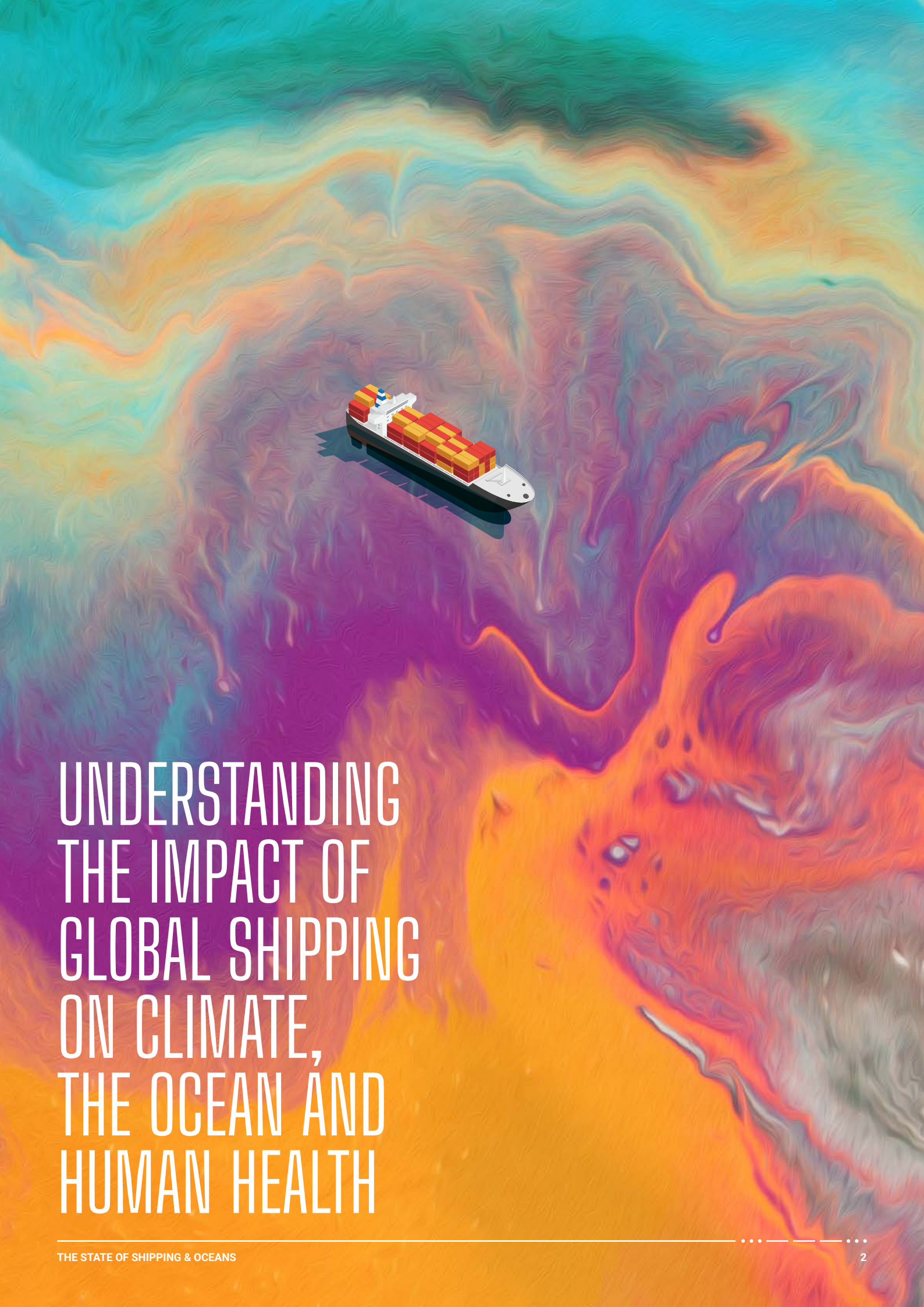




THE STATE OF SHIPPING & OCEANS REPORT



UNDERSTANDING THE IMPACT OF GLOBAL SHIPPING ON CLIMATE, THE OCEAN AND HUMAN HEALTH

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EXECUTIVE SUMMARY

THE STATE OF SHIPPING & OCEANS



The International Convention for the Prevention of Pollution from Ships (MARPOL), the principal international legal agreement regulating the environmental harm done by shipping, is 50 years old this year. In this report we take stock of what has – and has not – been achieved by half a century of maritime environmental regulation.

The maritime shipping sector is a fundamental feature of modern life; the great, largely-invisible conveyor belt of global production, trade and consumption that carries more than 80% of all international trade. It is also traditionally viewed as the least environmentally damaging of the ways to move goods over long distances. With maritime trade concentrated in vast industrial ports, and ships spending most of their time out at sea, this benign reputation has relied heavily on the fact that so much shipping activity is *'out of sight, out of mind'*.

This report seeks to interrogate the widely-held assumption that shipping is an environmental friendly means of transport; creating (perhaps for the first time) something much closer to a full picture of the real cost of shipping; looking beyond the headlines (such as they are) to the almost numberless ways in which the relentlessly expanding web of global maritime trade is contributing to the degradation of the vital planetary life support systems that underpin human well-being and prosperity.

CLIMATE CHANGE

Maritime shipping is a significant contributor to anthropogenic climate change. It emits over one billion tonnes of carbon dioxide equivalent (CO₂e) each year in the form of CO₂, methane, black carbon, and other climate pollutants. Shipping's 3% share of global GHG emissions is comparable to a medium-sized industrialised country like Japan or Germany, and broadly the same as aviation or the fossil CO₂ emissions of the whole of Africa.

And yet, with international efforts being made to reduce emissions of GHG, the shipping sector has largely avoided contributing its fair and equitable share. If it continues business-as-usual, while other sectors and wider society decarbonise, shipping's share of global GHG emissions could reach 17% by 2050. As the latest IPCC report notes, 'deep and rapid reductions' are required across all GHG emitting sectors if the global warming limit of 1.5 degrees Celsius under the Paris Agreement is not to be exceeded. The IPCC further notes that improvements in national and international governance of shipping may be needed for its decarbonisation to succeed.

The IMO's current global emission reduction targets under the 2018 Initial Strategy are widely recognised as unambitious and inadequate. Its goal to halve emissions by 2050 and decarbonise as soon as possible this century will cause the sector to overshoot any target compatible with the Paris Agreement temperature limits, and by a very large margin.

A meaningful contribution by shipping to keeping within the Paris Agreement limit of 1.5 degrees Celsius would require an emission reduction of one-half by 2030 and full decarbonisation by 2040. Any further delay will not only mean steeper emissions reductions in the future but also higher climate change-related losses from falling demand and increasing damage to ports and other infrastructure. Each year of delay is also predicted to add an extra \$100 billion to the total cost of decarbonising the industry.

To achieve decarbonisation a combination of policies and measures is needed, including economic incentives, improved technical regulation, operational measures (such as speed reduction) and the management of demand. A shift to zero emission fuels and energy sources, including their full production lifecycle, is key. In addition, unlike many other industries, shipping has, through the use of modern wind technologies, the opportunity to use wind as a direct source of motive power, and this presents the sector with a real and exciting opportunity.

OCEAN HEALTH

All aspects of shipping pose a threat to ocean health through pollution or direct impacts.

Large, catastrophic oil spills are becoming less frequent. Smaller, routine-but-illegal discharges are thought to collectively discharge much more oil into the oceans each year than the disasters that still grab headlines. A staggering 90% of all the oil discharged by ships is attributed to deliberate illegal dumping of oily residues from routine operations. Satellite data strongly suggests that illegal discharges are commonplace. Prosecutions are rare and the penalties negligible.

A wide range of chemicals, including many considered hazardous and noxious substances (HNS), are regularly transported via the sea in liquid form or in bulk. Between 9,000 and 20,000 tonnes of HNS are estimated to be spilled into the oceans in an average year. Operational tank-cleaning regulations under MARPOL still allow many tens of millions of litres of liquid HNS to be legally discharged each year, along with an estimated 78,500 tonnes of solids. Deliberate dumping even extends to the disposal of whole vessels, along with their toxic contents. The IMO's HNS convention, with its 'polluter pays' requirements, remains unratified after more than 25 years.

The 80,000 tonnes of antifouling paint used each year (projected to double by 2030) contain a range of toxic compounds to stop biological growth on ship's hulls. Eventually, with time, these are released into the sea where they are toxic to other species and food webs. It took the IMO 20 years to ban the worst (tributyltin), in 2008, but legacy damage persists and the products are still available. Modern, less harmful replacements still rely on a range of toxic compounds and heavy metals to achieve their intended purpose. Some 6-7% of antifouling coatings are lost into the sea each year, contributing to a detectable trail of microplastics, toxic additives and plastic polymers in ships' wakes. New bans on the use of biocidal compounds are being introduced but only after evidence of their environmental toxicity can no longer be ignored.

More than 250 million tonnes of sewage and greywater – with a payload of bacteria, microplastics, contaminants and pathogens – are discharged into the world's oceans each year from shipping. (A cruise ship's 3,000 passengers generate about 100,000 litres of human waste and 706,000 litres of greywater each day.) Sewage must be crushed and disinfected before discharge, but studies show that very few onboard treatment plants comply and the majority discharge 'virtually untreated raw sewage'. Greywater discharges – with bacteria, nutrients, solids and pollutant levels comparable to raw sewage – are largely unregulated. Raw effluent from cattle carriers is routinely washed overboard; 214 million litres of it each year into the Mediterranean and Black Sea alone.

