. Recently, 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, but extrapolating to a quantitative assessment of ALDFG entering the world’s 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, geographical 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. 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.

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 fishery operations, cleaning costs) and environmental (e.g. morbidity and mortality caused to living resources, habitat degradation and destruction). Given that litter 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 that are not solely responsible for its generation.

GESAMP Working Group 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

The UN FAO and the 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 now adopted policy instruments to address sea-based sources of marine litter 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 45th Session of GESAMP, which took place at FAO Headquarters in Rome, September 17-20, 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 73rd session of IMO's Marine Environment Protection Committee (MEPC), held in London, October 22-26, 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. 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.

The overall objective of GESAMP Working Group 43 on Sea-based Sources of Marine Litter is 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. 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.

Working Group 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, drawing upon the expertise of the FAO, IMO, UNEP and other relevant organizations and experts. The outputs of WG 43 are intended to support the mandates and programmes of work within FAO, IMO and UNEP related to marine litter. The Working Group will address data gaps, including those that have been highlighted through the respective relevant governing bodies of these organizations, such as the FAO Committee on Fisheries (COFI), and the IMO's MEPC and the London Convention/London Protocol.

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 abandoned, lost, or otherwise discarded fishing gear (ALDFG) as a particularly damaging form of sea-based marine litter, in order to inform and advance interventions. The terms of reference (ToR) for WG 43 are as follows:

Workstream 1

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

- fishing operations;
- aquaculture;
- shipping;
- dumping of waste and other matter at sea; and
- other sea-based sources (e.g. recreation).

ToR 2, Estimate the relative contribution and impacts of different sea-based sources of marine litter.
ToR 3, Analyze 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.
ToR 4, Assess data gaps, as identified under ToRs 1 to 3, and prioritize for further work.

Workstream 2

ToR 5, Identify ALDFG hotspots.
ToR 6, Quantify the environmental, social and economic impacts of ALDFG.
ToR 7, 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 and subsequent reports, 'sea-based marine litter' is any form of man-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 harbors, 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 to research and fact-finding

This report represents progress made by WG 43 to date, June 2019 - May 2020. WG members have conducted thorough reviews of the published scientific literature and unpublished "grey" literature (e.g. technical reports, white papers) on fishing, aquaculture, shipping, ocean dumping, and other at-sea activities (e.g. recreational fishing, boating, marine research) as sources of marine litter. 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 to date 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.

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 ToRs 1 and 2, these large topics would be taken up by subgroups to optimize efficiency and avoid duplicative work. The Working Group 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 on January 29, 2020.

This second interim report builds on content initially presented in the first interim report. Herein, WG43 fully addresses Term of Reference (ToR) 1, Identify sources of marine litter from sea-based sources, including but not limited to fishing operations, aquaculture, shipping, dumping of waste and other matter at sea; and other sea-based sources. This second interim report also presents new and further work on: ToR 2, Estimate the relative contribution and impacts of different sea- based sources of marine litter; ToR 4, Assess data gaps as identified under ToRs 1 to 3 and prioritize for further work; and ToR 6, Quantify the environmental, social and economic impacts of ALDFG. Terms of Reference 3, 5, and 7 (see Section 1.2.2 for detail) will be addressed in the final technical report.

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2 FISHING AS A MARINE LITTER SOURCE

2.1 Background and Introduction

The Working Group conducted an extensive literature review to identify sources, levels, impacts, preventative measures, knowledge gaps and research priorities for 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 information available about ALDFG sources, levels, impacts and preventative measure are cited to their original publications.

2.1.1 Defining abandoned, lost or otherwise discarded fishing gear (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). Because abandoned, lost or otherwise discarded fishing gear (ALDFG) is a major component of sea-based marine litter, the Food and Agriculture Organization of the United Nations (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). 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.
- The term "derelict fishing gear" is synonymous with ALDFG, but does not imply how the gear ended up in the sea without control by a fisher.

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, including the full complement of gear components (e.g. a complete gillnet with leadline, corkline, mesh and marker buoys); a portion of a gear item with one or more of the gear components present (e.g. a piece of net mesh 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 mesh from a net, or a foam marker buoy from a pot).

2.1.2 Fisheries, fisher populations, and fishing fleets

Global Capture Fisheries Production

In 2016 global fish production reached a peak of 171 million tonnes, with 53% of production from capture fisheries and 47% from aquaculture. Approximately 88% of total production was for human consumption. Capture fish production totaled 90.9 million tonnes, with the marine sector comprising

87.2% (79.3 million tonnes) and the inland sector 12.8% (11.6 million tonnes) (FAO 2018) (Fig. 2.1). Overall, marine capture production has plateaued since the late 1980s. There has similarly been no substantial growth in inland capture production over the last seven years. A 2% decrease observed in capture fish production from 2015-2016 was compensated for by a 5% increase in aquaculture production (FAO 2018).

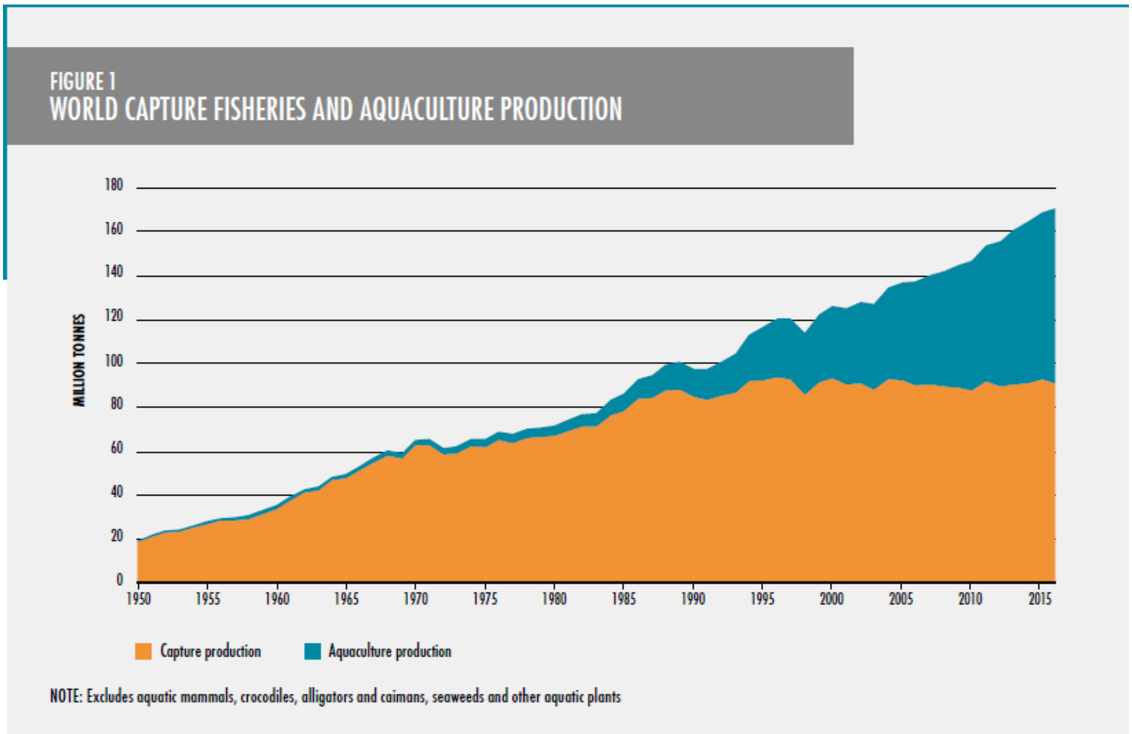

Fig. 2.1. World capture fisheries and aquaculture production. (From FAO 2018).

Capture fisheries comprise artisanal, recreational, commercial and industrial (see Section 2.1.4), 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 2012). No absolute definition exists for other capture fishery categories, and there are no clear-cut boundaries among them.

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] Small-scale fisheries 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 *et al.* 2017; World Bank 2012).

[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).

Large-scale Fisheries

The large-scale fisheries sector is characterized by large high-capacity vessels which may be equipped with on-board 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 boats, 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 many 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 to efficiently yield large catches. While large-scale fisheries account for half of the total global fish production used for direct human consumption, only 10% of the total global capture fisheries work force is represented in the large-scale fisheries sector (World Bank 2012).

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 2016 the global fishing fleet was estimated to include 4.6 million vessels (FAO 2018). Asian vessels comprised 75% of the global feet, with 3.5 million vessels. Engine-powered vessels in comprised 61% of the global fleet, with 2.8 million vessels (FAO 2018). Vessels greater than 24 m length overall (LOA) (i.e. large-scale fishing vessels) comprised only 2% of all motorized vessels, and mostly fished out of ports in Europe, North America and Oceania. Vessels less than 12 m LOA (i.e. small-scale fishing vessels), most of which are undecked, comprised 86% of the global fleet in 2016. The majority of non-motorized vessels are deployed in Asia (1.2 million) and Africa (~0.5 million). The global fishing population in 2016 was estimated to include 59.6 million fishers, of which 67.3% (40.3 million) were engaged in capture fisheries and the rest in aquaculture (FAO 2018). Approximately 85% of fishers were based in Asia, 10% in Africa, and 4% in Latin America and the Caribbean region combined. Women accounted for approximately 14% of all fishers in 2016.

2.1.3 Fishing gear: Types and components

The types of fishing gear examined in this report will follow to the extent possible the International Standard Statistical Classification of Fishing Gear (ISSCFG) as adopted by the FAO Coordinating Working Party on Fishery Statistics at its 25th Session held in Rome in October 2010 (ISSCFG 2010). 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 (Table 2.1).

While the ISSCFG provides useful, broad categorical terms and descriptions for fishing gears globally, there are significant numbers of fishing gear sub-gear types employed by fishers around the world. These more specific gear types and variations often originate from traditional fishing cultures, 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.

Fishing gear components that contribute to the global ocean burden of marine litter can be generally categorized as follows:

- Netting, which is largely comprised of mono- or multifilament fiber 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, comprised of a variety of non-biodegradable polymer materials, including polypropylene (PP), PE, ultra-high molecular weight polyethylene (UHMWPE) and PA.
- Floats and buoys, commonly comprised of PE, acrylonitrile butadiene styrene (ABS), expanded polystyrene (EPS) 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	Sub-gear types	Gear characteristics	Operational characteristics	Material types[1]
Surrounding Nets	Purse seines, Surrounding nets	**General:** Differentiated by type of gear characteristics, e.g. with or without cod-ends (or bunts). Floating line with floats, sinking line with sinkers, pulling line ***Purse seines:*** Main body, a shoulder and wing nets, cod-end (or bunt) or harvest section nets. Purse line with purse rings.	Differentiated by type of fishing operation, e.g. single-boat or two-boat operated	**General:** Lines: polymer fibres, e.g. PP, PE, UHMWPE, PA. Plastic floats along floating line; lead sinkers along sinker line. ***Purse seines:*** Net mesh: woven polymer fibres, e.g. PA/nylon, PES. Iron or brass purse rings.
Seine Nets	Beach seines, Boat seines	Long wall nets with floating and sinking lines. Some use cod-end(s) or bunt(s) ; if employed, single cod-end or multiple cod ends (bunt(s)).	Differentiated by whether they are deployed by a boat.	**General:** Net mesh: PE, PA. Lines: Floating: PP/PE/PA with plastic floats ; Sinking: fitted with lead block or other sinker materials
Trawls	Beam trawls, Single boat bottom otter trawls, Twin bottom otter trawls, Multiple bottom otter trawls, Semi-pelagic trawls	**General:** Main trawl net body, including a top and bottom panel, and a cod-end. Headline (float line), Footropes (sinker line), Bridle lines. ***Single boat:*** Otter boards are used to spread trawl net.	Differentiated by type of fishing operation, e.g. single or pair boat, bottom or mid-water trawl	**General:** Net mesh: woven polymer fibres, e.g. PA/nylon, PE, UHMWPE. Lines/Ropes: PP/PE/UHWMPE/PA, rubber blocks, ABS, and metal materials such as wire rope and shackles. ***Single boat:*** Otter boards comprised of steel or engineered plastics.
Dredges	Towed dredges, Hand dredges, Mechanized dredges	***Towed dredges:*** Iron frame assembled with a “cutting bar” on the bottom margin with a net bag or chain bag attached. ***Hand dredges:*** Include hook tooth dredges, harpoon dredges, hook dredges,	***Hand dredges:*** Often used in small-scale artisanal fisheries ***Mechanized dredges:*** Hydraulic pumps provide high-pressure water jets for dredging up shellfish	***Towed dredges:*** Iron cutting bar, PE net bag

Gear Type	Sub-gear types	Gear characteristics	Operational characteristics	Material types[1]
		shovel dredges and shovel tooth dredges. ***Mechanized dredges:*** Include same structural characteristics as towed dredges, with additional hydraulic pumps.	buried in shallow seabeds.	
Lift nets	Portable lift nets, boat-operated lift nets, shore-operated stationary lift nets	Relatively simply configured. Meshes, rope lines and vault/lateral poles.	Typically operated for in-shore or near-shore subsistence or recreational activities. ***Boat-operated lift nets:*** Some used in commercial activities, such as stick-held nets for Pacific saury (*Cololabis saira*).	Meshes: PE/PA fibre; Rope lines: PA/ PP fibre, with plastic floats and/or lead blocks for floating and sinking lines; Vault/lateral poles: Natural, plastic or metal.
Falling gear	Cast nets, Cover pots/lantern nets	Hand lines, brail lines, meshes, sinking line (weight rope) with blocks.	Typically, traditional fishing gears used in subsistence or recreational fisheries. Some commercial fishing operations also use boat-operated falling gears with light aggregating cast nets.	Meshes: PA fibres; Sinking line (weight rope): lead blocks. ***Commercial, light-aggregating, boat-operated cast nets:*** PP/PE/PA fibre nets and ropes (with same configuration as traditional cast nets).
Gillnets and entangling nets	Set gillnets (anchored), Drift gillnets, Encircling gillnets, Fixed gillnets (on stakes), Trammel nets, Combined gillnets-trammel nets	Single-walled, two-walled or three-walled. Set gillnets (anchored) and drift gillnets can be a combination of single-walled and two-walled gillnets with trammel nets. Headlines and footropes. Buoys. ***Set gillnets:*** Iron anchors.	Set or drift, surface or bottom.	Netting: Monofilament nylon or multifilament twisted or braided polyethylene, polyester or nylon. Headlines and footropes: PP/PE monofilament ropes combined with plastic floats or lead sinkers. Attachment components: include natural materials and plastic buoys for a variety of gillnets, and iron anchors for set gillnets.

