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Shipping, Ships and the Environment

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1.1 Introduction

Many people around the globe rely on the low-cost transport of goods and commodities that commercial shipping provides. Indeed, about 90 per cent of the world's traded goods are transported by sea, with more than 70 per cent of this being containerized cargo (United Nations Conference on Trade and Development, 2017). Shipping densities are illustrated in Figure 1.1, demonstrating the great concentration of traffic along key routes.

In most cases, the beneficiaries of this method of trade are unaware of the environmental impacts ships cause. The diverse nature of the environmental impacts of modern ships in terms of the sources of impact, their magnitude and their persistence is shown in Figure 1.2.

1.2 Shipping

1.2.1 International Demand for Shipping

Never before has the demand for global shipping been greater. However, there have been multiple and significant changes in recent decades relating to the technologies and operational procedures used by the shipping sector, with many of these changing the environmental impact of the industry. Data showing the growth of various categories of cargo are presented in Table 1.1.

Consequently, understanding the cumulative environmental impact of ships has never been more important. Research across the environmental disciplines is increasingly uncovering the complexity and incredible levels of interconnectivity between environmental partitions, as well as the fragility of many of the life-support systems provided by our planet. This is perhaps especially true in the field of marine environmental research, where recent discoveries regarding the intricacies of cell-to-cell communication between microbes and higher organisms, the sophisticated navigation behaviour of fish, reptiles and cetaceans and the susceptibility of marine organisms to synergistic environmental stressors are just a few of many possible examples of how our understanding of organism behaviour is improving all of the time.

As we learn more about the way our oceans function and the goods and services they provide us, it is even more pressing that we measure how our use of the oceans affects these

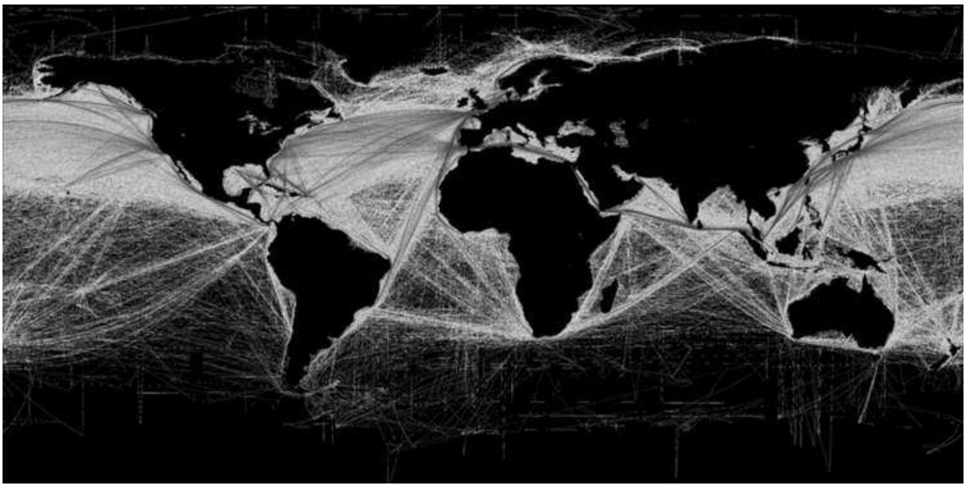

Figure 1.1 A global map of human impacts on marine ecosystems, showing relative commercial shipping densities.
Source: Halpern *et al.* (2008)