Ships must retain their plastic waste and dispose of it on land, but monitoring and enforcement are so weak that between 7% and 34% of plastic waste never reaches port disposal facilities and is assumed to end up in the sea. Nearly 2% of all fishing gear – much of it plastic – is abandoned, lost or discarded at sea every year. Nets, ropes, buoys, pots and boxes are almost 40% of all beach litter. Lost or abandoned gear causes ‘ghost fishing’, catching and killing marine life indiscriminately. Container wrecks are now a major source of plastic in the oceans; at least 1 trillion raw plastic pellets have been lost at sea in eight maritime disasters since 2011. About 100,000 tonnes of microfibres are estimated to be shed from synthetic clothing washed in ships’ onboard laundries before being discharged into the sea as (unregulated) greywater.

Along the world’s busiest shipping routes over the last half century the underwater soundscape has seen a 32-fold increase in the low frequency noise typical of maritime traffic. Ship-emitted noise pollution is ubiquitous, even in the deep and far away from its source. The continuous low-frequency noise emitted by ships overlaps with the typical ranges used by various marine species, interfering with their communication, behaviour and wellbeing. IMO guidelines on noise reduction are not mandatory so their adoption and implementation has been extremely limited.

Collisions with ships are amongst the leading causes of death for whales. Many populations around the world are known to be particularly at risk, including the critically-endangered and declining North Atlantic right whale. While much research has been done over the years to understand the nature of marine mammal ship strikes and to inform management measures, the risks to other endangered species, such as the whale shark and seabirds, are only now emerging.

Invasive aquatic species are a leading threat to global biodiversity, and international maritime trade is a key driver. In addition to profound ecological effects, invasive species can wreak havoc on local communities and economies. Ship’s ballast and biofouling on a ship’s hull are the two main mechanisms by which invasive species are transported by ship. Whilst ballast water is regulated to reduce the risk of further disseminating invasive species, biofouling remains largely unregulated. As perhaps one of the most pervasive impacts of shipping, a feature since shipping first began, the rate of ship-mediated invasions is believed to increase considerably in line with the continuous growth in maritime trade.

Port developments are hotspots for impacts of all kinds: poor air quality, high concentrations of heavy metals from biofouling paints, marine pollution including underwater noise, coastal degradation and habitat loss, extensive damage to the seafloor from ship anchors, as well as the uprooting of local communities and the triggering of cross-cultural conflict. The emergence of ever-larger mega-container ships places increasing demands on port infrastructure and maintenance, including the need for bigger berths and the large-scale dredging of sediments. As the global shipping network expands into emerging economies, many new ports are either in development or planned around the world.

With Arctic sea-ice retreating, this beleaguered region is now seen as a short-cut between the Pacific and Atlantic Oceans and a hotspot for natural resource extraction and industrial development. Arctic shipping is already increasing and with it the full range of associated environmental risks. For fragile Arctic ecosystems, the consequences of an accidental oil spill could be more severe than anywhere else. Black carbon emissions make Arctic snow and ice less reflective, sharply exacerbating its climate heating effect. Underwater noise pollution from ships is now doubling in less than three years, faster than anywhere else in the world. Shipping has been found to be responsible for almost half of invasive species arriving in Arctic waters. The use of nuclear ships and power plants risks creating its own particular problems. The Indigenous Peoples of the Arctic (about 10% of the 4 million living there) are in the frontline of rapid and profound change, with extractive industries reaching into previously inaccessible areas and shipping routes encroaching on their traditional spaces for hunting, fishing and transportation.

HUMAN HEALTH

Ships generally use the cheapest and worst-quality fuel, and many of the emissions are important contributors to poor air quality, particularly in port cities and areas of high shipping density.

The tar-like heavy fuel oil (HFO) used by most ships releases a wide range of pollutants, with SO_x, NO_x and fine particulates (PM_{2.5}) the most common. Atmospheric SO_x and NO_x also contribute to soil and ocean acidification.

Each year poor air quality attributed to shipping emissions is responsible for about 250,000 early deaths as well more than six million cases of childhood asthma worldwide. These estimates are an improvement on historic values and reflect better health outcomes, with SO_x emissions from shipping having been reduced by the introduction in 2020 of a lower global limit on the sulphur content of fuel. In order to comply with this new sulphur cap ship operators can use 'scrubbers' that clean-out the pollutants from HFO. But this effectively turns atmospheric pollutants into marine pollutants because the estimated 10 gigatonnes of highly acidic and contaminant-laden effluents produced in this way worldwide each year can be discharged (legally) straight into the sea. The use of the novel and largely-untested very low sulphur fuels (VLSFO), quickly concocted to comply with the new global sulphur cap, may produce larger amounts of BC emissions and are suspected of causing engine damage and dangerous breakdowns.

The majority of ships are owned by wealthy countries (the EU, US, South Korea, Japan) but their owners use opaque and morally-questionable deals when they sell their end-of-life ships to avoid costly decommissioning in their own countries, yet still reap the economic benefits. More than 80% of shipbreaking is done in the developing countries of South Asia (such as Bangladesh, India and Pakistan), where pay, employment rights, workplace safety and environmental regulations are often lax. For the workers in shipbreaking yards, daily exposure to their high-risk and often toxic workplace, frequently without adequate health and safety equipment, means that injury, sickness and casualty rates are high.

Shipbreaking is considered one of the most dangerous jobs in the world and is still associated with child labour. Furthermore, the release of a vast range of highly toxic pollutants into the coastal and marine environments surrounding these shipyards leads to further degradation of the environment on which many of these communities rely for their livelihoods and wellbeing.

TIME FOR A NEW VISION

The maritime shipping sector stands at a crossroads, though the industry itself may be alone in not realising it. As this report captures, shipping's sustainability issues cannot be tackled fully by solely focusing on climate change and decarbonisation, hard as these challenges may be.

Given the strong interdependencies amongst the many threats posed by shipping, the urgent need to address all of the issues highlighted in this report in an integrated and coordinated manner should be self-evident. But to do so will require a fundamental rethink of the role shipping plays in a world facing the triple planetary crisis of climate change, pollution and biodiversity loss.

ACRONYMS

AIS	Automatic identification system
ECA	Emission control areas
DWT	Dead weight tonnage
GHG	Greenhouse gases
HNS	Hazardous and noxious substances
HFO	Heavy fuel oil
IMO	International Maritime Organization
IAS	Invasive aquatic species
LNG	Liquified natural gas (methane)
MARPOL	The International Convention for the Prevention of Pollution from Ships
MEPC	IMO Marine Environment Protection Committee. Committee established under the IMO to address environmental issues under IMO's remit
SOLAS	The International Convention for the Safety of Life at Sea
TEU	Twenty-foot Equivalent Unit is the exact unit of measurement used to determine cargo capacity for container ships. 1TEU = 1 container of dimension 20 x 8 x 8 (feet)
UNCTAD	United Nations Conference on Trade and Development
VLSFO	Very low sulphur fuel oil

1

KEY TRENDS IN GLOBAL MARITIME SHIPPING



GLOBAL TRADE

For most consumers maritime transport is the barely-visible backbone of the world economy, accounting for more than 80% of global trade by volume (UNCTAD, 2022). Over the past 40 years maritime transport volume has grown by 250% (UNCTAD, 2019). The sector is forecast to continue growing at an annual rate of up to 4%.

This worldwide web of specialised vessels, ports and infrastructure is also the great, ghostly facilitator of globalisation; compressing the vast, planetary distances; making everything available everywhere. As such, the vigour of international maritime trade is tightly linked to global production (UNCTAD, 2022) but even the shocks delivered by the 2008/2009 global financial crisis and, more recently, the Covid-19 pandemic only temporarily interrupted the shipping industry's long-term expansion (see Figure 1). In part this is because increasing the size of modern vessels has enabled shipping costs to be kept low, seemingly regardless.

As of 2023 there were more than 100,000 ships in the world's merchant fleet, with a total carrying capacity of 2.2 billion dead weight tons (UNCTAD, 2022; UNCTAD statistical data¹). Bulk, dry cargo and containers represent about two thirds of total trade volume, the remainder being oil, gas and chemicals (Figure 2).

Developing countries are responsible for 55% of global goods exports and 61% of imports. By volume Asia is the top trading region, followed by the Americas, Europe, Oceania and Africa (UNCTAD, 2022). Among the world's top five trading ports all but one (Singapore) are in China.

The distribution of shipping traffic shown in Figure 3 demonstrates how concentrated it is along key routes.

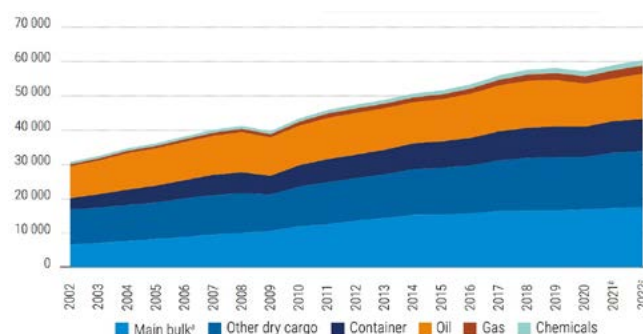


Figure 1: Growth in international trade 2002-2022 in billions of cargo tonne-miles. Data for 2021 and 2022 are estimates. Main bulk category includes iron ore, grain, coal, bauxite/alumina and phosphate. Other dry cargo includes minor bulk commodities, containerised trade, and residual general cargo. Source: UNCTAD, 2022.