Gear Type	Sub-gear types	Gear characteristics	Operational characteristics	Material types[1]
Traps[3]	Stationary uncovered pound nets; Pots[4]; Fyke nets; Stow nets[5]; Barriers, fences, weirs, etc; Aerial traps	***Traps (all excluding pots):*** Netting, headline with floats, groundrope with sinkers. T frames or beams for spreading trap nets. Trap attachments include an anchor, piles and buoy.		***Traps (all excluding pots):*** Netting: normally woven polymer fibres such as multifilament PE. Headline, groundrope: PE monofilament ropes with plastic floats and lead sinkers. T frames or beams: Plastic or steel pipes, or natural wooden or bamboo posts. Trap attachments: anchor: iron; Piles: Natural wooden or bamboo; Buoy: Plastic.
Hooks and lines	Hand-operated pole-and-line, Mechanized lines and pole-and-lines, Set longlines, Drifting longlines, Vertical lines, Trolling lines	***Longlines:*** Mainline, branchlines. Hooks. Floats. Sinkers.		***Longlines:*** Mainline and branchlines: PA monofilament fibres; Hooks: combination of steel and plastics; Floats: Plastics; Sinkers: Metallic lead.

Table 2.1: Major gear types, characteristics and composition (ISSCFG).

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

[3] For the purposes of this report, the term "trap" or "traps" will be used as the first-level gear classification that refers to the group of gear including stationary uncovered pound nets (e.g. large fish traps, Japanese set nets, etc.), pots, fyke nets, stow nets, barriers, fences, weirs and aerial traps.
[4] The terms "pot" and "trap" are often used interchangeably in fisheries literature and regulations. The ISSCFG categorizes "pot" as a second-level gear type under "trap" and defines "pots" as "transportable box-like or basket-like enclosures designed to capture fish by attracting them to the pot and luring them inside through one or more 'one-way' entrances" (Thomsen *et al.* 2010). For the purposes of this report, the term "pot" or "pots" will be used for such fishing gear regardless of the term used in the original literature, except in the reference list where the original title will be kept.
[5] While not included in the ISSCFG, the stow net category can be expanded to include more specific types of stow nets distinguished by gear characteristics (single/two/multiple anchor(s), single/two/multiple pile(s)), operational characteristics (seabed anchored or on boat), and the style in which the net is spread (stick, stretch rope, frame, beam).

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, ALD hook and line gear cannot always be easily categorized and/or distinguished by sector without analysis of other factors related to the ALD hook and line gear (e.g. region, location, size, configuration, 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, making it more easily distinguishable as recreational.

2.1.5 Fish aggregating devices (FADs)

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 areas or coastal areas or drifting (dFADs) following deployment in open seas. Drifting FADs are often equipped with electronic buoys and satellite-tracked by owners from a vessel or from the shore.

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 Voluntary Guidelines for the Marking of Fishing Gear (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 (unsubscribed).
- 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.

2.2 Causes for abandonment, loss or discard of fishing gear

There are many causes, unintentional and deliberate, for fishing gear abandonment, loss, or discard in the marine environment. ALDFG results from a range of environmental, conflict-based, management-related or operational causes, and the frequency and magnitude of ALDFG events vary across fisheries and regions. Gear can be lost on a regular or consistent basis as a result of the normal use of gear (e.g. hook bite-offs in longline fisheries). Gear can also be lost episodically or catastrophically when an irregular situation occurs during normal fishing operations (e.g. an extreme weather event or multiple user convergence on fishing grounds due to a management change). ALDFG can include a complete gear item of any type, or a portion of a gear item with or without one or more gear components still present (e.g. section of net mesh, with or without a lead line, or a rope and buoy). The relative size and composition of gear components that make an ALDFG item can indicate the cause of that item becoming ALDFG.

The potential for fishing gear to become ALDFG will depend on the geographic, operational and gear-type context, such as the depth where fishing occurs, gear size, soak times, and whether the gear contacts the seafloor or other obstacles. For example, intuitively speaking, bottom trawl gear and towed dredges are more likely to become ALDFG compared to mid-water 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 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. 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.* 2019).

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 plays a significant role in the amount of gear loss 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 both 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 (Akiyama *et al*. 2007; Al-Masroori 2002, Al-Masroori *et al*. 2004; Antonelis 2013; Ayaz *et al*. 2010, CFCL 1994, Cho 2011, Erzini *et al* 2008; FANTARED 2003, FAO 2016; Gilman 2015; Hareide *et al*. 2005; Jones 1995; Kim *et al*. 2016; Laist 1995; Long *et al*. 2014; Matsuoka 1997; Matsuoka *et al*. 2005; Ralston 1984; Ramirez *et al*. 2008; Revill and Dunlin 2015; Santos *et al*. 2003; Uhrin 2016; Uhrin *et al*. 2014; Wibowo *et al*. 2017, Thomas *et al.* 2020). When gear is snagged on seafloor obstructions, fishers may attempt to recover onto the vessel deck as much of the gear item 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 (Al-Masroori 2002; Al-Masroori *et al*. 2004; Arthur *et al*. 2014; Ayaz *et al*. 2010; Barry 1983; Bilkovic *et al*. 2016; Breen 1989; Erzini *et al*. 2008; FAO 2016; Gilman 2015; Guillory *et al*. 2001; Hareide *et al*. 2005; Kim *et al*. 2014; Macfadyen *et al*. 2009; Maufroy *et al*. 2015; Ozyurt *et al*. 2008, 2012; Revill and Dunlin 2015; Thomas et al 2020). Strong currents and/or 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 (Antonelis 2013; Bilkovic *et al*. 2016; Drinkwin 2016). 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 items (CEE 1987; FAO 2016; Goto and Shibata 2015; Lewis *et al*. 2009; Macfadyen *et al* 2009; Mathews and Uhrin 2009; NCDENR 2013; Uhrin 2016). In colder regions sea ice can drag static gear, cut buoy lines and force buoys underwater, resulting in gear damage and losses (CFCL 1994; Laist 1995; Long *et al*. 2014; Mallet *et al*. 1988; Weber 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 (FAO 2016).

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. Right whale entanglements in United States lobster pot fisheries, and more recently humpback, grey, and blue whale entanglements with vertical lines in the Dungeness crab fisheries on the West Coast, have raised serious concerns about wildlife impacts due to 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 (Richardson *et al*. 2019). Distinguishing between whale entanglements originating from active gear and ALDFG is a current knowledge gap described in Chapter 7 of this report. Other examples of wildlife interactions causing ALDFG include large sharks breaking longlines, gillnets and marker buoy gear (Anderson and Waheed 1990; Campbell and Sumpton 2009), and sea lions puncturing inflatable marker buoys (High and Worlund 1979).

2.2.2 Conflicts with gear

Gear conflicts primarily occur in areas where there is a high concentration of fishing activities. Passive gear such as pots and set gillnets are particularly prone to being towed away or extremely fouled, either intentionally 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 (Antonelis *et al*. 2018; Drinkwin 2016; Kim *et al*. 2014a). 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 (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 1987; NRC 2013; 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; NRC 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 (Al-Masroori 2002; Antonelis *et al*. 2011; Antonelis 2013; Antonelis *et al*. 2018; Bilkovic *et al*. 2014, 2016; Breen 1989; Drinkwin 2016; Long *et al*. 2014; Macfadyen *et al*. 2009; NRC 2013; NRC 2018; Sumpton *et al*. 2003).

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 gear 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; Guillory et al 2001; Hareide et al 2005; Hong et al 2017; Macfadyen *et al*. 2009; Matthews and Glazer 2010). (Additional discussion of 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 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, 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 illegal, unreported and unregulated (IUU) fishing. ALDFG arising from IUU arise from deliberate failures of communication among fishers and resource users; gear abandonment due to conducting fishing operations in marginal areas, in poor weather or at night to conceal activity, and aversion to being caught illegally fishing, or with illegal fishing gear onboard should inspection authorities approach the vessel (CFCL 1994; FAO 2016; Gilman et al 2015; Hareide et al 2005; Macfadyen *et al*. 2009; Masompour et al 2018; Richardson *et al*. 2018).

In some parts of the world certain fisheries management measures and regulations may unwittingly contribute to the problem of ALDFG. For example, in some parts of the United States, 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, a 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 (Fishing for Litter).

2.2.4 Operational losses and operator error

ALDFG often simply results from normal fishing operations onboard a vessel or from common user 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). Hooks and parts of branch lines on longline gear are frequently bitten off by target and non-target species (Richardson *et al.* 2019; 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; GAO 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 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 competency, experience, and knowledge. 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 knowledge 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; NRC 2013; NRC 2018; Perry *et al*. 2003).

2.3. Quantities and impacts of marine litter from fishing

2.3.1. Quantities of ALDFG from fishing

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. Because fishing gears are custom designed to catch specific target species that can vary significantly across geographic areas, 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 *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; Bilkovic *et al*. 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 2011; Barry 1983; Breen 1989; Northup 1978; Paul *et al*. 1994; PMFC 1978; Tegelberg 1970); gillnets and entangling nets, and pot and trap losses in Turkey (Ayaz *et al.* 2004; Ayaz *et al.* 2010; Ozyurt *et al*. 2008; Ozyurt *et al.* 2012; Tasliel 2008; Yildiz and Karakulak 2016); and gillnet and entangling net losses in Europe and the United Kingdom (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 these studies around quantitative amounts of ALDFG are important and relevant in their local contexts, large knowledge gaps remain concerning amounts and rates of ALDFG on larger 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), line losses (handlines and pole-lines) and trawl net losses. Most ALDFG studies summarizing quantitative 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; Chopin *et al*. 1995; Macmullen *et al*. 2002; Macfadyen *et al*. 2009; NRC 1990; O'Hara and Ludicello 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.

The first effort to rigorously statistically quantify a global estimate for ALDFG was recently completed (Richardson *et al*. 2019a) (Fig 2.2). A total of 68 publications from 1975-2017 that included quantitative estimates for fishing gear losses over specified time intervals, requiring that ALDFG estimates be time-bound to allow for rate estimations, were reviewed. Key gear characteristics and operational and environmental contexts that influence gear losses were identified. Literature reviewed spanned 32 countries and territories across the Atlantic, Indian, Pacific and Southern Oceans and the Baltic, Caribbean and Mediterranean Seas. 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).

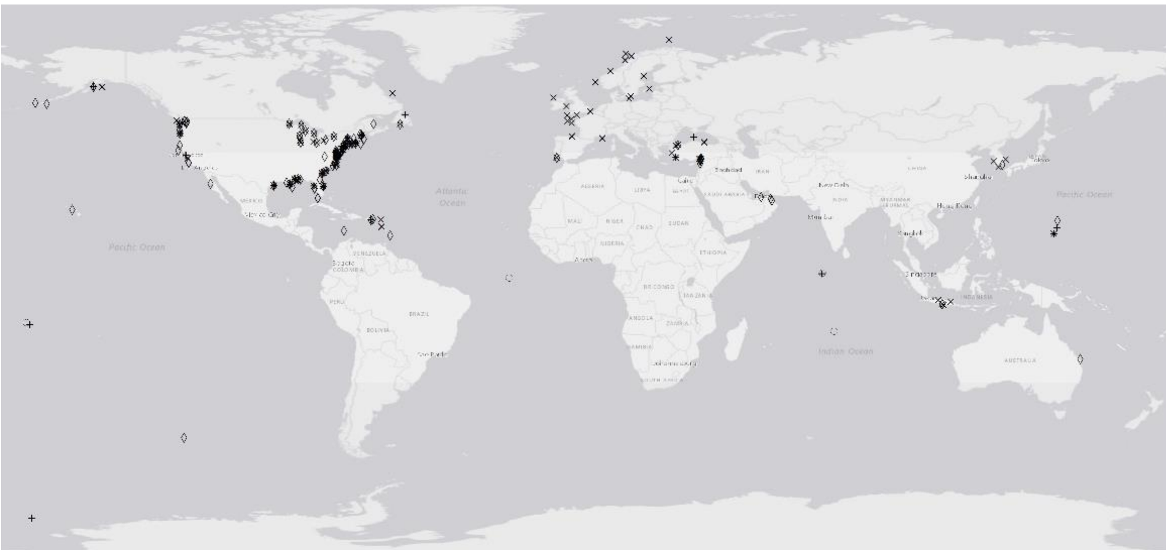

Fig. 2.2. Geographic areas for studies included in our analyses. Studies focusing on net fisheries are indicated by X; traps: ◊, lines: ○, fish aggregating devices (FADs) (from Richardson et al 2019).