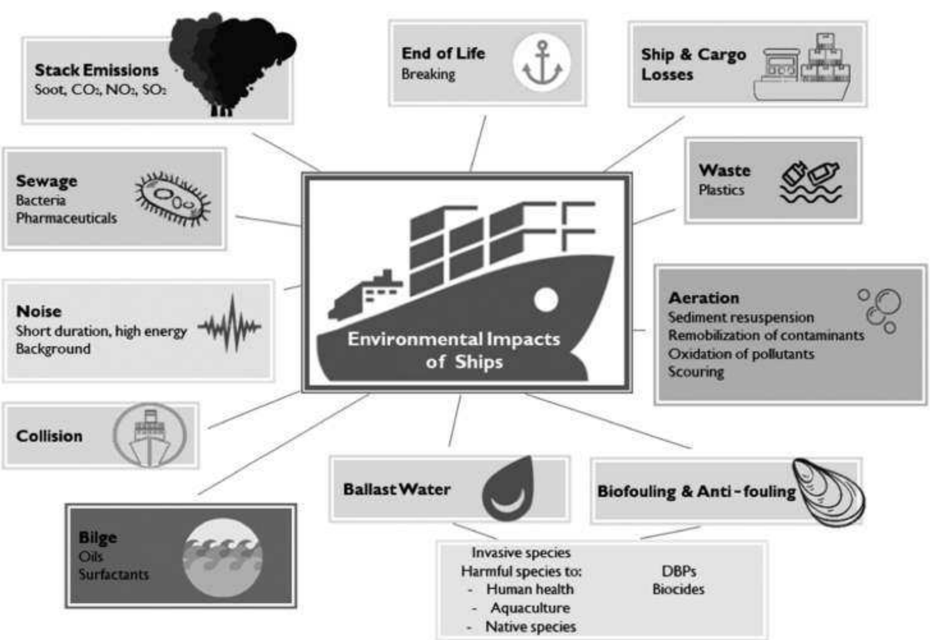

Figure 1.2 The diverse nature of the environmental impacts of modern ships.
DBP = disinfection by-product.

processes and manage our use accordingly. This is particularly the case within the shipping industry, with rapid changes taking place in relation to the way ships are designed, the fuel sources they use and how fast they move. Even the very seascape of our planet where ships travel is subject to change (Figure 1.3), with new shipping routes opening up in previously

Table 1.1. *Growth in international seaborne trade over selected years (millions of tons loaded)*

Year	Oil and gas	Main bulks[a]	Dry cargo other than main bulks	Total (all cargos)
1970	1440	448	717	2605
1980	1871	608	1225	3704
1990	1755	988	1265	4008
2000	2163	1295	2526	5984
2005	2422	1709	2978	7109
2006	2698	1814	3188	7700
2007	2747	1953	3334	8034
2008	2742	2065	3422	8229
2009	2642	2085	3131	7858
2010	2772	2335	3302	8409
2011	2794	2486	3505	8785
2012	2841	2742	3614	9197
2013	2829	2923	3762	9514
2014	2825	2985	4033	9843
2015	2932	3121	3971	10,023
2016	3055	3172	4059	10,287

[a] Iron ore, grain, coal, bauxite, alumina and phosphate rock.
Source: Compiled by the United Nations Conference on Trade and Development secretariat based on data supplied by reporting countries and as published on government and port industry websites and by specialist sources. Data for 2006 onwards have been revised and updated to reflect improved reporting, including more recent figures and better information regarding the breakdown by cargo type. Figures for 2016 are estimates based on preliminary data or on the last year for which data were available

unpassable waters, such as the Northwest Passage, due to the consistent decline in sea ice (Brigham *et al.*, 2009). It has never been more pertinent to measure and understand the impact that the global shipping industry has on our environment and our long-term well-being.

1.2.2 Global Dependence on Commercial Shipping

The ability to move goods, commodities and people on vessels has long been associated with wealth and power. Notable examples include the clinker built vessels predominantly used by the Vikings to great effect for trade, commerce and warfare during AD 793–1066. Before this, the beginnings of the spice trade that fuelled the global economy during the Middle Ages were largely dependent on commercial vessels as far back as 3000 BC.