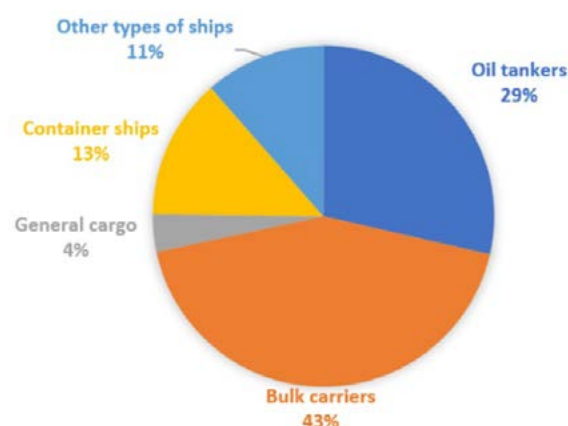


Figure 2: World fleet principal vessel types in 2022, by share of dead-weight tonnage. Data source: <https://unctad.org/statistics>

¹ <https://unctad.org/statistics>

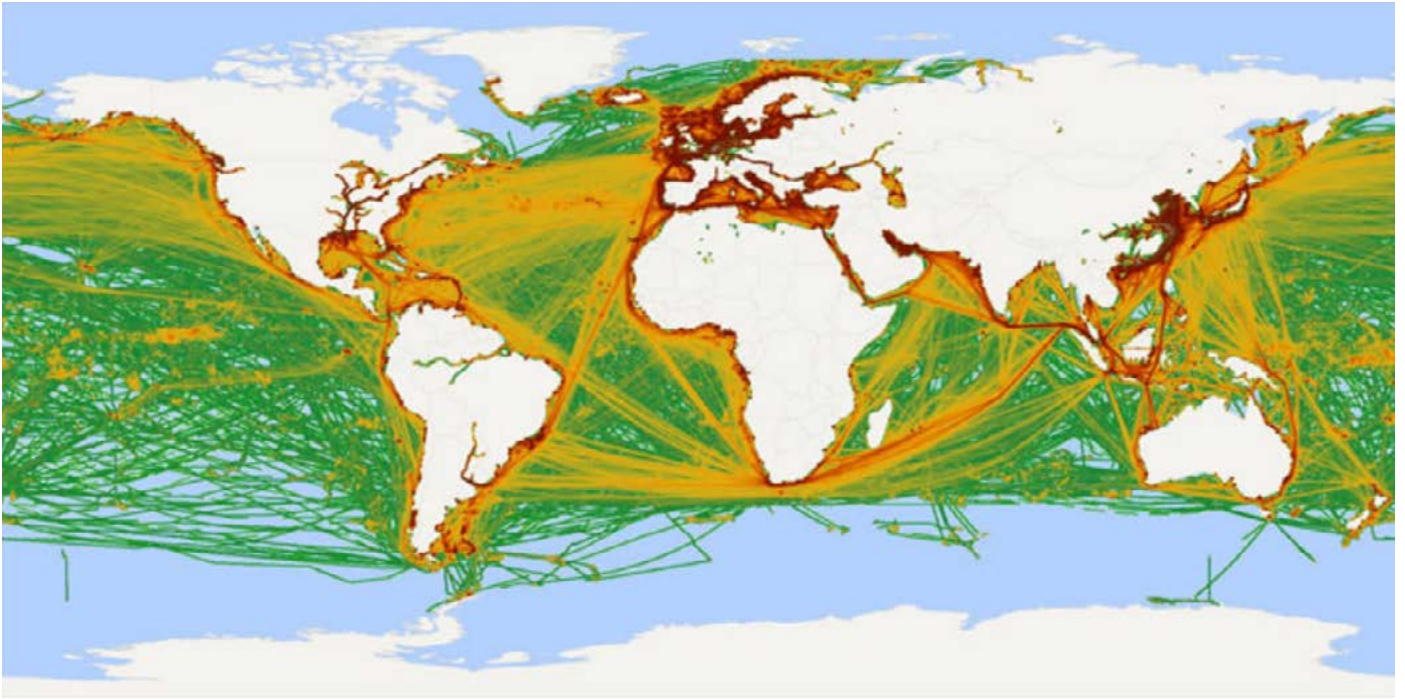


Figure 3: Global vessel density in April 2015 derived from AIS. Credit: Wu et al., 2017.

MORE SHIPS

The world's shipping fleet has been growing steadily since the early 20th century (*Figure 4*), reaching more than 100,000 ships (2.2 billion dwt) in 2023. Bulk carriers and oil tankers account for almost three-quarters of total carrying capacity (*Figure 4*). The number of liquified gas carriers (not shown) has lately grown most strongly (thanks to strong global gas demand), followed by container ships (UNCTAD, 2022).

OLDER SHIPS

Nonetheless, the fleet is ageing. Marine vessels have long service lives and their average age has increased from 20 to 22 years since 2011 (UNCTAD, 2022). This is important because older ships find it harder to comply with increasing environmental regulation. The lack of a clear international policy and regulatory framework for reducing the fleet's greenhouse gas (GHG) emissions is partly caused by the reluctance of owners and operators to invest in new ships (UNCTAD, 2022).

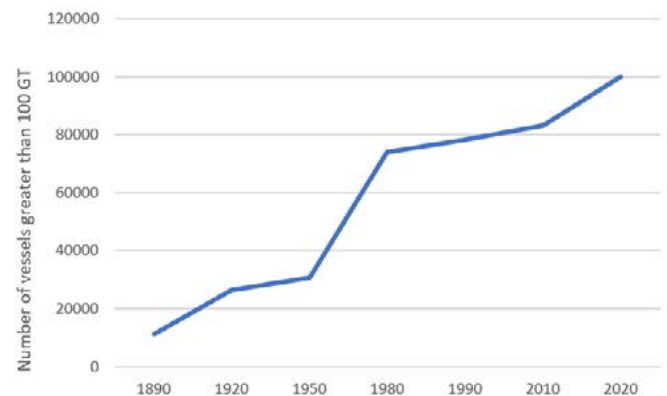


Figure 4: Historical trend in the number of ships, 1890-2020. Data source: composite of historical data from Lloyds Register collated in Laist et al., (2021) and UNCTAD stats data for recent years.



Figure 5: The Ever Alot, currently the largest mega-container ship in the world. With a carrying capacity of 24000 TEU, it measures 400m long and 61.5m wide. Credit: Hasenpusch Productions/www.hafen-hamburg.de

BIGGER SHIPS

The average size of ships has increased substantially in recent decades because larger vessels reduce the shipping costs per unit (things like crew, fuel, insurance, maintenance, etc.), making ever-larger ships attractive investments for shipping companies.

Container ships are the work-horses of the globalised economy, essential to the worldwide supply of goods even though they account for fewer than one-in-ten of the entire fleet (Merk et al., 2015). No ship type has grown faster than container ships; capacity has increased by 1,500% in 50 years (Allianz, 2021). Since the early 2000s the proportion of so-called mega-container ships – with a container capacity greater than 10,000 TEU² – has reached 40% of the global container fleet. Since 2017 74 ships bigger than 20,000 TEU have joined the fleet (UNCTAD, 2022). There is little to suggest that this trend will stop anytime soon as the feasibility of ships holding 30,000 TEU (and more) is already under consideration (Jungen et al., 2021).

It can be argued that larger vessels are an improvement because they are more fuel-efficient (Jungen et al., 2021, UNCTAD, 2022) and younger, and thus more likely to have been built in line with more recent environmental regulations. But bigger ships bring their own environmental and operational safety challenges. For example, they often require additional dredging (see Chapter 13) to enlarge or deepen channels and berths (Merk et al., 2015). If, and to what extent, the size of these vessels increases, the risks of ship strikes to whales and other large animals are yet to be determined.

Without question the sheer size of these mega-vessels makes it harder for them to respond effectively in an emergency, such as by finding a port of refuge with suitable access and infrastructure or the necessary specialist salvage equipment. This is especially true in developing countries. Mega-vessels have thus increased the risk of catastrophic losses such as oil spills and discharges of polluting cargoes (see Chapters 4 and 5), and the scale of the consequential impact on nature, the environment and human communities. The insurance company Allianz estimates that a major incident involving two mega-container/passenger vessels in an environmentally-sensitive region could cost more than \$4 billion (Allianz, 2022).

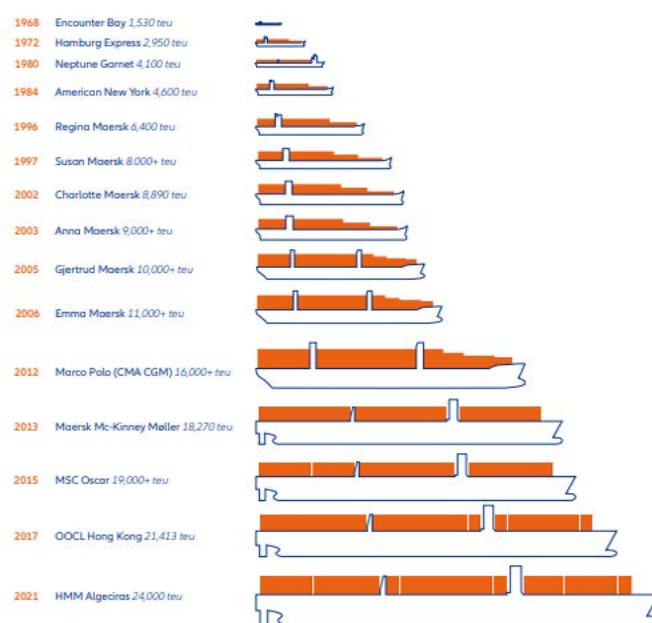


Figure 6: Container-carrying capacity has increased by around 1,500% since 1968 and has almost doubled over the past decade. Even larger vessels are on order. Credit: Allianz, 2022.