The Richardson *et al.* (2019) study acknowledges that while estimates should be applied conservatively, recognizing the limitations of the data available for review, it presents opportunities for extrapolation and 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, Dagteking et al 2018, Erzini et al 2008, Maufroy et al 2015, Ozyurt 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.

Net Type	**Average Proportion of Net Loss**	**Lower 95% CI**	**Upper 95% CI**
Gillnets and Entangling Nets	0.058	0.050	0.065
Drifting Gillnets	0.031	0.027	0.035
Set and Fixed Gillnets	0.084	0.073	0.095
Hard Bottom	0.027	0.021	0.033
Soft Bottom	0.072	0.062	0.083
Mixed Bottom	0.049	0.042	0.057
Bottom Type Unknown	0.19	0.17	0.21
Miscellaneous Nets	0.012	0.008	0.016
Purse Seines (net fragments)	0.066	0.059	0.073
Seine Nets (net fragments)	0.023	0.019	0.028
Trawl Nets (net fragments)	0.12	0.11	0.14
Midwater Trawls	0.070	0.058	0.082
Bottom Trawls	0.18	0.16	0.19
Soft Bottom	0.10	0.094	0.11
Bottom Type Unknown	0.26	0.24	0.28
All Net Types	0.057	0.050	0.064

Table 2.2. Average proportion of nets lost globally. Major gear types are presented in bold, with corresponding sub-gear types and bottom types below. (from Richardson *et al*. 2019)

Trap Type	**Average Proportion of Trap Loss**	**Lower 95% CI**	**Upper 95% CI**
Pots and Traps	0.19	0.18	0.20
Hard Bottom	0.25	0.24	0.26
Soft Bottom	0.18	0.18	0.19
Mixed Bottom	0.22	0.21	0.22
Bottom Type Unknown	0.11	0.11	0.12
Fyke Nets	0.041	0.038	0.045
Hard Bottom	0.059	0.055	0.064
Bottom Type Unknown	0.024	0.022	0.025
Pound Nets	0.026	0.024	0.028
All Traps	0.086	0.082	0.089

Table 2.3. Average proportion of traps lost globally, including pots and traps, fyke and pound nets. Major gear types are presented in bold, with corresponding bottom types below. (from Richardson *et al*. 2019)

Line Types	Average Proportion of Lines Lost	Lower 95% CI	Upper 95% CI
Handlines	0.23	0.22	0.24
Pole-Lines	0.65	0.62	0.69
Longlines	0.20	0.19	0.22
Hooks, longlines	0.17	0.16	0.18
Trolling Lines	0.22	0.20	0.23
All Line Types	0.29	0.28	0.31

Table 2.4. Average proportions for lines lost globally, including handlines, pole-lines, longlines and hooks from longlines and trolling lines. Average lower and upper 95% confidence intervals (CIs) are presented. (from Richardson *et al.* 2019).

On a final note, regarding the amount of ALDFG being deposited in the world's ocean, it is worth noting the recent dramatic increase in attention this are of inquiry has been given by researchers from government agencies, academia, non-governmental and other organizations, as reflected by the fact that 61% of ALDFG-related studies reviewed for this report were published in the last10 years (Appendix 1).

Despite the fact that large numbers of people fish recreationally, an absolute or even estimated quantity of ALDFG produced by recreational fishing does not exist. Annual estimates of lead fishing tackle sold by wholesalers, which could provide a rough estimate of lead 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 of America and Canada combined (Rattner *et al.* 2008; Haig *et al.* 2014), but because many anglers purchase new gear as surplus (Radomski *et al.* 2006), these numbers do not equate with quantities deposited in the marine environment (Haig et al. 2014). Research conducted in the United States reported that shoreside anglers lost 0.18 lead sinkers/hour and 0.23 hooks and lures/hour (Duerr 2019); vessel-based anglers in the Great Lakes region reported loss rates of 0.0127 lures/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).

2.3.2. Historical Estimations of ALDFG [Text Box]

The oft-referenced estimate that 640 000 tonnes of ALDFG are lost annually to the world's ocean reference likely originated from a now 45-year old study by the National Academy of Sciences (NAS) 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 6 400 000 tonnes of litter enters 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 percent of the NAS study estimation of 6 400 000 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 NAS study roughly estimated the portion of marine litter comprised of gear from commercial fisheries (as distinct from other categories of marine litter coming from fishing

vessels) to be 1 350 tonnes per year[6]. 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.

2.3.3. Impacts of litter from fishing

Economic impacts

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 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 to replace lost gear (Arthur *et al*. 2014; Bilkovic 2014; Butler *et al*. 2013; NOAA 2015).

Global estimates on economic costs of ALDFG are not available. However, USD 831 million in landings was estimated to be recuperated annually by removing less than 10% of the derelict pots from major crustacean fisheries (Scheld *et al*. 2016). 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 more 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-Masoori *et al*. 2004). An experimental ghost fishing study in the Cantabrian region of Spain estimated cumulative commercial monkfish catches from ghost fishing 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 over several 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, United States, which represented an economic loss of over USD 744 000 or 4.5% of the 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 United Kingdom of Great Britain and Northern Ireland.

[6] 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 United States Department of Commerce.

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 United Kingdom gillnet fishery to estimate the costs of a hypothetical EU gillnet retrieval programme. Their model showed an overall benefit/cost 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 represent the difference between EUR 46 500 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; over the course of four years, USD 42 373 was directly paid to the commercial partners of a lost gear recovery program (Sullivan *et al*. 2019). 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.

Impacts on target and non-target resources

Most fishing gears are designed to achieve selectivity in catching targeted species; however, this attribute is adversely affected 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. 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 for its influence on community structure of intertidal marshes, is at high risk of mortality due to impacts surrounding ALDFG and ghost fishing. ALD blue crab traps on the United States East Coast and 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).)

Impacts on marine wildlife

Documentation of incidences of marine wildlife entanglement in and ingestion of marine litter have doubled from 1997 to 2015, from 267 to 557 among all groups of wildlife species (Kühn *et al.* 2015). Marine wildlife entanglement and ingestion rates for marine taxa are estimated to be 100% for marine turtles (7 extant species), 66% of marine mammals (123 extant species) and 50% of seabirds (406 extant species) (Kühn et al 2015). One-hundred ninety-two 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 by ALDFG (e.g. Adimey *et al.* 2014; Ainley 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 and 2016). 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 vs. active gear at the time of entanglement (becoming ALDFG after entanglement) is not known. 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). These comprised 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 especially from 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 ingestion, which require detailed analyses including dissection of gastrointestinal tracts to determine the material ingested (Richardson et al 2019). 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 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 (Dau *et al*. 2009; Butterworth *et al*. 2012; Haig *et al*. 2014; Hong *et al.* 2013; Rattner *et al*. 2008; Raum-Suryan *et al*. 2009; Reinart *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 entangling seabirds can cause loss of body parts or prevent birds from flight, nesting, and/or foraging activity (Dau *et al.* 2009; Butterworth *et al*. 2012). Invertebrates, such as Dungeness crab and red rock crab, have been found mortally entangled in large masses of mixed recreational fishing gear (monofilament line, lures and lead weights) near popular fishing docks in the Puget Sound, United States (WA DGDB 2019), with similar impacts observed in horseshoe crabs in New Jersey, United States (Save Coastal Wildlife 2019).

Impacts on 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 submerged in sediments, causing mortality (Erftemeijer *et al*., 2012; Rogers, 1990). In a study examining the impact of ALDFG on corals around Koh Tao, Thailand, 143 ALDFG items were observed to have caused tissue loss, damage and fragmentation for 340 corals underneath and 1 218 corals close to the ALDFG items (Ballesteros *et al.* 2018). 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 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 – 2008 noted damage due to lost fishing nets and lines on reefs in all the countries where investigations were carried out (Tanzania, Mozambique, Kenya, Seychelles, Mauritius, Sri Lanka) (Linden *et al.* 2002; Obura *et a.l* 2008; Souter *et al*. 2000, Souter and Linden 2005). Lost hook and line gear have 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 impacts. Similar ALDFG impacts by other fishing gear types on the coral reefs of the Northwestern Hawaiian Islands were documented by Donohue *et a.l* (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 (Edwards *et al.* 2020; Katsavenakis *et al*. 2014; Kiessling *et al.* 2015; Link *et al.* 2019; Pham *et al.* 2012; Sweet *et al.* 2019).

Social impacts

An understanding of the socio-economic 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 socioeconomic 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).

2.3.4. 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 United States Atlantic Coast (Bilkovic *et al*. 2016). The Chesapeake Bay is an 11 600 km^2 estuary on the United States Mid-Atlantic Coast situated between the states of Virginia and Maryland. While a variety of fisheries occur 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 x 0.6 m x 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.

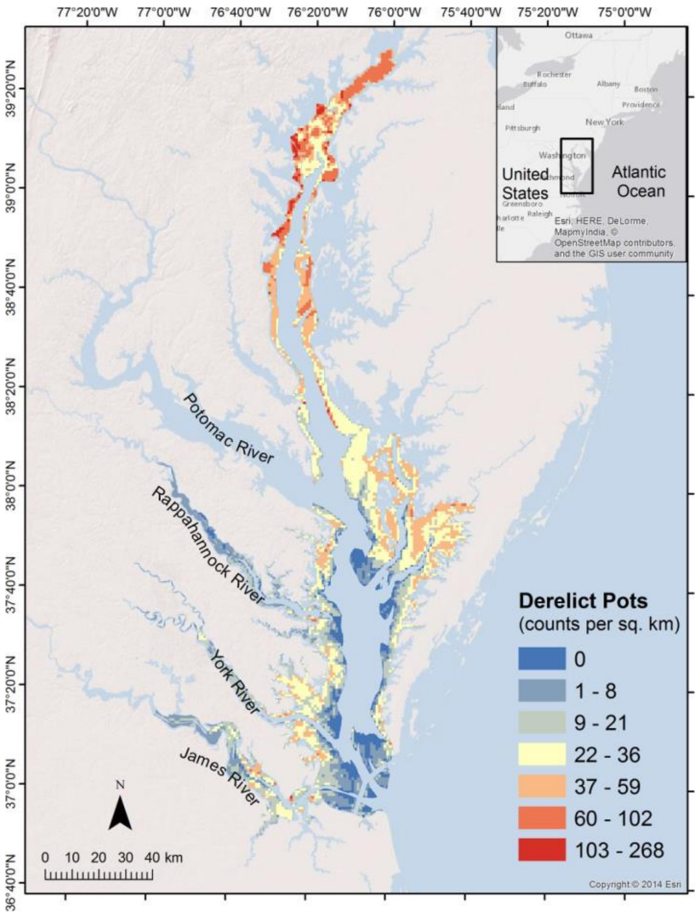

Fig. 2.2: Abandoned, lost and otherwise discarded crab pot densities and spatial distribution in Chesapeake Bay (Bilkovich et al 2016)

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 ALD pots was estimated (Figure 2.2). 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 observed to entrap over 3.5 million white perch and nearly 3.6 million Atlantic croaker throughout the Bay each year. Habitat impacts on submerged aquatic vegetation and oyster beds were also observed but were relatively less significant compared to the ALD pot impacts on marine species.

Economic analysis of ALD pots impacts on Chesapeake Bay blue crab and the results of ALD pot removal 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, blue crab harvests increased by 394 kg 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.

2.4. Chapter Summary [Text box]

- Capture fish production was 90.9 million tonnes in 2016, with the marine sector comprising 87.2% (79.3 million tonnes). In 2016 the global fishing fleet was estimated to be 4.6 million vessels. Asian vessels comprised 75% of the global feet, with 3.5 million vessels. Globally, 59 600 000 fishers were estimated to be engaged in fisheries in 2016, of which 67.3% (40.3 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, 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 expanded polystyrene.

- There are many causes, both unintentional and deliberate, for the generation of abandoned, lost or otherwise discarded fishing gear (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. 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.

- Large 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 amount of ALDFG entering the world's ocean each year. A 2009 UNEP/FAO estimate posited 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.

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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 recently produced reports on the subject of aquaculture-derived marine litter provide excellent summaries of the available knowledge base (Huntington 2019; Sandra *et al*. 2019). 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 the global ocean litter burden as is possible.

Marine aquaculture takes place entirely in the ocean, whereas coastal aquaculture is practiced in or immediately adjacent to coastal areas (e.g. in estuaries and lagoons). For the purposes of this report, and as a reflection of available global-level data, a distinction between sea-based and coastal aquaculture as sources of marine litter will not be drawn; for the remainder of this report, "aquaculture" will refer to ocean and coastal farming, and this report will 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 demand for seafood, as scientific research elucidates substantial health benefits of a fish-based diet and sociocultural dietary preferences shift. As a result of overharvest, wild fish stocks are in global decline. In contrast, aquaculture production has been on a steady rise of approximately 5.8% annually since the start of the 21st Century (FAO 2018), with double-digit growth in some countries (particularly African nations). As of 2016, 202 nations were engaged in aquaculture, producing 110.2 million tonnes of fish and shellfish (80 million tonnes) and aquatic plants (30.1 million tonnes) for human consumption, with an estimated first-sale value of USD 243.5 billion (FAO 2018) (Fig. 3.1). In 2016, farmed seafood included 54.1 million tonnes of fin fish, 17.1 million tonnes of molluscs, 7.9 million tons of crustaceans, and approximately 940 000 tonnes of other animals (e.g. sea cucumbers, urchins). Aquaculture now contributes nearly half (46.8%) of the world's total global output from fisheries and aquaculture combined, with growth of aquaculture in China contributing substantially to this trend. In 2016, 37 nations accounting for half of the world's human population were producing more farmed than wild-caught fish.