In modern times, approximately 10 billion tonnes of cargo are moved globally by commercial vessels (United Nations Conference on Trade and Development, 2017). Approximately 78 per cent of surface European Union freight is moved by sea shipping in Europe compared with 17 per cent by road and 3 per cent by rail (ACEA, 2011). Shipping is the global link that connects commodity suppliers with production and

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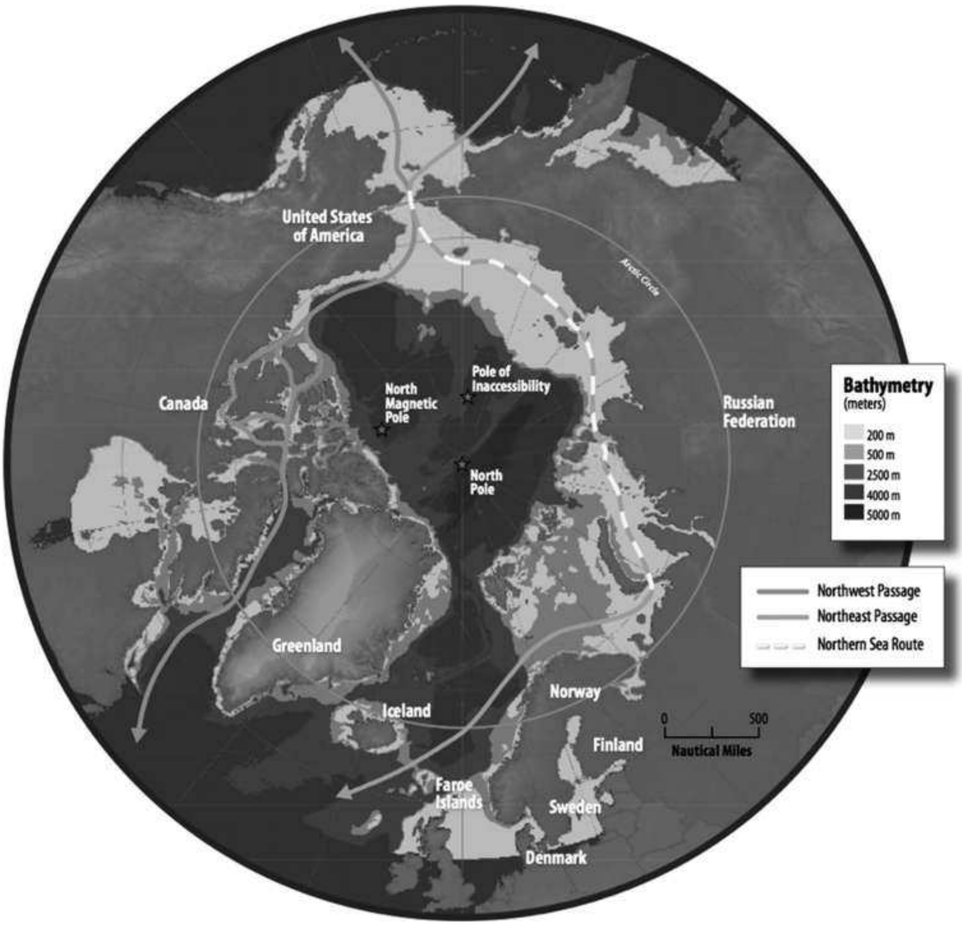

Figure 1.3 Map of the Arctic region, showing the Northeast Passage, Northern Sea Route and Northwest Passage shipping routes and bathymetry.

manufacture processes. On completion of manufacture, market-ready products are then distributed for sale across the globe. Increasingly, the by-products of our vast levels of global consumerism are also transported by shipping, such as waste and reuseable materials that can only be economically recycled in bulk form. Plastic waste generated from products manufactured and consumed in Western Europe is now a standard cargo destined for waste treatment plants in China. Recycled materials are then transported in bulk via ships back to manufacturing plants, so completing the link between product life cycles and shipping.