A SECTOR IN TRANSITION

Like many other sectors of the world economy maritime transport has been disrupted by recent global events, such as the Covid-19 pandemic, and is having to adapt to large scale structural shifts. Supply chain vulnerabilities experienced during Covid-19, trade tensions and geopolitical unrest are all pushing companies to build more resilience into their supply chains and to find ways to insulate themselves against future shocks. Moving production closer to consumption centres ('onshoring') and the sourcing of more supplies from close at hand are expected to lead to less trans-continental transport, more regional or local supply chains and shorter average transport distances. But, on the flip side, emerging and fast-growing economies are taking a larger share of world trade, with the web of global shipping expected to expand south- and eastward and to intensify around emerging economies. Other trends shaping the sector include new consumption patterns (as e-commerce takes hold) and the digitalisation and automation of transport and logistics (UNCTAD, 2022).

2 Twenty-foot Equivalent Unit is the exact unit of measurement used to determine cargo capacity for container ships. 1 TEU = 1 container of dimension 20 x 8 x 8 (feet).

2

CLIMATE CHANGE



Ships, like almost every other type of modern transportation, rely on fossil fuels. Their emissions contribute significantly to the climate crisis (IPCC, 2022). Whilst maritime transport is considered an ‘efficient’ form of transport – it emits fewer greenhouse gases (GHG) per tonne-kilometre than most other forms of transport – the sheer scale and continuous growth of the shipping industry has put it among the top 10 contributors to global heating.

Meeting the climate mitigation goals of the Paris Agreement will require transformational change in the whole transport sector, and that includes shipping (IPCC, 2022).

SHIPPING’S CONTRIBUTION TO CLIMATE CHANGE

The global shipping industry is responsible for about 12% of total transport-related CO₂ emissions (about the same as aviation) or 3% of all the CO₂ emissions caused by human activity (anthropogenic) worldwide; about the same as major carbon-emitting countries like Germany or Japan – or the entire African continent (SLOCAT, 2021; Crist, 2009)³. Shipping continues to increase its absolute level of GHG emissions – now 9.6% higher than a decade ago – whilst also growing its overall share (IMO, 2020). Operational efficiency gains have reduced shipping’s carbon intensity but have been more than offset by the increase in global shipping activity (IMO, 2020). International shipping accounts for 70% of total shipping emissions, the remaining 30% being from domestic activity.

CO₂ is the main source of shipping’s climate impact, accounting for 91% of total carbon emissions (measured in CO₂e⁴) from international shipping (IMO, 2020). Black carbon – the small soot particles in engine exhausts, which have an extremely strong climate-heating effect – accounts for 21% of CO₂e emissions on a 20-year timescale and 7% on a 100-year timescale⁵ (Olmer et al., 2017). Other GHG emissions include methane (CH₄), a strong climate-forcer released by ships using gas or dual-fuel engines, or via leaks from liquefied natural gas (LNG) carriers. In addition, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF₆) are GHGs used as refrigerants in air conditioning and cargo cooling systems. Nitrogen oxides (NO_x), sulphur oxides (SO_x) and carbon monoxide (CO) are also short-lived climate forcers. Other GHG emissions include particulate matter (PM) and non-methane volatile organic carbons (NMVOCs).

As well as contributing towards global warming, some of the aforementioned compounds (including SO_x and NO_x) are also important atmospheric pollutants harmful to human health (see *Chapter 3*). CO₂, SO_x and NO_x all contribute to ocean acidification as well (Hassellöv et al., 2013).

3 Climate Watch Historical GHG Emissions. 2022. Washington, DC: World Resources Institute. Available online at: climatewatchdata.org/ghg-emissions. Retrieved April 2023 <https://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE>.

4 CO₂ equivalent is the concentration of CO₂ that would cause the same radiative forcing as a given mixture of CO₂ and other forcing components (IPCC glossary).

5 CO₂ and BC have different radiative efficiencies and have different atmospheric lifetimes. The 20- and 100-year timescale warming potentials are used to compare and account for different gases.

Shipping emissions are concentrated in a handful of ship classes. Container vessels, bulk carriers and oil tankers (*Figure 7*) are by far the main sources of carbon emissions. Together with general cargo ships and tankers (chemical and LNG), these classes also contribute about 85% of total global shipping emissions when calculated on a per-voyage basis, in other words the emissions caused by a journey between two ports in different countries (IMO, 2020). Estimates based on the fuel consumption of different ship types indicate that container, cruise and vehicle carrier ships make the largest relative contribution. However, when both domestic and international emissions are taken into account, cruise ships have the highest per ship fuel consumption and emissions (IMO, 2020).

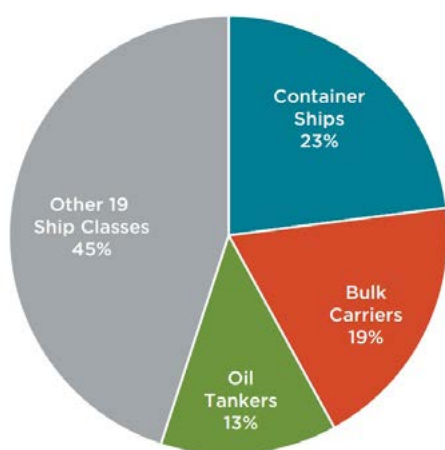


Figure 7: Share of CO₂ emissions by ship class.
Credit: Olmer et al., 2017.

Black carbon (BC) emissions are of particular concern because of their strong climate-forcing capabilities. Studies estimate that larger ships are responsible for most BC emissions (Comer et al., 2017). Container ships, bulk carriers and oil tankers together produce 60% of the total. Within this group, container ships (7% of the global fleet but 14% by dead weight tonnage) emit the most BC (26% of the global shipping total). Cruise ships account for 6% of BC emissions despite accounting for less than 1% of the global fleet (Comer et al., 2017). Given BC's lifespan in the atmosphere of just days, reducing these emissions would have an immediate effect in reducing shipping's climate impact.

Shipping relies on a range of predominantly fossil fuel-derived energy sources (including heavy fuel oil, marine diesel oil, LNG), mostly for propulsion but also for heating, lighting, etc. Heavy fuel oil (HFO) – the tar-like by-product of crude oil refining, also known as bunker fuel or residual fuel oil – is the principal fuel in international shipping (79% of all fuel consumed in 2018, measured by energy content). HFO also produces more BC than cleaner distillate fuels (Comer et al., 2017) like marine diesel oil (which powers just 6% of shipping) or liquefied natural gas (1%) (IMO, 2020).

THREE DECADES OF SLOW PROGRESS ON SHIPPING EMISSION REDUCTIONS

Emissions from fuel used in maritime transport have been in scope of international climate change mitigation efforts since the United Nations Framework Convention on Climate Change (UNFCCC) entered into force in 1994, nearly 30 years ago. The 1997 Kyoto Protocol called for reductions in GHG emission from marine bunker fuel, and yet it was not until 2013 that the IMO initiated measures aimed at reducing shipping's carbon footprint (see *timeline in Table 1*).

Table 1: Short-term measures adopted by IMO under the MARPOL Convention in line with its Initial Strategy to reduce carbon emissions in international shipping. (Adapted from IEA Energy Technology Perspectives 2020 and updated to include latest measures).

Name	Geographic scope	Year introduced	Description
Energy Efficiency Design Index (EEDI)	Global	In force in 2013	First legally-binding climate change regulation targeting international shipping. Requires minimum energy efficiency per tonne-km for new large vessels. Mandates improvement steps depending on vessel type – 10% in 2015, 20% in 2020 and 30% in 2030 – compared to the average performance of vessels built between 2000 and 2010. NB: the EEDI does not imply a limit on absolute emissions.
Ship Energy Efficiency Management Plan (SEEMP)	Global	Adopted in 2016	Monitors ship efficiency performance in existing and new ships. Mandates collection and submission of relevant data and establishes mechanisms to improve efficiency of existing ship operations. NB: SEEMPs are mandatory but there are no binding rules for what they should contain or the improvements required.
Data collection systems (DCS) for fuel oil consumption	Global	2018	All ships over 5,000 tonnes engaged in international voyages must collect consumption and other data for each type of fuel oil consumed. Flag states must collect and aggregate the data and submit to the IMO. NB: DCS is a data collection system with no requirement to reduce emissions.
Energy Efficiency Existing Ship Index (EEXI) and annual operational carbon intensity indicator (CII)	Global	2022	Requires all ships to calculate their EEXI and adopt technical measures to improve their energy efficiency (believed to be most easily achievable through main-engine power limitations). Ships are also expected to calculate their annual operational carbon intensity indicator (CII), on a scale of A to E, which links their GHG emissions to the amount of cargo carried over distance travelled. Administrators, port authorities and stakeholders are encouraged to provide incentives to ships rated as A or B. Ships rated D for three consecutive years, or E, are required to submit corrective action plans. NB: No limit on absolute emissions, and requirements have been set so low that they are, broadly speaking, equivalent to the improvement in energy efficiency that was taking place spontaneously and in the absence of regulation. No sanctions for non-compliance.