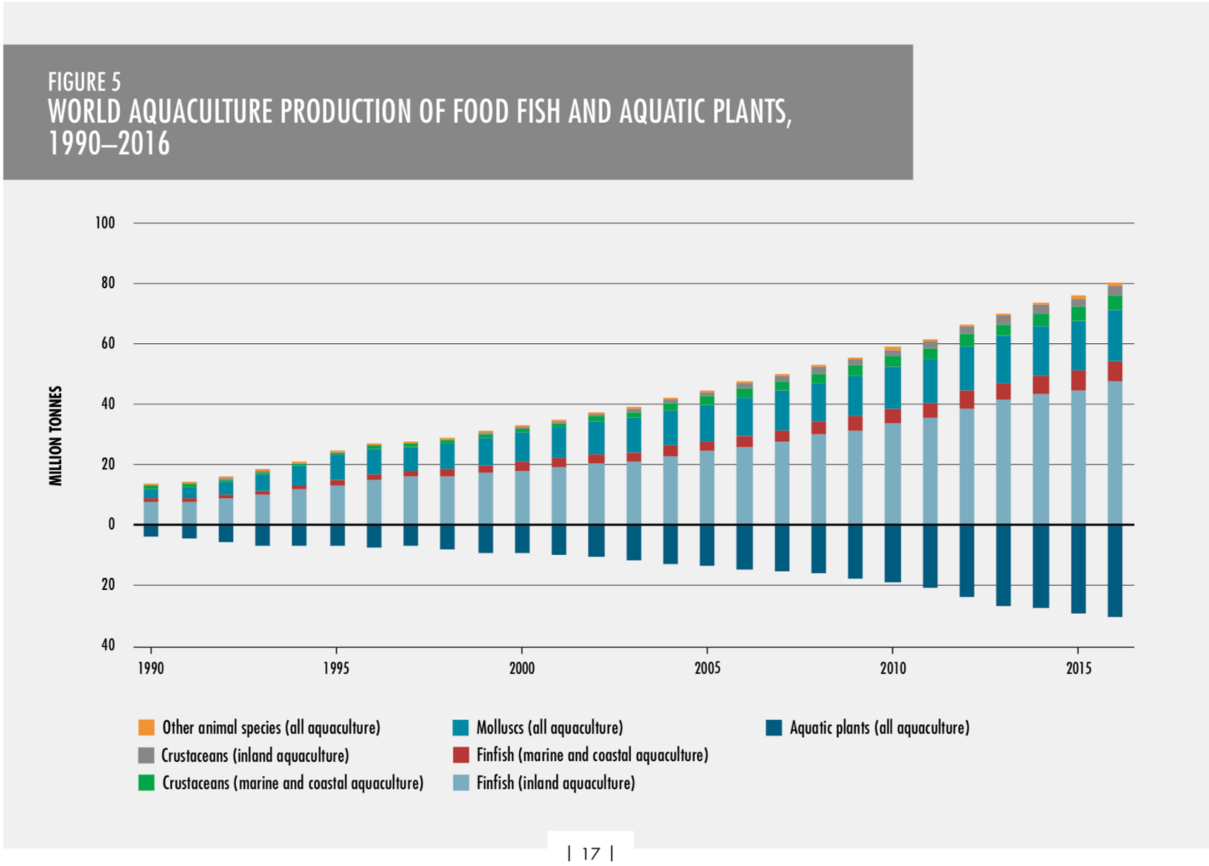

Fig. 3.1. World Aquaculture Production of Food Fish and Aquatic Plants (from FAO 2018).

While inland (land- or freshwater-based) aquaculture is providing an increasing proportion of the world's farmed food fish (64.2%), coastal and marine aquaculture remain predominant systems for food fish production in many ocean basins and coastal nations (FAO 2018). 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. 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), Viet Name, 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 plants (primarily seaweeds) for both human consumption and extracts (e.g. carrageenan, a thickening agent used in foods and beverages) has doubled from 1995 to 2016, reaching over 30 million tonnes in 2016; most of this growth in seaweed farming has occurred in Indonesia. Open-ocean finfish farming is primarily centered on salmon, trout, tuna, seabass, seabream, and yellowtail production, while coastal aquaculture facilities mainly produce of shellfish (mussels, oysters, clams), shrimp and marine plants (seaweeds).

3.3 Aquaculture as a source of marine litter

3.3.1 Aquaculture equipment and plastics

A significant portion of gear utilized for aquaculture in both marine and freshwater systems is comprised of 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 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 suspends in the water column. Sea cages are enclosed and comprised of rigid flotation materials, are either partially of fully submerged, and are anchored to prevent drift. In contrast, shellfish culture equipment is typically comprised of 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 (for mussels and oysters). Bottom-cage systems are also used (e.g. for clams, oysters, scallops). All systems incorporate ropes, buoys, mesh bags, and anti-predator netting to a certain extent. While crustaceans (shrimp) are mostly grown in land-based, plastic-lined ponds adjacent to coasts where seawater can be pumped into the ponds, crustaceans are also grown out in plastic mesh bags suspended in shallow estuarine and lagoon environments.

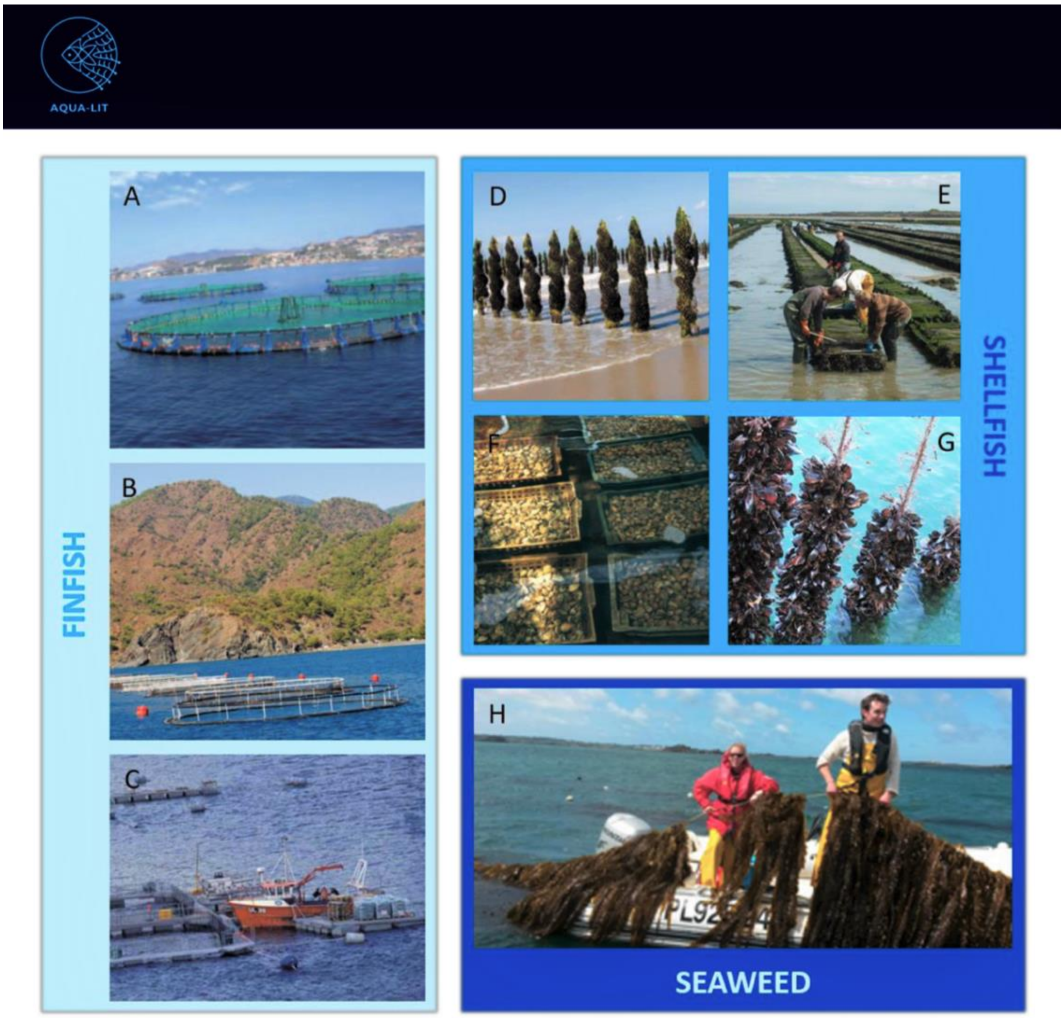

Figure 5: Examples of European marine aquaculture farms. The collage above depicts several types of aquaculture performed in the North Sea, Baltic Sea and Mediterranean Sea. Nevertheless, aquaculture types can differ per region and country. Besides this, various shellfish farming techniques can be used for the cultivation of multiple shellfish species. A) Net cages for cultivation of seabass; B) Net cages for cultivation of seabream; C) Net cages for cultivation of Atlantic salmon; D) Pole culture for mussel cultivation; E) Bottom culture for oyster cultivation; F) Bottom culture for clams farming; G) Suspended rope culture for mussel cultivation; and H) Suspended rope seaweed farm (Sources: s.Pro, CNC France, GAA and European Commission).

Fig. 3.2. Examples of marine aquaculture operations (from ASC 2019).

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. Forms of plastic used in aquaculture include: expanded polystyrene (EPS, or "styrofoam") 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 (Fig. 3.2).

To better understand aquaculture as a source of marine litter, the Aquaculture Stewardship Council (ASC) recently 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 and 3.2).

Table 3: Overview of different plastics used in aquaculture

Material	Use in aquaculture	Characteristics	
		In use / recyclability	When lost
Acrylic (PMMA)	Incubation jars, containers, laboratory equipment	Lightweight, shatter-proof thermoplastic alternative to glass. Recyclable.	Slow levels of abrasion.
Expanded polystyrene (EPS)	Fish boxes, insulation material, floatation	Extremely light and can be formed into specific shapes. Mainly expanded polystyrene (EPS) used to fill floatation devices (inc. net collars), either by extrusion (within a plastic or metal shell) or as blocks. Is very light and has high insulation properties. Recyclable (see NOWPAP MERRAC, 2015)	Very buoyant, so accumulates on beaches. Easily abrades and breaks into smaller and smaller pieces[4].
Fibre-reinforced plastic (FRP)	Fish transportation tanks, boats, floats, plastic gadgets	Includes glass-reinforced plastic (GRP). Difficult to recycle.	Will splinter in time.
High-density Polyethylene (HDPE)	Floats for cages, twines and ropes, net webbing, monofilament for making nets and hapas, storage tanks, pipes and fittings for water supply, aeration, drainage, pools for water holding, tubs, buckets, trays, basins, and different components of aquaculture implements, laboratory wares	Tough, chemically resistant rigid thermoplastic. Linings 12-100 mm. Commonly recycled.	Will fragment, abrade and weather leading to secondary microplastic formation[5].
Linear low-density polyethylene (LLDPE)	Pond liners	Very flexible, but strong plastic. Linings 0.5 - 40 mm.	Will fragment, abrade and weather leading to secondary microplastic formation.
Low-density polyethylene (LDPE)	Small-scale pond linings, greenhouse canopy poly cover, fish seed transportation carry bags	The most common type of plastic sheeting. It is a flexible sheeting form (0.5 - 40 mm). Due to its flexibility is conforms well to a variety of surfaces but is not as strong or dense as some other types of plastic sheeting. Increasingly recyclable.	Will fragment, abrade and weather leading to secondary microplastic formation.
Nylon (Polyamide, PA)	Twine and ropes, fish nets	Strong, elastic and abrasion resistant.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polyethylene (PE)	Rope, fish transport bags	Cheap rope material.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polyethylene terephthalate (PET) or polyester	Rope	More expensive, strong but inelastic, water resistant rope material. Also used to make plastic bottles. Readily recyclable.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polypropylene (PP)	Twines and rope, crates, feed sacks, tubs, buckets, trays, basins, laboratory wares	Reasonably cheap floating rope but abrades fairly easily. Increasingly recycled.	Will fragment, abrade and weather leading to secondary microplastic formation.
Polyvinyl chloride (PVC)	Pipe and fittings, aeration pipeline, hosepipes and fittings, valves, cage floats, cage collars, drums, jerry cans, prawn shelter, fish handling crates, etc.	Tough and weathers well. Rarely recycled. Should not be burnt as releases toxins.	Will fragment, abrade and weather leading to secondary microplastic formation.
Ultra-high molecular weight polyethylene (UHMwPE)	Ropes and nets	Expensive, very light and strong.	Unknown, but stronger than most materials.

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[4] Clean Water Action (2011) | [5] Kalogerakis et al, 2017

Table 3.1: Overview of different plastics used in aquaculture (from Huntington 2019).

Table 2: Plastic use in different aquaculture systems

System	Key plastic components	PMMA	EPS	FRP	HD-PE	LLD-PE	LD-PE	Nylon	PE	PET	PP	PVC	UHMw-PE
Open-water cages and pens	Floating collars (inc. handrails)				✓							✓	
	Collar floatation		✓										
	Buoys (in mooring systems)				✓		✓		✓				
	Ropes (in mooring systems)							✓		✓	✓		
	Net enclosures				✓			✓			✓		✓
	Predator and other nets				✓			✓	✓				
	Feeding systems (pipes & hoppers)			✓	✓							✓	
Suspended ropes / longlines	Buoys (in mooring systems)				✓		✓		✓				
	Ropes (in longlines & mooring systems)				✓			✓		✓	✓		
	Raft floatation		✓		✓								
	Stock containment (nets/meshes)				✓			✓			✓		✓
Coastal and inland ponds	Pond liners				✓	✓	✓						
	Sampling / harvest nets				✓			✓			✓		✓
	Plastic green / poly housing						✓						
	Aerators / pumps				✓							✓	
	Feeding systems (pipes, feeders & trays)			✓	✓							✓	
Tanks (inc. recirculated aquacultu-re systems RAS)	Spawning, incubation & stock holding tanks			✓	✓								
	Pipework (inc. connectors, valves)			✓	✓							✓	
	Office / laboratory fixtures & fittings	✓	✓				✓	✓				✓	

Table 3.2: Types of plastics used in aquaculture equipment and operations (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. plastic mesh screens, mussel socks), especially to bivalve farming.