1.2.3 Transportation of Fuels

Of all the commodities, the transport of fuels such as coal and petrochemicals has historically been closely linked with shipping. Until the recent and rapid development of renewable energy capability, the transport of crude fuels by sea following its production and subsequent distribution after refining has been a lifeline that has directly underpinned a significant proportion of the global economy and allowed much of the recent rapid development of new technologies to take place. There is little doubt regarding our dependence and reliance on shipping. However, our understanding of the environmental cost of this dependence is less clear.

1.3 Ships

1.3.1 Vessels and Scale of the Industry

The scale of the shipping industry is vast, despite not being visually obvious to many who depend on it. Some 90,000 commercial vessels of all classes were reported in 2017, with a total global tonnage of 1.86 trillion deadweight tonnage (dwt) (United Nations Conference on Trade and Development, 2017). Of these, approximately 43 per cent of vessels are bulk carriers. A typical bulk carrier can be in the region of 290 m in length overall and 45 m in breadth extreme, with a hull area of approximately 19,000 m^2.

Some forms of environmental impact produced by these ships have been characterized by current research, such as greenhouse gas emissions. In contrast, other forms of input, such as scrubber emissions, noise and pollution during shipbreaking, have not yet been fully addressed in terms of measuring either the global scale of the input or the severity and persistence of the impact that is produced.

Regarding leisure vessels, determining the numbers of such vessels on a global scale is challenging, with many vessels being unregistered. Approximately 500,000 leisure vessels were recorded in the UK in 2012, with between 80,000 and 100,000 of these being motorboats (Royal Yachting Association, 2012). The number of vessels actually in service, however, is less clear. Although leisure vessels are subject to less regulation and record-keeping, they may play an important role in perpetuating some of the environmental impacts that originate from commercial vessels, with the spread of hull-fouling species being a prime example.

The fuel consumption of large commercial vessels is immense, and a typical car carrier of 200 m in length overall can burn between 50 and 60 tonnes of fuel per day when steaming at around 20 knots (Bialystocki & Konovessis, 2016). Combustion gases from heavy fuel oil produce far higher levels of greenhouse gas emissions and other pollutants that contribute to human health issues, such as particulates, compared to combustion gases from most other transport fuels. For example, typical heavy fuel oil contains several thousand times more sulfur than standard road diesel. To provide context on just one fraction of atmospheric inputs, the huge volume of fuel consumed by the international shipping industry currently produces approximately 2–3 per cent of global anthropogenic CO_2 emissions. This ranks CO_2 emissions from commercial shipping vessels somewhere between the emission ratings of Germany and Japan.

1.3.2 Changes in Technology and Operational Practice

There has been much change in terms of technology and operational practice in recent years, which has affected the environmental impact of ships. Although subject to short-term variation, the size of general commercial vessels has increased over recent decades, affording greater economies of scale to the trader and consumer (Malchow, 2017). Advances in the scale and efficiency of ship construction techniques have led in part to this increase in size. Increasing vessel size has also driven the expansion of ports, together with the deepening and widening of shipping channels, all of which result in environmental impacts at multiple scales that should be considered in assessing the overall impact of shipping.

The steaming speeds of vessels continue to change as a result of multiple drivers, including demand, fuel oil prices and propulsion technology. Vessel speed has direct implications for fuel consumption, exhaust emissions, marine noise levels, biocidal release rates from hull coatings and collision risks with cetaceans and reptiles. As commercial vessel speeds vary with bunker prices, the environmental impacts also vary in relative severity and importance. For example, when slow steaming, hull coatings designed for faster speeds become less effective, increasing fuel consumption and greenhouse gas emissions.

Ship speeds can also result in highly significant impacts on vulnerable species such as the North Atlantic right whale, for which approximately 35 per cent of deaths are attributed to collisions with commercial ships (Knowlton & Kraus, 2001).

Changes in hull design also track bunker prices, with substantial retrofitted hull modifications, such as the removal or replacement of bulbous bows, being carried out in attempts to optimize hull performance in order to match required steaming speeds.