The 2015 Paris Agreement commits countries to emissions reductions across all sectors. However, the reporting of international emissions under the Agreement (including those from shipping and aviation) is at the discretion of the individual country and, if done at all, must be reported separately, which invariably results in international shipping emissions being left out of national emission reduction commitments⁶.

The lack of clarity under the Paris Agreement about how to account for international shipping emissions, and the implications for effective governance, was raised in the latest IPCC report (IPCC, 2022). The report further notes that ‘improvements to national and international governance structures would further enable the decarbonisation of shipping’ (IPCC, 2022).

⁶ <https://unfccc.int/topics/mitigation/workstreams/emissions-from-international-transport-bunker-fuels>

INITIAL IMO STRATEGY ON REDUCTION OF GHG EMISSIONS FROM SHIPS

The IMO's 2018 Initial Strategy is a high-level international policy framework intended to lay out a pathway to reduce shipping's GHG emissions. It envisages the phase-out of GHG emissions from shipping as soon as possible this century (IMO, 2018). Specific objectives include:

- Carbon intensity reduced by at least 40% by 2030, and 70% by 2050 (from a 2008 baseline).
- GHG emissions to peak 'as soon as possible', with annual emissions cut by at least 50% by 2050.
- 'Pursuing efforts towards phasing out [GHG emissions] as soon as possible' this century and achieving a reduction in CO₂ emissions 'consistent with the Paris Agreement's temperature goals'.
- Increased energy efficiency for all new ships.

The short-term measures proposed to reduce carbon intensity in line with this strategy fall into two categories: operational and technical (*listed in Table 1 above*). Mid- and long-term measures currently under discussion include implementing market-based measures (such as cap-and-trade and levies) to raise revenue and incentivise emissions reductions along with the introduction of a global fuel standard (IMO ISWG-GHG 12/INF.2, IMO MEPC 77/7/17, IMO ISWG-GHG 10/5, IMO ISWG-GHG 12/3/5).

DECARBONISATION

Shipping climate emissions depend on a range of factors but three in particular: fuel type (including emissions during production, transport and storage); the ship-board technologies in use (including engine type); and certain operational factors, especially speed.

To be successful any pathway towards reducing the sector's dependence on fossil fuels is likely to be a hybrid of policies and measures aimed at several targets: reducing demand; increasing investment (by business and government); developing the technologies needed to create alternative zero-carbon fuels and means of propulsion; and constructing the necessary infrastructure at-scale and in a timely fashion (IPCC, 2022).

ALTERNATIVE FUELS AND ENERGY SOURCES

Most shipping emissions stem from the use of fossil fuels, hence much work is being done to develop alternative means of propulsion and low/zero-carbon fuels, as well as to scale-up their availability. *Figure 8* shows the types of fuels currently being considered.

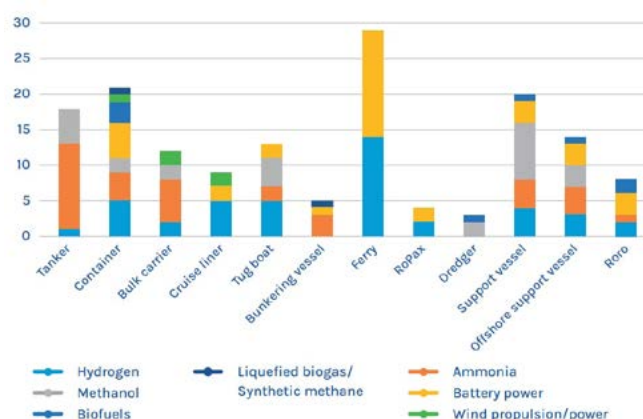


Figure 8: Total number of ship technology projects by ship type fuel focus 2016-2022. Credit: Baresic & Palmer, 2022.

LNG deserves a special mention here because it is widely touted as a ‘transition fuel’ key to the short-term decarbonisation of shipping. This argument ignores the fact that LNG is nothing more than liquefied methane, itself a GHG 30 times more potent than CO₂. Studies show that unburnt LNG fuel (in the form of so-called methane ‘slip’ from dual-fuel internal combustion engines, but also from methane leakage throughout the LNG supply chain) can result in higher overall CO₂e emissions than traditional marine fuels (Comer, 2022). Even the use of 100% renewable LNG would increase GHG emissions (Comer et al., 2022). In short, LNG fuel cannot help the shipping industry decarbonise in any meaningful way. It is also incompatible with the Global Methane Pledge launched at COP26 in November 2021, under which countries committed to collectively reduce methane emissions by at least 30% below 2020 levels by 2030⁷.



Figure 9: Prototype of fully wind-powered vessel.
Source: Wallenius Marine

Details on the range of alternative fuels currently under consideration (including biofuels, hydrogen, ammonia and methanol), as well as their respective advantages and disadvantages, can be found in Balcombe et al., (2019), IRENA (2021) and Together in Safety (2022).

Particularly noteworthy are the R&D projects exploring the use of the cleanest, quietest and most cost-efficient energy source of all: wind power. This technology – used either to improve the energy efficiency of conventional ships or as the main source of energy for a new generation of merchant vessels – has the potential to play an important role in the decarbonisation of the sector (Chou et al., 2020; IMO MEPC 79/INF.21). The first wind-assisted ships are already in operation and various initiatives around the world are looking into wind-assisted propulsion and fully wind-powered cargo shipping (Figure 9).

VESSEL EFFICIENCY IMPROVEMENTS

A variety of new designs and operational improvements are becoming available to improve ship’s energy efficiency. These include: improved biofouling management (biofouling has been found to increase GHG emissions by up to 55% (IMO, 2022)); more efficient main engines; optimised propellers; the design or retrofitting of hulls that reduce drag and improve fuel efficiency; and adjustments to ship size and weight (larger ships see increased efficiencies and reduced fuel consumption). Operational changes include: routing optimised for weather; optimising the trim, draft and ballast of vessels; reductions in onboard power demand or the use of shore power when in port; and preventing hull and propeller roughness to reduce resistance through the water.

Limiting speed could however make the biggest contribution to improving efficiency and be the easiest way to reduce emissions in the short term (Elkafas & Shouman, 2021). Regulatory action by the IMO or at the national or regional level could lock those benefits in.

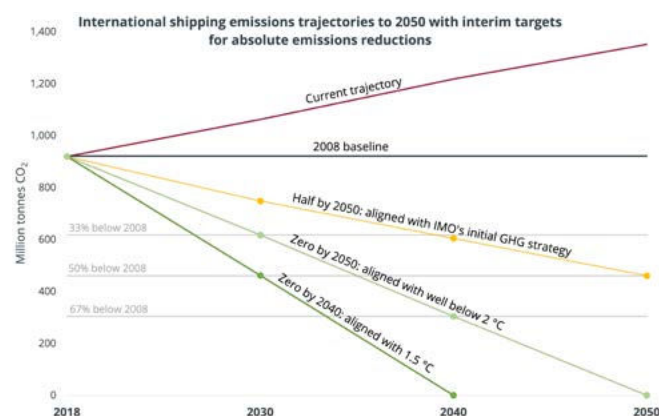


Figure 10: International shipping emissions pathways consistent with Paris Agreement temperature goals. Credit: Comer, 2021.

⁷ <https://unfccc.int/topics/mitigation/workstreams/emissions-from-international-transport-bunker-fuels>

OUTLOOK

Maritime shipping is responsible for 3% of global anthropogenic GHG emissions and these emissions are continuing to grow rapidly (IPCC, 2022). According to the IMO's own estimates business-as-usual would see shipping emissions increase more than five-fold by 2050 (IMO, 2020). Shipping's share of global emissions has also increased (IMO, 2021), implying that the sector is out of step with worldwide efforts to decarbonise commerce (IPCC, 2022). If the industry does not act and begin making a fair contribution to reducing GHG emissions, it could be responsible for 17% of total global emissions by 2050 (Cames et al., 2015).

There is widespread agreement among key observers (IPCC, OECD, IEA and ICCT, to name but a few), major industry stakeholders (Søgaard et al., 2021) and many individual countries that the IMO's current GHG targets and reduction measures are woefully inadequate to the task of aligning maritime transport with the Paris Agreement goals and to trigger the transformation needed to decarbonise the sector. Indeed, the most recent IPCC report (IPCC, 2022) signalled that improvements to national and international governance structures might be required before shipping can achieve decarbonisation.

Analysis of the various emission trajectories for shipping (*Figure 10*) indicates that the ambitions contained in the IMO's Initial Strategy will cause the sector to overshoot any targets compatible with the Paris Agreement, and to do so by a very large margin. To stay within the 2°C limit would require GHG emission reductions of one-third by 2030 and full decarbonisation by 2050. To meet the preferred Paris Agreement limit of 1.5°C would require a reduction of one-half by 2030 and full decarbonisation by 2040. Further delay in action will only mean steeper emission reductions will eventually be needed and bring the zero-emissions deadline even closer (Comer, 2021).