Expanded polystyrene (EPS) is the most frequently documented form of aquaculture-sourced marine litter in scientific papers and reports. 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 (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 had been the major debris type on Korean beaches in previous decades (Hong *et al*. 2014). 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 buoys are lost or discarded (Chen *et al.* 2018).

Similarly, shellfish culture facilities in southern Chile are believed to be the major source of plastic marine debris: in shipboard surveys conducted in 2002-05, EPS and plastic bags and plastic fragments comprised 80% of floating marine debris documented in the fjords, gulfs and channels of southern Chile (Hinojosa and Thiel 2009). Presence of EPS was attributed to the extensive use of EPS buoys in the mussel farming industry in the northern region. A further study posited that floating marine debris, including EPS, corresponded with the distribution of human activities on the coast, and that floating marine debris concentrations were highest on sections of the Chilean coast where aquaculture activities are most intense (Hinojosa *et al.* 2011). 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 of marine plastic litter (Andréfouët *et al*. 2014).

While there is very little data to substantiate, 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). 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; poor siting, installation and maintenance; and extreme weather events (Huntington 2019). Coastal pond aquaculture is also a high-risk source due to farm de-commissioning (and subsequent degradation due to lack of maintenance) and extreme weather. 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 (AQUA-LIT).

3.4 Quantities and impacts of marine litter from aquaculture

Currently there are no global estimates of 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), including in China, the world's largest aquaculture producer, for which no data are available on marine litter generated by aquaculture operations. Availability of non-scientific data, e.g. claims filed with the aquaculture insurance agencies by operators, is also essentially zero: typically, claims are for stock

losses after extreme weather, disease outbreaks, and/or damage due to unforeseen events (accidents), and therefore insurance claims do not provide quantitative or qualitative data on tonnage of aquaculture gear lost to the ocean as a result of storms or accidents.

What data and assessments do exist are regionally specific. In the European Economic Area, aquaculture-associated gear and debris losses are grossly estimated at 3 000 to 41 000 tonnes annually, and aquaculture debris already in the ocean may be 95 000 – 655 000 tonnes of litter (Sherrington *et al*. 2016). Norwegian aquaculture 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 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. Sherrington *et al.* (2016) extrapolated these figures to estimate that 11 kg of plastic waste is generated for every ton of aquaculture product output in Norway. More recently, Sundt (2018) estimates 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 has used data amassed from the scientific literature as well as publicly available maps and datasets on beach, sea surface, and underwater surveys to estimate the proportion of marine litter (primarily plastic) in the North, Baltic and Mediterranean Seas that is attributable to finfish and shellfish aquaculture (Sandra *et al*. 2019). This study reveals that 14.75% of seafloor debris, 11.25% of sea surface debris, and 4.08% of beach debris is derived from aquaculture operations in these ocean regions, with hotspots in the northwest Adriatic and around Corfu Island.

Plastic debris entering the ocean from aquaculture in Korea was estimated to be 39 700 tonnes of nets, ropes and EPS buoys in 1999 alone (Cho *et al*. 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 buoys are lost or discarded (Chen *et al*. 2018).

3.5. Chapter Summary [Text box]

- Aquaculture production has been on a steady rise of approximately 5.8% annually since the start of the 21st Century, with double-digit growth in some countries (particularly African nations). As of 2016, 202 nations were engaged in aquaculture, producing 110.2 million tonnes of fish and shellfish (80 million tonnes) and aquatic plants (30.1 million tonnes) for human consumption. Aquaculture now contributes nearly half (46.8%) 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 is comprised of plastic. Expanded polystyrene (EPS) is the most frequently documented form of aquaculture-sourced marine litter in scientific papers and reports.

- 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

- Currently there are no global estimates of the amount of plastic waste 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 anywhere in the world.

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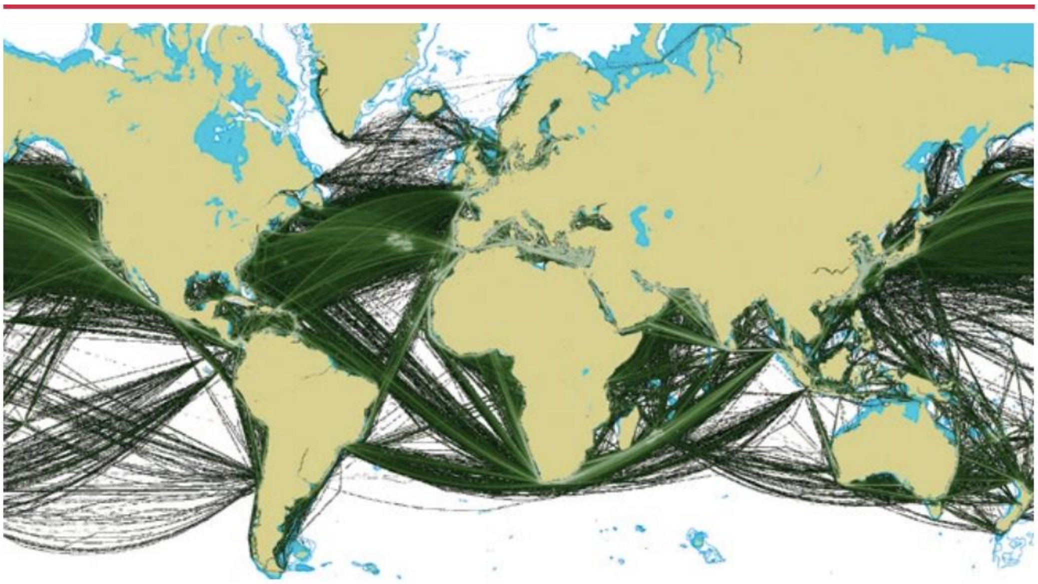
4 SHIPPING AND BOATING AS A MARINE LITTER SOURCE

4.1. Background and introduction

International maritime trade is closely tied to the expansion of the global economy. From 1970 to 2017, global maritime trade increased an average of 3% annually (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. 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 tonnes in 2018 (UNCTAD 2019). 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 cargos (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 (UNCAD 2019). The significant relative decrease in the tanker trade may be due to the relative increase in cargo shipping, or may reflect 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 this report, approximately 53 000 merchant ships are registered by the International Maritime Organization (IMO) globally, comprised of general cargo ships (32%), bulk carriers (22%), tankers (oil, gas and chemicals) (30%) and passenger ships (10%). In early 2018 the total carrying capacity of the world’s merchant fleet was 1.9 billion dead-weight tonnes (dwt), an increase of 62 million dwt from 2017, reflecting an increase of approximately 4% per year during the last five years (2013-18). Except for general cargo ships, all categories of merchant ships increased considerably in tonnage. The most important ship-owning economies account for about 50% of the world’s fleet. These include companies based in Greece (17%), followed by Japan, China, Germany and South Korea. The leading countries for flags of registration include Panama, the Marshall Islands, Liberia, Hong Kong, Special Administrative Region of the People’s Republic of China, and Singapore (Lloyd’s List 2019).



Source: Prepared for UNCTAD by Marine Traffic.
Note: Data depict container ship movements in 2016.

Fig. 4.1. Density of containerships in different parts of the oceans in 2016. Key nodes are in East and Southeast Asia, North America and Western Europe; busiest “choke points” are the Panama and Suez Canals, southern tip of South Africa and Sri Lanka, and the Malacca and Gibraltar Straits.

The rapid expansion in merchant shipping over the last five years has led to more congested shipping lanes, which increases the risk for both accidental and operational impacts to the ocean from shipping (Fig. 4.1). 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). The environmental impacts resulting from shipping include: air and water pollution from daily operations, including chemicals such as oil, sewage, sulphur oxides, nitrogen oxides, and greenhouse gas emissions, as well as particulates and noise; 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).

The global ocean cruise industry has shown remarkable growth, from some four million passengers per year in the early 1990s to an estimated 27 million in 2020, equivalent of an annual growth of nearly 7% (Cruise Market Watch 2019). In 2018 13 new ocean cruise ships with a capacity of more than 33 000 passengers were added to the fleet. Pre-COVID19 pandemic forecasts from the industry indicated that from 2018 to 2020, 37 new cruise ships would add approximately 100 000 to the passenger capacity of the global fleet. However, the pandemic brought the global cruise industry to a virtual halt during the first half of 2020, and it remains to be seen when and to what degree it will recover to pre-pandemic levels in terms of numbers of ships and passengers on the water.

4.2. Types of marine litter from shipping and boating

Large shipping 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.) and sewage are among numerous waste items deposited into the marine environment from merchant ships and cruise liners. These items are most often disposed accidentally through bad handling or unfavorable weather conditions. However, waste on many vessels may be handled inadequately, either due to inadequate storage facilities on board or lack of reception facilities in ports (GESAMP 2016). The shipping industry is a source of microplastics after routine cleaning of ship hulls, and mishandling of cargo comprised of plastic items or accidental spills of industrial resin pellets (GESAMP 2016). 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).

While shipping waste categories, defined in Regulation 1 of MARPOL Annex V, includes food, domestic and operational waste, single-use plastics, cargo residues, incinerator ashes and cooking oil generated during normal ship operations, the analysis around sources of marine litter from shipping presents several challenges that result in an inherent degree of uncertainty. Marine litter is not only composed of a large fraction of unidentifiable items, but also of items which originate from a number of different shipping-related activities (Veiga *et al*. 2016). Recent trends show that stranding of items from merchant shipping is increasing (Ryan *et al*. 2019).

Understanding the different types and categories of marine litter specifically derived from shipping 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 (including fisheries) 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, paints. Certain marine litter items or groups of items found together can indicate shipping litter, such as galley waste, domestic waste from crews, maintenance wastes and lubricants (Fig. 4.2).

Fig. 4.2. Classical litter items originating from shipping. (1) Large rope; (2) piece of pilot stair; (3) Wreck (recreational boating); (4) piece of container; (5) shipping mark; (6) pieces of paraffin; (7) rescue kit (obsolete); (8) oil sampling device; (9) drum(oil); (10) boot; (11) engine oil Filter [Photo credits: L. Hervé, 1 and 2;, IFREMER, 3, Sea-Mer Asso 4, 6-9 and 11; L Colasse, 5, JY Le Tollec, 10].

Some marine litter items are exclusive to shipping sources, such as large ropes, injection gun cartridges, oil drums, light bulbs/tubes, and clinkers. Ship-generated solid waste also includes glass and tin (Jägerbrand *et al.* 2019). More generally, a variety of heavy litter types, likely ship-generated, are found on the seafloor along shipping lanes, including anchors, other pieces of metal from engines, barrels, and cables (Ramirez-Llodra *et al*. 2013). That said, a distinctive characteristic of shipping-related litter is that it may be comprised of items that are used for another purpose (e.g. plastic containers cut to use as bailers or as paint pots; tires 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.

The distribution of marine litter on shore 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) or areas around shipping lanes (Van Gennip *et al.* 2013) that may be more affected by debris from shipping. The issues may be more consequent in protected areas, without any possible control of stranding. In a study in six marine protected areas in the Mediterranean Sea (Liubartseva *et al.* 2019), 55%–88% of stranded litter were attributed to shipping, given the short distance of surveyed areas from shipping routes. The correlation between deep sea litter and shipping routes was also described by Ramirez Llodrat (2013), indicating that litter found accumulated in canyons or bathyal plains with high proportions of plastics has predominantly a coastal origin, while litter collected on the open slope, dominated by heavy litter, is mostly ship-originated, especially at sites under major shipping routes.

Marine litter on the seafloor also includes clinkers, which are residues from coal-burning steamships. In the Mediterranean Sea, data collected through trawling for fish stock assessments indicate that clinker is a very common type of litter, representing up to 28.4% of total litter in weight, at the same level as plastic litter, and mainly located in urban areas and along shipping routes (Garcia Riviera *et al.* 2018)

Paraffin or wax is often used for “stripping” solid residuals in tanks during tank-washing and are included in some marine litter monitoring programs because they are found on beach surveys (OSPAR Commission 2010). In the North East Atlantic, such shipping-related litter items were found in 371 of 2 824 litter surveys performed on 151 different beaches, mainly in the North Sea, with a mean estimated abundance of 14.6 items per meter of strandline (max 738 items/m). Pieces of wax were also commonly found during beach litter surveys in Southern California, Panama, South Korea, Brazil, Spain, Italy, Bulgaria, South Africa, Hawaii, Russia, and even in remote areas (e.g. the Pitcairn Archipelago, Macquarie Island, and Tristan da Cunha) (Suaria *et al*. 2018) and are thereby a useful indicator of tanker shipping as a source of marine litter.