Propulsion methods and engine designs are also changing, with resulting consequences for the environmental impact of ships. Additional retrofitted sections to standard fixed propellers are available that can improve the efficiency of the unit under certain conditions. Fixed propellers are often replaced by multidirectional pods and thrusters, which can influence levels of efficiency and manoeuvrability and the generation of marine noise. Modern propulsion systems can also influence levels of physical scour and erosion from wash-in ports, harbours and shallow-water anchorages, as is discussed in Chapter 8.

Engine design and operation have been the focus of much research and development, with modern engine configurations competing to offer increasing power-to-weight ratios and to achieve fuel savings. Advanced engine management systems that allow the engine to run at different speeds under different loads are also helping to save fuel and to reduce environmental impacts, along with fuel additives and blends that reduce harmful emissions from the exhaust stack.

Advances in engine design, propulsion systems and the ability to closely monitor a vessel's hull and fuel efficiency are driving the shipping industry to demand manufacturers of hull coatings to improve hull efficiency by increasing anti-fouling performance. Fuel efficiency and, to a lesser extent, the translocation of non-native marine organisms have moved higher up the agenda in global shipping circles, requiring coating manufacturers to innovate and to provide new products, despite the tightening up of permissible biocides for used in anti-fouling coatings.

Effective coatings can increase fuel efficiency and reduce exhaust emissions, yet between 80 and 90 per cent of the global fleet are operating with biocidal coatings, with much of the biocidal content leaching out and disassociating from the coating into the marine environment over the life cycle of the coating. Modern biocide-free anti-fouling coatings are becoming more widely used, but they do not always offer the same performance as biocidal systems, especially after extended static periods or at slow steaming speeds. Although the environmental benefits of biocide-free or low-leach-rate coating systems seem obvious, the environmental implications of the wide-scale use of these technologies are still not fully understood and are the subject of current research programmes.

Alternatives to heavy fuel oil as a fuel source are available, although the numbers of vessels powered by cleaner fuels such as liquified natural gas are relatively low, reaching 200 vessels in 2017 (Riviera, 2017). Recent advances in battery technology have enabled the use of electric engines for specialist vessels operating in particular routes. The year 2017 saw the introduction of one of the first electric battery-powered 2000-dwt coal carriers operating with a 40-nautical-mile range.

Trials of renewable energy use on commercial cargo ships have also been conducted since the 1980s in the form of wind-powered kites. Modern renewable energy options such as turbines, wings, rotors, kites and photovoltaics are all commercially available to supplement the primary propulsion systems of vessels or to provide power to auxiliary systems at sea and in dock.

Despite these advances, the majority of the global fleet (between 80 and 90 per cent) still operate on heavy fuel oil, which results in high levels of greenhouse gases being emitted by ships stacks. In order to reduce sulfur emissions from marine fuels, the International Maritime Organization (IMO) has introduced Emission Control Areas, which control emissions of SO_x, NO_x and particulate matter in coastal areas around North America and Europe, and the global sulfur cap for marine fuels was reduced from the current 3.5 per cent to 0.5 per cent in 2020. Far from being only an offshore problem, the common practice of running combustion engines in ports to provide power for electrical generators results in direct exposure of coastal communities to highly toxic exhaust gases.

1.4 The Environment

1.4.1 Environmental Impacts

Many of the environmental impacts of ships are felt in coastal communities and habitats. However, the impacts of ships can also be felt on a much wider scale, which makes them difficult to measure and quantify. For example, vessel exhaust stack emissions, which originate from a marine point source, can quickly spread across terrestrial environmental compartments, making it challenging to track them and to measure their full impact.

Specific characteristics of the receiving environment also affect the severity of the environmental impact. For example, many major shipping routes, harbours and anchorages are located in estuaries and waterbodies where environmental salinity drops well below typical marine levels. Environmental salinity can have significant implications for the environmental impacts of shipping in relation to the efficacy of the electro-chlorination systems of ballast water treatment systems, the efficacy of biocidal anti-fouling coatings and the fate of pollutants from vessel exhaust stack scrubbers. As a consequence, freshwater bodies that receive high levels of shipping activity may be uniquely susceptible to the environmental impact of ships.