The inadequacy of the IMO's Initial Strategy has nevertheless spurred much-needed discussion of what is really required in terms of stronger policies to decarbonise shipping. A shift to renewable energy sources is fundamental to these efforts (IPCC, 2022, Baresic et al., 2022). In turn, that means development of a worldwide shipping fleet powered by zero emission energy sources as well as the infrastructure and supply chains to deliver new fuels synthesised from renewable energy in very large quantities all over the world (Smith 2019). How to trigger such a shift? As with other sectors there is no one-size-fits-all route to decarbonisation. As an industry with truly global presence, reach and economic significance there is general agreement that the mobilisation must start with governments and international regulators raising their ambitions, and acting to develop the policies, financing mechanisms, demand and technology base that can enable the industry to create the level playing field it needs for an equitable transition (Smith et al., 2021).

Among the measures being proposed are market-based interventions, improved regulation, information campaigns to influence behaviour, as well as a number of voluntary initiatives and actions at the national and regional levels (Baresic et al., 2022). The right policy mix might also include economic instruments to create value-generating opportunities for shipping companies.

A central challenge is to overcome the competitiveness gap between cheap conventional fuels and zero-emission alternatives which can be twice as expensive (Baresic et al., 2022). Responses include setting a price on carbon, creating emissions trading systems (ETS) and/or using tax breaks or subsidies to reduce the costs of zero-emission alternatives. From 2024 the European Union's ETS will apply to emissions from large ships calling at EU ports, regardless of the flag they are flying or the location of their registered ownership. ETS, along with a number of the other measures mentioned above, are currently under discussion at the IMO as part of the work to revise the Initial Strategy, due for completion in 2023 (IMO MEPC 80/INF.39).

The momentum behind raising shipping's decarbonisation ambitions has been building for several years. In late 2021, in anticipation of COP26, the Getting to Zero Coalition (more than 200 organisations and companies across the maritime, energy, infrastructure and finance sectors) issued a Call to Action for Shipping Decarbonization (Søgaard et al., 2021; Global Maritime Forum, 2021b). It urged regulators to set a target for zero-emissions shipping by 2050 (in line with the Paris Agreement) and to deliver practical progress, such as a meaningful market-based measure to make zero-emissions shipping economically viable (Søgaard et al., 2021). The revenue generated by an ETS mechanism (or other market intervention) could help meet the costs of the necessary new fuel infrastructure (Baresic et al., 2022). Since COP 26 the voices calling for shipping to raise its ambitions have been joined by the World Bank and the Science Based Targets initiative⁸ (SBTi – a global body supporting businesses in setting emission reduction targets in line with climate science).

If decarbonisation is to be achieved by 2050 an estimated \$1.4-1.9 trillion will need to be invested between 2030-2050 to create a new, primarily land-based, fuel production and distribution infrastructure. Research suggests that these costs could be fully met from the revenues generated by emissions-based interventions like levies/taxes, 'feebates' or an emissions trading system (Baresic et al., 2022).

The shipping industry as a whole also has much to lose from climate change. A recent study estimated that climate change-related losses to the sector (such as damage to port infrastructure and falling demand) could amount to \$25 billion per year by 2100 (Van Houtven et al., 2022). Another study has calculated that each year of delay in the start of material reductions in emissions will add \$100 billion to the total cost of decarbonising the sector (Smith et al., 2022).

8 <https://sciencebasedtargets.org/news/sbti-launches-world-first-roadmap-for-net-zero-shipping-by-2040>

3

AIR POLLUTION



Watch the black smoke coming out of a ship's funnel and it is easy to understand how the cheap, poor quality, heavy fuel oil (HFO) burnt by most ships is not only contributing to climate change (*discussed in Chapter 2*) but also doing direct harm to the health of humans and the environment. Atmospheric pollution from shipping has rightly been attracting increased attention in recent decades having been recognised as a growing problem with serious implications that recognise no boundaries.

SHIPPING'S CONTRIBUTION TO HARMFUL ATMOSPHERIC EMISSIONS

Shipping emissions are heavily influenced by the type of fuel burned in the ship's engine. The main source of all shipping emissions is the widespread combustion, in large diesel engines, of a fuel which is composed mainly of 'residuals' (in effect, waste products) from the crude oil refining process.

Atmospheric emissions from ships include carbon dioxide (CO₂), sulphur oxides (SO_x), nitrogen oxides (NO_x), carbon monoxide (CO), black carbon (BC), organic carbon, ammonia (NH₃), and non-methane volatile organic compounds (NMVOC). Some of these compounds – in particular NO_x and SO_x – are major contributors to the formation of secondary fine particles (PM_{2.5}⁹) and ground-level ozone (Eyring et al., 2010; Lv et al., 2018). SO_x, NO_x and PM_{2.5} are generally understood to be the most common pollutants from maritime transport.

Before the introduction of a range of measures to limit harmful emissions from shipping (more on this later) around 15% of total global man-made NO_x and between 4% and 9% of SO₂ emissions were from ships (reviewed in Eyring et al., 2010). The atmospheric lifetime of NO_x and SO_x ranges from several hours to nearly a week, so the highest concentrations and strongest deposition are found close to the source, but can extend hundreds of kilometres inland (Endresen et al., 2005; Eyring et al., 2005). Unsurprisingly, major ports and areas of high shipping traffic are pollution hotspots (Eiof Jonson et al., 2020; Endresen et al., 2005).

⁹ Smaller than 2.5 µm in diameter

HUMAN AND ENVIRONMENTAL HEALTH IMPACTS

Each year poor air quality caused by international shipping is thought to cause about 400,000 early deaths from lung cancer and cardiovascular disease as well as about 14 million cases of asthma in children worldwide. This represents more than 15% of all deaths attributable to transport-related emissions including road transport, and an annual cost to global society of \$158 billion (Anenberg et al., 2019). The contribution from shipping emissions is particularly high in the United Kingdom (38%) and Japan (41%) (Anenberg et al., 2019).

When comparing international and domestic shipping activity it is emissions from international traffic that make the biggest contribution to shipping-related health impacts (*see Figure 11*). Though in some regions – including northern European countries, China, and Japan – ship-derived health impacts are also strongly associated with domestic shipping (Zhang et al., 2021).

The environmental impacts of shipping emissions stem from the contribution of SO_x and NO_x to the formation of a variety of acids when in contact with water; the 'acid rain' (sulphuric and nitric) that jump-started the environmental movement in developed countries in the 1960s. Atmospheric SO_x and NO_x thus contribute to soil and ocean acidification (Blasco et al., 2014), doing considerable and well-documented damage not only to the environment but also to buildings and other heritage structures. In fact, SO_x and NO_x have been found to cause a similar degree of ocean acidification as increased atmospheric CO₂, but with potentially greater local environmental consequences because of the higher strength of sulphuric and nitric acids (Hassellöv et al., 2020).

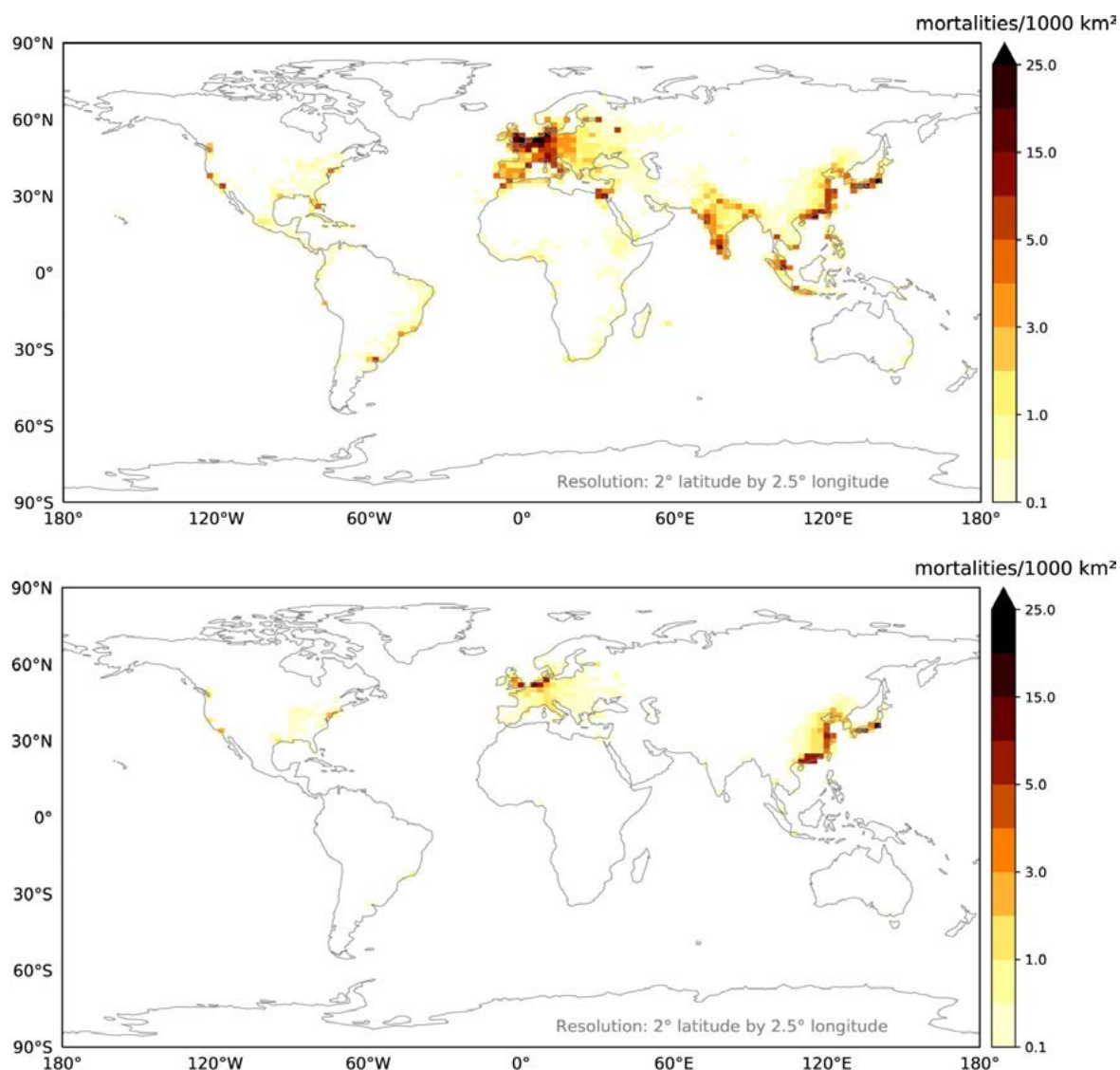


Figure 11: Global distribution of mortality associated with ship-related PM_{2.5} attributed to emissions from international (top) and domestic (bottom) vessels. Credit: Zhang et al., 2021."