Specifically evaluating the composition of shipping-related litter that is plastic is challenging because very few studies have focused on the question of the amount of plastic that comprises total shipping-related marine litter items. For example, on the remote island of Tristan da Cunha, the stranding of plastic drink 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). By 2009, Asia surpassed South America as the major source of these plastic drink bottles, and by 2018, Asian bottles comprised 73% of accumulated and 83% of newly arrived bottles. The rapid growth of marine debris, coupled with the recent manufacturing of these items, indicates that ships are responsible for most of the bottles floating in the central South Atlantic Ocean. As another example, glass bottles were more often found on the sea floor along ferry lines before they were replaced by plastic cups in the more recent years (Galgani *et al.* 2000).

In a study on pollution incidents reported by observers on fishing vessels in the Western and Central Pacific Ocean from 2003-2015, more than 10 000 incidents were observed (Richardson *et al.* 2017). When the subcategories included under "waste accidentally dumped" were analyzed further and compared to total pollution incidents, plastics were found to make up the largest portion of total pollution incidents at 37% for purse seine and 60% for pelagic long line 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 long line fishing. Expanded Poly Styrene (EPS) and other plastic fish boxes has 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

At sea, ships generate a number of waste streams that can result in discharges of microplastics to the marine environment, including sewage, gray waters, hazardous wastes, oily bilge water and ballast water. Ships also emit pollutants to the air and water. These wastes can all be a significant source of microplastics. Particular types of wastes, such as sewage and gray 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 paints and marine coatings, from grey water management and discharge systems, and transported through ballast waters (Table 4.1).

Ships and other marine structures made of metal are often covered in epoxy-based paint with an overcoat, as epoxy is not resistant to ultraviolet 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 anti-fouling 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, anti-corrosive and anti-fouling compounds. Particle size of material recorded by Chae *et al.* (2015) was generally in the size range of 50-300 µm and was considered equivalent to the general size range of living microplankton, thus having significant potential to be taken up by planktivorous species (IMO 2019)

The polymeric backbone of binding agents in biocidal 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. While microplastics are released from a vessel during normal operations, which may be a relatively small direct source of microplastics, the expansion of in-water cleaning may significantly increase localized microplastics pollution. Sciani and Georgiades (2019) described the in-water cleaning continuum as removal for the prevention of biofouling, using divers or ROVs, applying brushes or water jets, and some with debris capture and treatment

Finally, cruise ships, large tankers, and bulk cargo carriers use a tremendous amount of ballast water to stabilize the vessel 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, while ballast water does not necessarily generate microplastics, ballast water discharges may typically contain microplastics that are then transported across the ocean.

Area	Area subcategory	Release mechanism	Pathways
Wastewater streams		Laundry, shower, wet cleaning, etc.	Wastewater
Outdoor	Underwater section of hull	Dust/paints particles from wear and tear, maintenance	Direct emission to seawater
	Hull (above waterline) and superstructures	Dust/paints particles from wear and tear, maintenance	To air: settling on deck, wet cleaning To air: settling in pools To air: to surrounding (sea/ port) areas
Indoor	Decks	Dust/paint particles from wear and tear, maintenance	To air: settling on floors and surfaces, vacuum cleaning To air: settling on floors and surfaces, wet cleaning To air: settling in pools
	Tanks, machinery	Dust/paint particles from wear and tear, maintenance	To tank contents and machinery effluents, e.g. ballast water, wastewater
Ballasts waters	Transport	Directly dropped at sea	Not generated on board, but released at sea

Table 4.1 Emission pathways for microplastics on board cruise ships (from Folbert 2020)

4.3. Causes of marine litter from shipping and boating

4.3.1. Shipwrecks

Ships of all kinds have sunk as a result of severe weather, armed conflict especially during the First and Second World War periods when large numbers of vessels were sunk in a short time, and human error. The largest concentrations of wrecks are located in the Western Pacific, the North East Atlantic, and North West Pacific (Michel *et al.* 2005), with 25% of wrecks found in the North Atlantic and 4% in the Mediterranean Sea (European Parliament 2012). Shipwrecks are particularly problematic where they occur in small, enclosed ocean regions like the Baltic Sea, which was the scene of intense naval actions in the last century (Zaborska *et al*. 2019). Abandoned boats are another common and a growing problem on the foreshores, beaches, mudflats, harbours, marinas, reefs and mangroves 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 or sunk offshore or abandoned on the substrate in the inter-tidal 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 is a common practice in many coastal countries, such as Australia, Malta, New Zealand and the USA, to use these boats and wrecks as artificial reefs. A dedicated 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 United States, 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 were paints, plastics, timber, expanded polystyrene (EPS) and masonry, while items logged included ropes, tires, canisters, electronic equipment and a variety of metal objects that were either fixed to or contained by the boats.

That said, fibre-reinforced plastics (FRP) have been commercially available for boat production since the 1950s and are given a life expectancy of 30-50 years (IMO 2019b). This has resulted in a growing number of end-of-life vessels with limited options for their disposal at landfills. The issue of end-of--life management of FRP vessels has been raised since the 1980s, resulting in a study to review the possible options for the disposal and recycling of end-of-life FRP boats without fully viable financial markets for recycling. While there is limited research, 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. In addition, FRP material will ultimately break up to potentially become microplastics.

4.3.2. Lost containers and cargoes

Extreme weather conditions at sea can be dangerous for shipping vessels, and waves can cause ships to roll, pitch, and lose containers stacked on them. Vessels and containers are most commonly lost at sea during problematic weather conditions when forces, including parametric rolling, place the hulls, stacked containers, and lashings under excessive stress (Surfrider Foundation 2014; Danish Maritime Accident Investigation Board 2014). In some cases, infrastructural failures may also be linked to, or exacerbated by, negligence (Surfrider Foundation 2014). Containers that are improperly loaded, in poor condition, unsecured, or illegally overloaded can fall 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.

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 the nature of goods lost at sea (Galafassi *et al.* 2019). The estimation of containers lost at sea every year is quite controversial. No centralized database is maintained with comprehensive container loss statistics, because damage and loss reports are rarely shared beyond line operators, involved local maritime authorities and providers of protection and indemnity insurance (Frey and DeVogelaere 2014). Estimates for total annual container losses vary massively, from between 350 to 10 000 per year (Frey and DeVogelaere 2014; Vero Marine 2011; World Shipping Council 2014; WSC 2017).
One of the main aims of the project LOSTCONT was to analyze the rate of loss for containers in the Bay of Biscay between 1992 and 2008 (Kremer 2009). A total of 159 incidents were recorded with 1 251 containers lost, probably underestimated because of under-declaration. Losses were far lower in the Mediterranean Sea (one accident, one container) and from the English Channel (six accidents; Galgani *et al*. 2012).

Losses of containers notwithstanding, it is the nature and quantity of contents of lost containers that contributes to the marine litter burden. For example, on October 2011 the vessel *Rena* ran aground near Tauranga, New Zealand, resulting in both an oil spill and the loss of containers of plastic resin pellets. In Hong Kong after Typhoon Vicente in July 2012, containers with over 150 tonnes of plastic resin pellets were lost at sea that later washed up on the southern Hong Kong coast. In Durban, South Africa, a spill of approximately 2 billion plastic resin pellets (49 tonnes) from a shipping container in Durban Harbor required extended cleanup efforts, with pellets also washing up on the shore in Western Australia.

4.3.3. Passenger ships

While cruise ships make up 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). For a large cruise ship approximately eight tonnes of solid waste are generated during a one-week cruise (United States 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. For this reason and due to both their mobility at sea and their possible terrestrial origin, the pollution they create is difficult to source, especially where multiple States and jurisdictions are located in close proximity.

The problem of storage of waste 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, waste minimization, and recycling. As much as 75% of solid waste is incinerated on board, and 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 aluminum 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 (United States Senate 2010).

Furthermore, cruise ships generate, on average, 31.8 L/day/person of sewage, and a large cruise ship (3 000 passengers and crew) can generate an estimated 56 800 – 113 600 L per day of sewage (United States Senate 2010). Cruise ships also generate an average of 253.6 L/day/person 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/person/day. MARPOL Annex V requires vessels to treat sewage before discharge, but does not require that grey water be treated before discharge.

4.3.4. Fishing vessel operations

It is important to note that the fishing industry does not just comprise fishing vessels, but also vessels not directly deployed for fishing operations, e.g. supply ships and catch transport vessels. Identification and characterization of litter from the fishing industry includes litter from all types of vessels in operation, and is not well differentiated from litter in the form of ALDFG. In the Western and Central Pacific Ocean, an estimated 71% of the purse seine pollution incidents were documented as waste dumped overboard, and only 13% as abandoned, lost or dumped fishing gear (Richardson *et al*. 2017). For longline fishing, 80% of the incidents were in the form of waste dumped overboard, and 17% as ALDFG. 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 that may affect the amount of waste that might be generated; the number of crew, which might affect the amount of domestic waste 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 bought in from 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.

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, aluminum cans, six-pack yokes, and recreational fishing gear (UNEP 2009; Mouat *et al*. 2010). Plastic bags, aluminum cans, and glass bottles are the most frequently reported materials associated with recreational boats (Widmer *et al.* 2002). However, because these types of materials would be common in debris items 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. In a study in the North Sea, data from standardized beach litter monitoring surveys collected during a 16-year period that were attributed to potential sources estimated 7% of items were from recreational boating (Schaeffer *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 tonnes 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 clearly in many cases these can be attributed to recreational boating activities. In the Mediterranean Sea, an inventory made through participative science and diving 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%) are 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). Approximately 10–15 million tonnes of ships will 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 number of negative environmental and social impacts that hinder the sustainable development of this blooming sector, including the production of marine litter, including glass fiber (glass wool), solid foam (shell of glass fiber products) and polyvinyl chloride (PVC) (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 at 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 FT-IR spectroscopy as polyurethane, nylon, polystyrene, polyester and glass wool. The morphology of these materials was also studied using a scanning electron microscope. Overall, there were on average 81 mg of small plastics fragments per kg of sediment. The described plastic fragments are considered to have resulted directly from the ship-breaking activities at the site.

4.4. Quantities and impact of marine litter from shipping and boating

4.4.1 Quantities of marine litter from shipping and boating

Few detailed studies are available that quantify the amounts and types of plastic litter from shipping. Even if 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 outputs among ships of the same type. Fortunately, one relatively recent study is comprehensive, and 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). 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. It 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, and that ships use different treatment methods and often only partly treat a waste stream.

Additionally, in order to establish a best practice for plastic consumption that can be applicable to the maritime industry, Wilhelmsen Ship Management and other parties in the Wilhelmsen Group have embarked on extensive analyses of the amounts of litter generated by a range of different ships. Preliminary results from a study of 61 cargo vessels and 22 ports estimate the total plastic waste produced per vessel in 2017 at 27.4 m^3, comprised of 19% plastic bottles, 7% plastic drums, 20% plastic wrapping, and 53% other plastic waste (Wilhelmsen 2019). However, a much more extensive study is presently being carried out involving more ships and several categories of vessels.

Some areas are more exposed to sea-based litter due to their proximity to shipping routes (Table 4.2). 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 be from shipping (Liubartseva *et al.* 2016). For the Mediterranean Sea, estimated inputs of plastic marine debris from shipping lanes were approximately 20 000 tonnes per year Liubartseva *et al.* (2018).

Sea	% Litter from shipping	Remarks	References
North Sea	25		Strand *et al*. 2015
German North Sea	21		Schaefer *et al*. 2019
Scotland	1.7		Potts T. and E.Hastings, 2011
Baltic Sea	10		Strand *et al*. 2015
Baltic Sea	4		Helcom, 2019
Adriatic	6.3		Vlachogianni *et al.* 2018
Malta	78	Modelled	Liubartseva *et al.* 2018
Libya	43	Modelled	Liubartseva *et al.* 2018
Cyprus	33	Modelled	Liubartseva *et al.* 2018
Greece	23	Modelled	Liubartseva *et al.* 2018
Egypt	2.2	Modelled	Liubartseva *et al.* 2018
Greece	13.2		Vlachogianni *et al.* 2018
Turkey	2.0		Liubartseva *et al.* 2018
Albania	4.7		Vlachogianni *et al.* 2018
Montenegro	1.5		Vlachogianni *et al.* 2018
Italy/ Adriatic	14.6		Vlachogianni *et al.* 2018
Colombia/ Carribean	9	Islands	Buitrago *et al*. 2019
Northern Persian Gulf (Iran)	< 8		Sarafraz *et al*. 2016
French Polynesia	8	Islands	Verlis and Wilson, 2020
Australia (NSW)	48 % of stranded bottles		Smith 2018
Malaysia	1.5		Mobilik *et al*. 2016
China	<1%		Chen *et al.* 2020
South East Asia	8		Nowpap Merac 2013

Table 4.2: Calculations or models estimating percentage of sea-based litter from shipping in various regions of the world ocean.

In a 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) an estimate was made of how much waste is (potentially) discharged at sea (Table 4.3). Quantification of waste discharged at sea is difficult in the absence of direct data available. Although garbage delivered in ports has increased since the introduction of the PRF Directive, a significant delivery gap remains, estimated between 60 000 and 300 000 tonnes, i.e. 7% to 34% of the total to be delivered annually.