1.4.2 Out of Sight, Out of Mind

Despite many citizens of our planet depending on shipping to underpin their modern way of life, it is likely that many of them will not be familiar with the full range of environmental impacts that vessels can produce, resulting in a phenomenon known as 'sea blindness'. There are many examples of the environmental impacts of shipping having escaped attention, perhaps simply because ships predominately operate on the world's oceans, where the impacts are less obvious than equivalent terrestrial industries. Examples of the incongruous environmental situation concerning shipping include exhaust scrubbers that remove many of the pollutants from the atmosphere only to deposit them in the oceans or the fact that shipping was exempt from the United Nations' Paris Agreement.

1.4.3 Environmental Legislation

Globally, we are becoming more aware of the impacts of shipping, and legislation is being applied to control and limit environmental degradation. Examples include the Energy Efficiency Design Index (EEDI), which seeks to non-prescriptively promote the use of more efficient equipment and engines and in doing so stimulate technological development and innovation.

The IMO's International Convention for the Control and Management of Ships' Ballast Water and Sediments (BWM Convention) and the IMO MARPOL low-sulfur fuels regulation seek to address other environmental inputs in order to reduce their impacts. Even secondary levels of environmental and human health protection, such as limits on volatile compound concentrations in marine coatings, are all contributing to increased environmental awareness and in many cases are driving technology development forwards to meet new environmental compliance standards.

However, despite these advances, substantial gaps remain between the implementation, compliance and enforcement of these rules and regulations on the high seas. Recent examples have demonstrated that, for large-scale operators, the fines and penalties associated with breach of environmental compliance are financially favourable compared to the levels of investment required to meet environmental standards.

Additionally, whilst relatively high-margin fractions of the shipping sector, such as the cruise industry, might be able to invest in meeting these new environmental standards, the procurement and operation of environmental compliance technology, such as ballast water treatment systems, are likely to be beyond the financial reach of the lower-margin fractions of the sector, such as the European short sea shipping industry. The economic cost of environmental compliance is likely to produce longer-term environmental and socio-economic impacts.

Unsurprisingly, new environmental legislation may be met with resistance from the commercial shipping industry. This is understandable to a certain extent, as the industry can justifiably claim that 99.98 per cent of oil reaches its destination port without issue (IMO, 2001). In addition, it is generally acknowledged that terrestrial sources of pollution in the sea are far greater than marine sources, yet these terrestrial sources receive less attention in terms of regulation. Despite this, estimates that marine transportation sources contribute approximately 12 per cent of total marine pollution suggest that scrutiny should not be relinquished (GESAMP, 1990).

1.5 The Future

Penalties for breach of environmental regulations need to be realistic in order to provide a sufficient deterrent, whilst still retaining flexibility to allow smaller organizations, with less capacity to invest, to comply. It is also clear that, when pushed, technology development continues to deliver alternatives with the potential to reduce the environmental impacts of shipping, with ballast water treatment systems being one recent example.

As the shipping industry develops and technology and operational standards change, it is imperative that we remain vigilant and open-minded about the source, fate and impacts of outputs from ships. Before global shipping can be managed in an informed way, a balanced, impartial and holistic view of the environmental impacts of ships is required. Crucially, we need to consider the long-term fate, severity and persistence of cumulative impacts and the full range of environmental compartments across which they transcend. It is exactly in this capacity that this book intends to contribute.

With concerted effort and awareness, we have the potential to develop the most efficient source of mass transport on the globe, allowing for the sustainable development of our planet. If we are not aware of the environmental impacts of shipping, or if we fail to mitigate them, there is grave potential for shipping to measurably accelerate the ongoing degradation of the oceanic environment upon which we all depend.

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