THREE DECADES OF SLOW PROGRESS ON REDUCING ATMOSPHERIC POLLUTION

Mounting concern over decades has triggered a number of measures aimed at reducing polluting emissions from ships but regulation has been much less ambitious than for road transport.

Since the late 1990s the IMO has progressively curbed the sulphur content in fuel and NO_x emissions via engine-specific emission limits in so-called emission control areas (ECAs). In 'sulphur ECAs' the current sulphur limit in fuel is 0.1% by mass (m/m). Everywhere else a cap of 0.5% m/m has applied since the beginning of 2020 (see *Table 2*). To put things into context, the allowed sulphur content under this new regulation means that maritime fuel largely used around the world still contains 500 times more sulphur than the 0.001% maximum allowed for fuels used in European trucks or passenger cars (EC, 2020).

In terms of limiting NO_x emission, the IMO has established an NO_x framework of emission standards according to the age of the vessel (see *Table 2*).

Table 2: Evolution of international regulations under MARPOL Annex VI for sulphur and nitrogen emission reductions.
Adapted from Endres et al., 2018 and Karl et al., 2019.

International regulation of ship-derived sulphur emissions

	Date of regulation	Sulphur limits for fuel (% m/m) ¹⁰
Sulphur emission control areas (ECAs): Baltic Sea, North Sea and English Channel, North American area and US Caribbean Sea area (Puerto Rico and US Virgin Islands). Mediterranean Sea from 1st January 2025.	Before 1 July 2010.	1.5%
	1 July 2010 – 1 Jan 2015.	1.0%
	1 Jan 2015 - present.	0.1%
Other sea areas.	Before January 2012.	4.5%
	1 January 2012 – 1 January 2020.	3.5%
	Since January 2020 (IMO 2020 sulphur cap).	0.5%

International regulation of ship-derived nitrogen emissions

	Date of regulation	Total weighted cycle emission limit for nitrogen (g/kWh) ¹¹
Tier 1 regulation.	Vessels constructed on or after January 2000 with new engines greater than 130KW.	17 – 9.8
Tier 2 regulation.	Vessels constructed after 1 January 2011.	14.4 – 7.7
Tier 3 regulation.	For new vessels operating in nitrogen ECAs: Baltic Sea (2021), North Sea and English Channel (2021), North America (2012) and US Caribbean Sea area (Puerto Rico and US Virgin Islands) (2014).	3.4 – 1.96

Table 2, above, shows that mitigation strategies vary widely between SO_x and NO_x. This is because managing sulphur is about the type of fuel used; NO_x emissions depend on the combustion processes within a ship's engines, and hence can only feasibly be applied to new vessels. As a consequence, the effect of sulphur emission control measures are pretty much immediate, whereas the full impact of nitrogen emission reductions won't be apparent until the entire ship fleet is renewed, decades from now (Kalli et al., 2013).

¹⁰ For reference, the global average of sulphur content in HFO was 2.68% in 2002 (Endresen et al., 2005).

¹¹ Emission intervals reflect varying limits associated with different engine's rated speed (rpm).

UNINTENDED CONSEQUENCES OF THE IMO GLOBAL SULPHUR CAP (IMO 2020)

The January 2020 introduction of a new global upper limit for marine fuel sulphur content (0.5%, down from 3.5%) is known in the industry as 'IMO, 2020'. Established under MARPOL Annex VI, this mandatory measure was predicted to trigger a 77% reduction in total SO_x emissions from ships and a substantial reduction in the harmful effects on human and environmental health (Friedrich et al., 2007; IMO, 2020). The sulphur cap is undoubtedly a promising policy and preliminary evidence points to its success in reducing SO_x emissions (Younger 2022). However, IMO 2020 has also led to several unintended consequences.

The industry was given two options to comply with IMO, 2020: switching to compliant fuels (with most operators choosing to use a variety of newly developed very low sulphur fuel oils (VLSFO) over other compliant but costlier options); and installing exhaust gas cleaning systems, commonly known as 'scrubbers'.

SCRUBBERS

By removing sulphur dioxide from exhaust gases, scrubbers enable ships to continue using cheaper, high-sulphur HFO and still meet the IMO 2020 standards. SO_x emissions are controlled by spraying the exhaust gases either with seawater (open-loop) or an alkaline water solution (closed-loop), with the water subsequently discharged overboard (IMO MEPC 77/16/Add.1). This wastewater is highly acidic (from the sulphur and nitrates) and rich in the contaminants that have been filtered out of the exhaust emissions, such as heavy metals and polycyclic aromatic hydrocarbons (PAHs – known carcinogens) (Endres et al., 2018; Hassellöv et al., 2020; Hermansson et al., 2021; IMO PPR 9/INF.5; IMO PPR 10/INF.3; Koski et al., 2017; OSPAR 2022). Even closed-loop scrubbers – designed to store accumulated sludge for disposal on land – very often

lose highly-concentrated contaminated wastewater into the sea (Comer et al., 2020). Scrubber wastewater also introduces an entirely new contaminant into the marine environment: chromium (Hermansson et al., 2021).

Few studies have sampled and analysed scrubber wastewater to evaluate its ecological impact when discharged at sea, but one has found that it kills zooplankton (Koski et al., 2017). Furthermore, ecosystem-wide impacts are expected to be amplified through bioaccumulation of the various contaminants, whilst further contributing to ocean acidification and eutrophication (Hassellöv et al., 2020). Even before IMO 2020 came into force these obvious environmental concerns had prompted numerous countries to create their own special measures to control scrubber wastewater discharges (Osipova et al., 2021). As of 2023 nearly 50 countries have established such regulations (Comeret et al., 2020; NorthStandard, 2023).

Recent data (Osipova et al., 2021) indicate that around 4,000 vessels use scrubbers, 74% of them being either bulk carriers, container ships or oil tankers (*Figure 12*). One-third of cruise ships have scrubbers installed, the highest proportion of any ship type. The vast majority of scrubbers (85%) are open-loop.

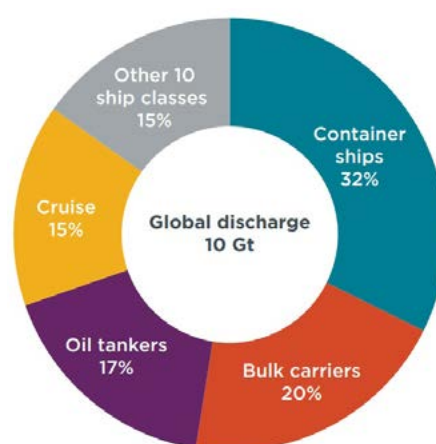


Figure 12: 2021 Scrubber wastewater discharges by ship type. Credit: Osipova et al., 2021.

It is estimated that a total of 10 gigatonnes of toxic scrubber wastewater is discharged into the oceans every year, 80% of it within 200 nautical miles of shore (inside a country's Exclusive Economic Zone). Hotspots are closely associated with shipping traffic bottlenecks, including around Europe, the Caribbean and the Strait of Malacca (*Figure 13*). Some even coincide with IMO-designated Particularly Sensitive Sea Areas (PSSA), which are deemed to require special protection because of their ecological value.

Of the scrubber wastewater discharged into PSSAs, two areas in particular receive 91% of it: the Western European PSSA (from the top of Scotland down the western seaboard to the Algarve, including the Irish continental shelf, Celtic Sea, the Bay of Biscay and western Iberia), and the Baltic Sea PSSA (Osipova et al., 2021). Among the other PSSAs affected are the Jomard Channel (Papua New Guinea) and Australia's Great Barrier Reef, both home to vulnerable tropical reef systems and, in the case of the latter, a UNESCO World Heritage Site.