	MARPOL Annex I		**MARPOL Annex IV**		**MARPOL Annex V**		**MARPOL Annex VI**
	Merchant shipping	All, incl. fishing and recreational craft	Merchant shipping	All, incl. fishing and recreational craft	Merchant shipping	All, incl. fishing and recreational craft	All (only merchant shipping)
Waste to be delivered (after treatment and legal discharge)[7](	1 226 000 m^3	1 290 000 m^3 Merchant: 1 226 000 m^3 Fishing vessels: 55 000 m^3 Recreational craft: 9 000 m^3	1 362 000 m^3	2 312 000 m^3 2 562 000 m^3 Merchant: 1 362 000 m^3 Fishing vessels: 500 000 / 750 000 m^3 Recreational craft: 450 000 m^3	434 000 tonnes	881 000 tonnes Merchant: 434 000 tonnes Fishing vessels: 266 000 tonnes Recreational craft: 171 000 tonnes	24 000 m^3 sludge 360 000 m^3 bleed off (generated by scrubbers operating in closed-loop mode)
Actually delivered	1 195 000 m^3	*Unknown*	1 226 000 m^3	*Unknown*	Range from 286 000 to 404 000 tonnes	Range from 580 000 to 820 000 tonnes	*Unknown*
Delivery gap (%)	31 000 m^3 (2.5%)	*Unknown, but 31 000 m^3 plus contribution from fishing vessels 64 000 m^3 from fishing vessels.*	136 000 m^3 (10%)	*Unknown*	Between 30 000 to 148 000 tonnes (7% - 34%)	Between 60 000 - 300 000 tonnes (7% - 34%)	*Unknown*

Table 4.3: Ship waste generated and delivered annually, and the resulting "waste gap." Source: 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)

[7] *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)*

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 waste delivery data available. This approach has been implemented by using:

- The MARWAS model: this model was developed and applied in the context of the Impact Assessment support study (Ecorys/COWI 2017), and 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) analysed the issue of marine litter from sea-based sources

Regarding the sewage that originates from merchant shipping that is to be delivered to port, it is estimated that approximately 10% of the sewage that should be delivered on 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. Available data on waste deliveries show that after a three-year decrease in volumes delivered, a slight increase has been recorded since 2008. However, lack of registration of delivered sewage and insufficient knowledge of on-board treatment and mixing with grey water 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 are presently available to determine whether there is a similar waste gap. However, based on available sources, estimations point to a possible waste gap for sewage representing 10% of the total volumes to be globally delivered annually.

Other waste categories are at present not as problematic, but may become an issue in the future. Current volumes of MARPOL Annex VI waste, which includes the sludge from exhaust gas cleaning systems (also referred to as "scrubbers") as well as the bleed-off water from these systems, are limited, as there are only a small number of ships that have installed scrubbers on board. Future developments, such as special areas being designated under MARPOL and increasing oil prices, may lead to an increased use of these systems on board to meet more stringent sulphur emission norms. A higher uptake of scrubbers will result in more sludge and bleed-off water being generated. As no waste delivery data is currently available, it has not been possible to calculate the waste gap for this type of waste. However, currently the IMO Subcommittee on Pollution Prevention and Response (PPR) and MEPC are considering performing a risk assessment on discharge streams to the water phase (preliminary research being conducted by the GESAMP Task Team on Exhaust Gas Cleaning Systems), with a draft report to be made available at PPR 7 in February 2020.

An estimated 733 containers were lost at sea each year on average for the 2011-2013 period, jumping to an annual loss of 2 683 containers when including catastrophic losses, such as the 2013 sinking of the *MOL Comfort* in the Indian Ocean, resulting in the loss of all 4 293 containers on board —the worst containership loss in history (WSC 2017)—.
In a more recent 2017 survey, average number of containers lost at sea from 2014-16, excluding catastrophic events, was 612, which is about 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 being attributed to catastrophic events. In 2015, for example, almost 43% of the containers lost at sea were due to the loss of the *El Faro* vessel, which sunk in the Bahamas with all its containers on board as a result of Hurricane Joaquin (WSC 2017).

The *MSC Zoe* that sank in Dutch waters in January 2019 was estimated to have lost at least 345 containers (Royal Netherlands Institute).

Paints are often made of anticorrosive products like vinyl, lacquers, urethanes, or epoxy-based coatings (Durkin and Toben 2018). The IMO (2019) 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 anti-fouling 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. One study estimates that 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 -1 194 tonnes per year, representing less than 1% of total inputs of microparticles in the marine environment in Europe (Hahn *et al.* 2018). Another estimate states that marine coatings account for 3.7% of releases of primary microplastics in the world ocean (IUCN 2017).

Per capita, the input could be at the level of 2.3 g per year, resulting in approximately 11 270 tonnes per year of marine paint-sourced microplastics introduced to the world's ocean, based on a population of 7.55 billion inhabitants (Galafassi *et al*. 2019). Sundt *et a*l. (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 m^2 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) considered this an underestimate and suggested that, as smaller fragments are likely to be washed away, microplastic losses from a maintenance worst case scenario give an estimated tonnage of microplastic losses from Norwegian shipyards to be 330 tonnes per year with a fraction to soil and the remainder to sea. The report also noted that the recreational sector also creates microplastic waste, from both yards and owners working on their boats.

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 fibre-reinforced plastic. 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 2019) 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 dwelling organisms of as a result of elevated metal concentrations in sediment (Muller –Karanassos *et al*. 2019).

4.4.2 Impacts of marine litter from shipping and boating

Reports of entanglement of marine organisms in litter from shipping are almost non-existent. Other types of impact, like 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 could be more important when considering items like lost containers or cargos from shipwrecked vessels that may be the source of industrial plastic resin 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 expanded polystyrene (EPS) (Rani *et al.* 2017). These items may degrade rapidly to microparticles and must be considered as potential source of toxic chemical such as

hexabromocyclododecanes, with abundant release observed from the open sea surface and on exposure to sunlight irradiation.

Plastic debris contained in grey water, microplastics in ballasts, and even floating wrecks or items from shipping operations (e.g. containers, quays, navigation marks, and debris from harbors) may contribute to the transport of organisms. While the contribution from shipping is difficult to evaluate, extreme events (tsunamis, flooding, hurricanes, etc.) may favor processes bringing large amounts of debris to the sea and supporting long term transport of and significant impact on biodiversity. In the case of the Great East Japan earthquake and tsunami on March 11, 2011, an estimated 5 million tonnes of debris, largely from ships, were washed way in a single, tragic event (Murray *et al*. 2018). The increase in debris influx to surveyed North American and Hawaiian shorelines was substantial and significant, representing up to 10-time increase over the baseline in some areas (Washington State, United States) and amongst the various types of debris found along the shore, 12.4 % was attributed to shipping.

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 EUR 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 EUR 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 EUR 60 million and EUR 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)

The presence of and process of generating any type of marine litter exert 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. Collisions with marine litter can cause significant damage to vessels and even pose a threat to human health. High levels of traffic in harbours and ports increase the risk of collision with waste. 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 (Source: 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 (Fig. 4.3). The most common incidences in surveyed harbours: 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 farther 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 shipping industry in the Asia-Pacific Economic Cooperation (APEC) region is USD 279 million per annum, however this figure must be treated with caution considering the lack of data on the issue (McIlgorm *et al*. 2008). There is a paucity of reports on harm to sea-users from marine debris. However 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).

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, 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 EUR 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 United Kingdom (EUR 8 035 per port per year) and the nine Spanish ports surveyed in the Atlantic (EUR 61 015 per port per year). Finally, this study estimated saving costs of approximately 12% (EUR 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) lead to significant reductions in the occurrence of these items as marine litter (Brouwer *et al*. 2015). 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 [Text box]

- Approximately 53 000 merchant ships are registered by the International Maritime Organization (IMO) globally in 2020; international maritime trade has reached a total volume of cargo of 11 billion tonnes in 2018, and in the last 30 years the global ocean cruise industry has grown from 4 million passengers per year to an estimated 27 million.

- Shipping vessels generate solid wastes daily that may end up as marine litter, often containing cargo waste, sewage, galley waste, domestic waste from crews, and maintenance wastes. A

growing number of end-of-life vessels and associated components like fiber-reinforced plastics, waste from ship breaking, including glass fiber, 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 paints and marine coatings, from grey water management and discharge systems, and transported through ballast waters.

- Fishing vessels may deliberately or accidentally release litter items such as gloves, storage drums, expanded polystyrene (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, and 0.01 to 0.1m^3 of operational waste and 0.003 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 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 expanded polystyrene (EPS) that may degrade rapidly to microparticles and must be considered as potential source of toxic chemical.

- Plastic debris contained in grey water, microplastics in ballasts, and even floating wrecks or items from shipping operations (e.g. containers, quays, navigation marks, and debris from harbors) 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.

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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 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 off-shore 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). 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 (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, the London Convention 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 the London Convention 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 in 1996 to update the London Convention, with the purpose of consolidating the higher levels of protection into a more precautionary instrument. This entered into force in 2006 as the London Protocol (LP 2006). Currently the two instruments are in force in parallel, with some states party to one or 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 the London Protocol will eventually replace the London Convention as the global standard for the regulation of dumping activities.
The definition of dumping under the London Protocol is very similar to that under the London Convention, 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 the London Convention, the London Protocol 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 than 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 are 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 or for capital projects such as new port or channel construction or the redevelopment of existing harbours that have become silted. Dredging is an activity common to all countries with a significant level of sea-based commerce, whether they are party to the 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 United Kingdom, for example) in order to balance the sediment input.

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 under the 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 2013-16 (IMO 2016b, 2017a, 2018a, 2019a). Given that many states are not party to the 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.

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 (macroplastic 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 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 London Protocol, 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 (2013-16), 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 (2013-16) 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 or 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 the LC-LP and IMO (IMO 2013a), and this is discussed further below.

In 2019, Italy presented a paper to the Scientific Groups of the 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 London Protocol 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 London Convention/London Protocol Waste Assessment Guidance 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 London Convention, 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 the LC-LP for the assessment of vessels proposed for dumping (examined further below) 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) (LC 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 London Protocol 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 above, in addition to the eight categories of waste specified in Annex 1 of the London Protocol, 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 more recent examples listed above (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 northwestern 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, nor 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 the London Convention and London Protocol 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 the LC (IMO 2014a) and incorporated as Annex 2 of the London Protocol (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, i.e. “a mechanism for screening candidate wastes and their constituents on the basis of their potential effects on human health and the marine environment”. 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 LC and 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 principal 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 in the form of a “Recommendation to Encourage Action to Combat Marine Litter”, agreed at their 38th 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 39th meeting of the 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". 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) to include such indicators in assessments of Good Environmental Status.

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 Waste Assessment Guidance (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 of 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 the 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 125m naval vessel *Cape Breton*, sunk under a

dumping permit in 30m 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 fibre-reinforced plastic (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 Waste Assessment Guidance under the 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 40th meeting in November 2018, Parties to the 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. Quantities 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

In a recent review, Worm *et al.* (2017) note 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 seafloor 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 4300 microplastics per kg) in sediments from a harbour in Tasmania. A more recent survey of sediments from 11 waterways in the United States, conducted by the United States 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 1000 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 (Worm *et al.* 2017; GESAMP 2019) and the apparent lack of correlation between abundance of microplastics and either the presence of macroplastic 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) note 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 Cauwenberg *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 fibers per unit weight of sediment. 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 United States 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 USACE that addressed the presence of macroplastic 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, the IMO (on request from the Scientific Groups to the 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 the LC-LP. The resulting report, published in 2016, highlighted many of the same issues summarized above, 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 recent 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 fibers, 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 fibers) 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 the 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 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 United States 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 above, 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 fibre-reinforced plastic (FRP or fibreglass) vessels may also be dumped at sea in some regions, perhaps as a largely unregulated and therefore unreported activity. The recently published 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 is almost no published information available on the issue. Review of reports to the LC-LP on permits issued over the last two decades 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 from 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 the London Convention 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 the 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 the 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 (United States FAA 2019), which has been subject to a relatively detailed ecological risk assessment by the New Zealand Ministry for the Environment (NZ MotE 2016; NIWA 2017). 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 the LC-LP have 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. It can be hoped that the work of the Correspondence Group will continue to collate such information in the coming year. In parallel, there is now an active dialogue between the Secretariat to the LC-LP and the United Nations Office for Outer Space Affairs (UNOOSA) and the UN Committee on the Peaceful Uses of Outer Space (COPUOS), which is intended to encourage an exchange of information on issues of common interest (IMO 2019g), and which may yield further quantitative information in the future.

5.5. Chapter Summary [Text box]

- 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 several decades, under the auspices of the London Convention and London Protocol and by some Regional Seas Conventions, information on the quantities of plastics or other litter contained in those wastes remains extremely limited.

- There is good 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.

- 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.

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6 OTHER OCEAN USES AS A MARINE LITTER SOURCE

6.1 Other ocean uses as a marine litter source

6.1.1. Offshore oil and gas exploration

Offshore oil rigs enable producers to 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 comprises 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 (Fig. 6.1).

A number of legal provisions dealing with pollution from offshore installations are stipulated in international conventions; however, the provisions are limited. The United Nations Convention on the 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. The London Convention 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. The MARPOL Convention 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 requires state parties to report discharges. The OSPAR Convention covers the Northeast-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 the 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 through a few discharge channels (Mepex 2016).

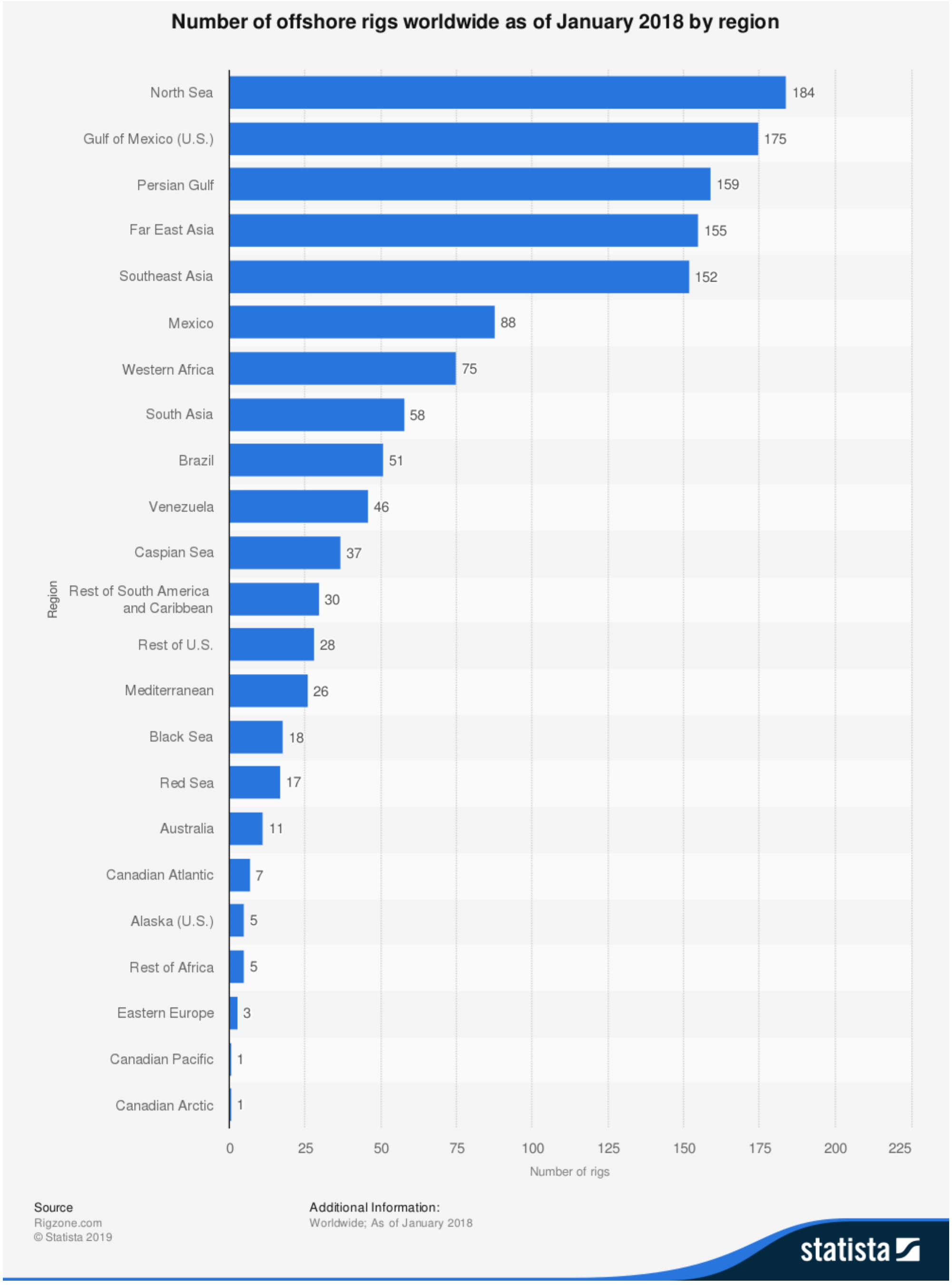

Fig. 6.1: Number of offshore oil rigs as of January 2018 by region (Statista, 2019).

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 (PEI) 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 (LCM). Proppants are designed to keep an induced 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 only intentionally 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 allowed in certain cases to be discharged into the sea as long as the oil content was below 30ppm (AFWEI 2017; Anonymous 2017). However, the level of use and potential discharge of these polymer inhibitors in not well known and considered to be low. It has been reported that the drilling operations in offshore oil and gas have the largest discharge frequency of plastics into the environment (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 onboard (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.* 2016; Sheavly 2005). Debris can fall, blow or wash off structures into the water, but there have been events recorded where items have deliberately been thrown overboard, primarily when there is limited storage onboard, and it is possible that those responsible are unaware of the impact (US EPA 2002). In the Northeast 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 an assortment of other offshore drilling equipment was abandoned on the seafloor (Caselle *et al*. 2002).

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. The nets do not work by deterring sharks, but rather by lethally intercepting sharks as a method to control local shark populations. The longest running lethal shark net program 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, with varying degrees of success. Similarly, '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.

Shark nets are made of polyester or nylon mesh, plastic rope, buoys and floats, as well as other various plastic materials. Standard nets used in Australia are typically 186 metres long and 6 metres deep, with a mesh size of 500 mm (Department of Agriculture and Fisheries, 2019). There have been reports of shark net break ups, 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 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 programs of stinger nets for use in the Mediterranean (Project Jellyrisk 2015).

Developing non-lethal alternatives to shark nets 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 (DPI 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 polystyrene 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 on-board meteorological stations. Since 2003, a network of 26 European meteorological institutes have engaged a fleet of 18 ships to participate in the Eumetnet-Automated Shipboard Aerological Program (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 polystyrene 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 polystyrene 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 has evolved both in its material consideration and complexity, and in the more recent inclusion of ecological conservation as an explicit goal (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, and the London Convention and Protocol/UNEP produced guidelines for the placement of artificial reefs (LCLP 2009). 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 Florida (Fig. 6.2), where up to two million unballasted tires 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, and 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).

Fig 6.2: Osborne Reef (Project Baseline, 2014).

Currently, a range of materials is used to construct artificial reefs. For example, polyvinyl (PVC) pipes are 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, PVC artificial reefs are overturned easily and displaced in light storms, they break apart easily, and eventually start to degrade. The main causes of artificial reef break up 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 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 like 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 minimising the impact of scientific operations in the ocean environment (Barbier and Pabortsava 2018). Several areas have been identified for improvement in order to minimise 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 better recovery at sea strategies for deployed equipment, and minimising equipment deployed 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 during Chinese New Year, Indian Diwali, or July 4th 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; Palaneeswaria and Muthulakshmib 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 debris originating from firework displays (NOAA 2018) (Fig. 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.

Fig. 6.3: Marine debris originating from fireworks (Project Aware, 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 World War I and II, has been known to occur in every basin of the global ocean. To this point little is known about the severity of impacts.

6.2. Quantities and impacts 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, 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.

6.2.2 Quantities and impacts 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 United Kingdom, 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 that of microplastic impacts, which are further considered by GESAMP WG40

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, these types of nets are being trialed 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 a contributor 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, tires from Osborne Reef have destroyed nearby coral reef structures, with an estimated 350 000 tires resting on or near the reef tract alone (FDEP 2009). 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 or reported by national research programs. 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. Programs like the Eumetnet-Automated Shipboard Aerological Program (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 programs 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 break up 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 July 4^{th} 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, breakdown and 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 [Text box]

- Quantifying litter and microplastics from ‘other’ sources outside of the 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, comprised in part of 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 the majority 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 and frequency by which single-use plastics are used in scientific research is not documented or reported by national research programs. Equipment deployed by researchers to monitor the ocean likely has minimal impacts on the marine ecosystem in comparison to shipping, drilling, oil platforms, etc

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7 ASSESSMENT OF DATA AND KNOWLEDGE GAPS

It is clear that while a very significant body of scientific work on marine litter and its sources, quantities and impacts has been produced and is being contributed to with new scientific papers every month from investigators around the world, certain gaps in our knowledge and understanding remain. These gaps warrant further investigation to inform mitigation and prevention strategies that can be applied locally, regionally and globally. The following sections first address fundamental, cross-cutting gaps that apply to all potential sea-based sources of marine litter, followed by sections that are more specific to ocean use sectors.

7.1. General data and knowledge gaps

- **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 insurance 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. This must be designed for multi-year functionality, with gradual enhancement driven by national monitoring capacities, developing technologies, gained knowledge and changes in the ocean circulation.

- **Appropriate methodology 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 meta-data analysis and machine-learning.

- **Distinguishing sea-based sources of marine litter from other land-based types of marine litter**: Common types of plastic marine litter such as water bottles, plastic gloves, plastic balloons, chips packets 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 better understanding the relative contribution of sea-based vs. land-based sources of marine litter, but also to inform waste management strategies 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 would enable 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, e.g. ALDFG, for certain regions around the world, significant challenges remain in being able to predict/model 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 is key to informing mitigation strategies.

- ***Socioeconomic impacts of marine litter generated at sea:*** Few local, regional or global estimates exist for direct and indirect costs arising from sea-sourced marine litter on ocean users, industries and coastal communities. It is especially important to understand socioeconomic 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, 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 harbors 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.

7.2. Fishing and aquaculture data and knowledge gaps

- ***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. hooks 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. Entanglement rates in ALDFG may be exaggerated if it is assumed that all entanglements, including those in actively deployed fishing gear, are due to ALDFG as marine litter. 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.

- ***Impacts of ALDFG on target and non-target species***: Population-scale impacts 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, and should be undertaken in regions where large-scale/industrial fishing vessels deploy large volumes of gear, such as purse seine fisheries using 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:*** There is a lack of quantitative information regarding 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.

- ***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**: The lack of reporting on loss, abandonment or discard of plastic materials from aquaculture operations by the majority of producing countries 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.

7.3. Shipping and boating

- **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, recreative, etc.), and if/where legal or illegal discharge of bulk solid and liquid cargoes is occurring. Such tools would help 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 related to shipping routes.

- **Microplastics in ship surface coatings**: There is little mention of marine coatings as a source of microplastics in the scientific and grey literature on marine litter. It is important to better understand if activities such as hull cleaning, replacement of hull coatings, and the normal wear of anti-fouling 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 anti-fouling substances and marine paints will help inform future management and/or policy development, and this is critical as the 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.

- **Socioeconomic 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.

7.4. Ocean dumping data and knowledge gaps

- **Geographic Gaps**: Even with the current list of 100 Parties to either or both the LC or LP, there remain an almost equal number of countries (some of them large, rapidly industrializing countries) that are not party to either instrument and for which 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 those countries, and therefore the types and quantities of plastic materials dumped or 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. Whereas 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, if not all, 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, farther 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.).

7.5 Other sources data and knowledge gaps

- **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 in order 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 activity; 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 items 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.

Appendix 1. ALDFG global literature review

The Working Group undertook an extensive literature review to identify sources, levels, impacts. preventative measures, knowledge gaps and research priorities for ALDFG from artisanal, commercial and recreational fishing operations, utilizing the Web of Science, Scopus, Google Scholar and Google. The review included relevant scientific publications 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 information available about ALDFG sources, levels, impacts and preventative measure are cited to their original publications.

Literature was included in this review if it contained information about ALDFG sources (including causes for loss), levels (i.e. quantitative amounts of ALDFG 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 were broadly categorized into causes arising from environmental conditions; conflicts and interactions with other gear types, vessels, fishers and/or marine users; fisheries management and regulations (either lack of or responsible for); and operational and user-based causes;
- Information collected for levels focused on quantitative amounts of ALDFG over designated 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 were 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); and
- 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 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, common 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: 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 were identified and reviewed. 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 alternatives.

Most of the studies reviewed reported data on ALD pots and traps (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)[8]. Many studies reported information about sources, levels, impacts and prevention measures for ALDFG for multiple gear types. Within the overall 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 overall 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 FADs); seine nets (including beach and boat seine); trawl nets (including bottom otter trawls, midwater otter trawls and midwater pair trawls); cast and other miscellaneous nets. Other miscellaneous net types reviewed included dip nets, reef nets, and a variety of unidentified net types. Within the lines category, studies reviewed reported data on handlines and pole-lines (both hand-operated and mechanized), longlines (set and drifting) and trolling lines.

The literature review encompassed papers and reports produced from 1970 to 2020, with most of the studies undertaken in the last decade (61%, N=141). 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), Republic of Korea (7%, N=16), Australia (6%, N=14), Canada (4%, N=10), Italy (4%, N=9), Turkey (4%, N=9), the United Kingdom of Great Britain and Northern Ireland or (4%, N=9), Japan (3%, N=8), Norway (3%, N=8), 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), Oman (1%, N=3), Sweden (1%, N=3), the United States 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 (Islamic Republic of), North Macedonia, Mexico, Morocco, New Caledonia, Russian Federation, Samoa, Sweden 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 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 fishing activities (IUU) (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 illegal, unreported or unregulated fishing activities (IUU) (22%, N=17).

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

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, count of gear lost, length 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 loss, most reported amounts of ALDFG losses in percentages (68%, N=67), ranging from 0-88.2% for both fleets and vessels; followed by counts/number of items of gear lost (57%, N=56) , which ranged from 0-500 000 items of gear lost for both fleets and vessels; total length of gear lost (km) (12%, N=12), which ranged from 0-1 028.37 km of gear lost for both fleets and vessels; counts/number of pieces of gear lost (9%, N=9), which ranged from 0-5 540 pieces of gear lost for both fleets and vessels; weight of gear lost (tonnes), on the fleet level (7%, N=7), which ranged from 0.2 135,400 tonnes of gear; and the percentage of fishers losing a piece of gear, on the fleet level (1%, N=1), which ranged between 2-4%.

Richardson *et al*. 2019 provides a literature review and meta-analysis of 68 publications from 1975-2017 that present quantitative estimates of gear losses over specified time intervals. Data was used from this literature review and meta-analysis to predict overall global gear loss rates of 5.7% for nets, 8.6% for pots and traps and 29% for all lines, for the year 2017. This study is discussed in greater detail in section 7.2.1 in this report.

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). Section 7.2.3 of this report describes impacts from ALDFG including information from the studies reviewed in greater detail. Impacts will be further explored in greater detail, beyond the scope of this current preliminary report, by the Working Group in future reports.

While it was not originally a key 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 sidescan 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 illegal, unreported or unregulated (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). A detailed review of these management recommendations will be summarized in future reports addressing prevention and mitigation of ALDFG.