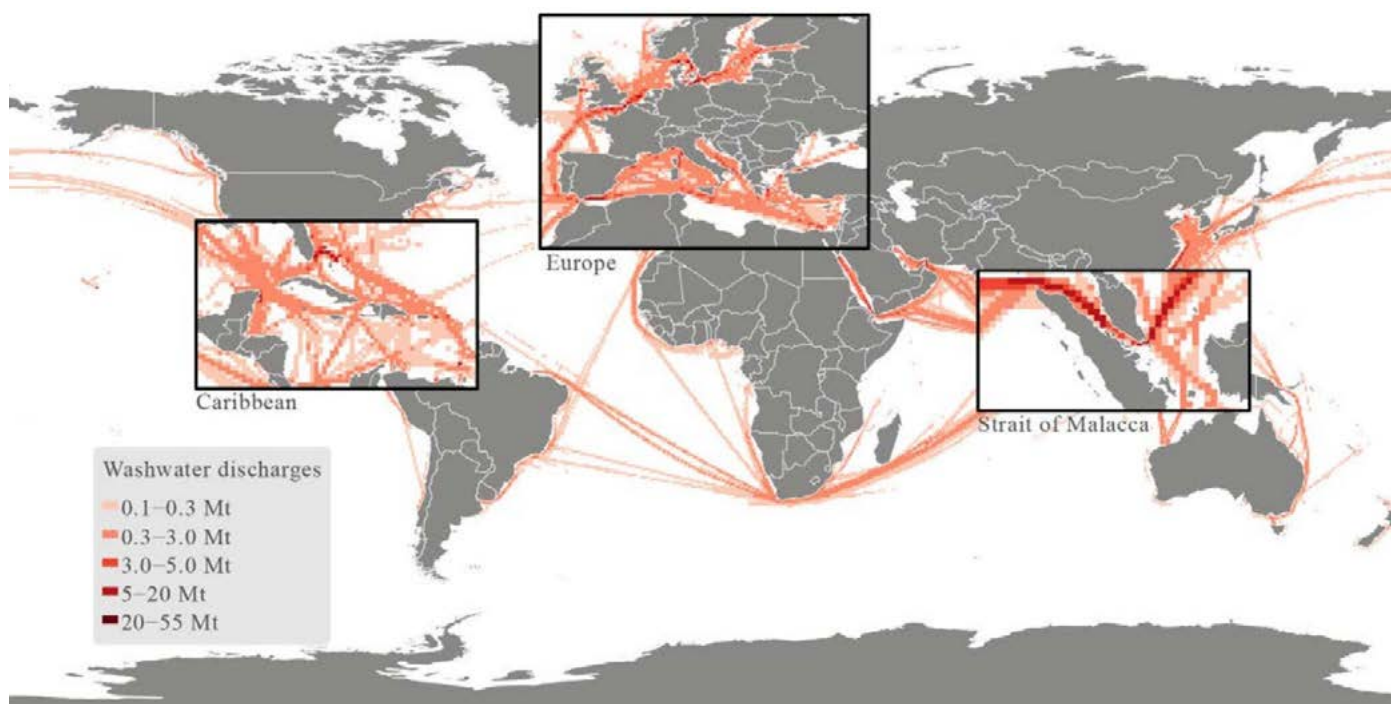


Figure 13: Global scrubber wastewater discharges distribution and hot spots. Credit: Osipova et al., 2021.

VERY LOW SULPHUR FUEL OILS (VLSFO)

VLSFO is a new class of marine fuel oils introduced to replace traditional HFO and comply with the IMO 2020 sulphur cap. The majority of ships worldwide have now switched to VLSFO. Unfortunately, this wide-scale introduction of a new class of largely-experimental fuel, introduced without much testing or scrutiny except for its sulphur content, has generated an entirely new set of challenges.

There is industry-wide concern about reports of major engine damage and breakdowns linked to the use of VLSFO (Allianz, 2022; Ju & Jeon, 2022; Kjellström, 2021, Singh & Shanthakumar, 2022). Further, the chemical analysis of various types of VLSFO has found them to be composed of up to three-quarters of polycyclic aromatic hydrocarbons (PAH), one of the most environmentally toxic substances and capable of causing cancers and genetic mutation (IMO PPR 8/5/1). The International Transport Workers Federation (ITF) wants to see better understanding of the implications and risks to crew and safety management systems associated with the handling and use of VLSFO (ITF, 2021). In 2020 the UN's Human Rights Office (OHCHR) even began an investigation into possible human rights abuses associated with the global shipping industry and exposure to toxic chemicals¹².

In regard to environmental health, higher risks of an engine failure can mean higher risk of oil spills, lost cargo, etc. It is too early to say whether a VLSFO spill will behave differently, or lead to different environmental impacts compared to traditional HFO, especially given the wide variety of 'recipes' being used by refiners (Sørheim et al., 2020; IMO PPR 10/ INF.12). Testing of some VLSFO products has found reason to believe that their physical properties might make oil spills even harder to deal with (Sørheim et al., 2020). The MV Wakashio disaster in July 2020, off the coast of Mauritius, was the first large-scale oil spill involving VLSFO (Scarlett et al., 2021) and serious concerns have been raised about the possible role of the new fuel in the disaster (Degnarain, 2021).

Lastly, to add further to the environmental conundrum VLSFO increasingly poses, its use might also be increasing the shipping industry's carbon footprint. This is because the high aromatic compounds (PAHs) content – used to replace sulphur compounds as lubricants – is leading to higher black carbon emissions (IMO PPR 8/5/1).

¹² <https://www.ohchr.org/en/special-procedures/sr-toxics-and-human-rights/call-submission-sr-toxics-and-human-rightsimpact-analysis-international-maritime-organization-imo>

OUTLOOK

Shipping emissions, particularly from the combustion of heavy bunker fuel, carry with them significant environmental and health effects. While NO_x, SO_x and other pollutants from land transport have been greatly reduced by regulation in recent decades, emissions in shipping remain a serious problem (Karl et al., 2019; Omstedt et al., 2015). Efforts have been made but challenges and unintended consequences persist as the industry tries to transition to cleaner and safer fuels.

Calculations and observations indicate that the IMO 2020 0.5% sulphur cap on marine fuels should deliver a substantial reduction in the amount of SO_x that ships contribute to air pollution. In turn, the lower sulphur content could result in significant reductions in ship-related mortality (34%) and illnesses (54%) (Sofiev et al., 2018). Nevertheless, low-sulphur fuels are still believed to be responsible for about 250,000 deaths and 6.4 million childhood asthma cases each year (Sofiev et al., 2018). In short, despite the undoubted progress made, ship-based emissions continue to pose a threat to human health.

While lower-sulphur fuels are benefitting ecosystems on land (such as by reducing their contribution to soil acidification), the techniques being used to comply with the sulphur cap at sea are having concerning unintended consequences. The use of scrubbers to filter out sulphur from regular HFO has done little more than turn atmospheric pollutants into marine pollutants. Strongly-acidic and highly-polluting effluents can thus be discharged legally straight into the sea. The alternative to scrubbing is for ships to switch to established, more expensive fuels such as marine diesel oil or to newly-developed and largely-untested VLSFOs. But the latter are raising serious concerns for ship safety and the chemicals used to replace the missing sulphur are increasing emissions of other climate pollutants, like black carbon.

For comparison, maritime fuel which complies with the current 0.5% sulphur content limit still contains 500 times more sulphur than the 0.001% maximum allowed in the fuels used in European trucks and passenger cars (EC, 2020).

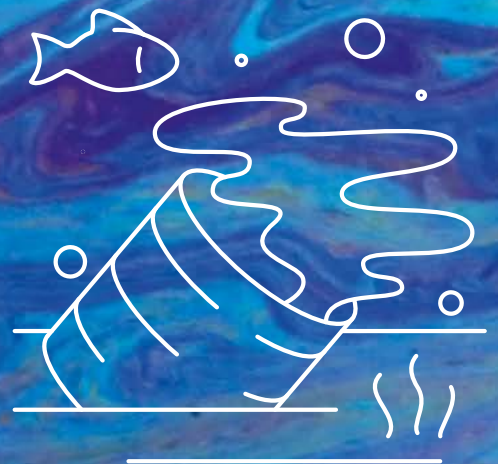
Clearly, much work remains to be done to fully understand the knock-on effects on the marine environment of the IMO 2020 sulphur cap and to develop appropriate, integrated mitigation strategies.

There are opportunities to reap important co-benefits from the work to decarbonise shipping (see *Chapter 2*). In particular the shift towards zero emission fuel could also bring important reductions in atmospheric pollutants. A study by Smith et al. (2019) indicates that a shift towards zero emission fuels would result in close to zero SO_x emissions and substantial reductions in dangerous particulates (PM). And, of course, the atmospheric emissions of any wind-powered ship would effectively be zero.

When it comes to reducing NO_x emissions it is hard to imagine much meaningful progress, in spite of the recently introduced regulations which will take time to show any benefits (Karl et al., 2019). In any case, estimates show that any emissions reductions will be offset by the growth in shipping traffic. Ultimately, since NO_x emissions are a by-product of the internal combustion process, they will still be produced when burning alternative fuels (Smith et al., 2019).

4

OIL SPILLS AND DISCHARGES



Oil spills are one of the most concerning sources of marine pollution. The bunker oil used to power most large ships is especially problematic because it is difficult to clean up and long-lasting, severely polluting marine ecosystems and coastal habitats along with the coastal communities and economies that rely on them (EMSA & EEA, 2021).

Large-scale oil spills – such as the well-known Exxon Valdez spill in 1989 – are normally the result of maritime accidents. Smaller discharges tend to be deliberate illegal discharges of oily ship effluents, though it is legal for ships to discharge some of the oily waste produced during their operation. A 2007 study by the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection (an advisory body to the UN) estimated that ‘smaller’, illegal discharges introduce significantly more oil into the ocean each year than big, headline-grabbing disasters (GESAMP, 2007). A further 2007 study, by the European Parliament, estimated the global annual total of all discharges (accidental, permitted and illegal) at 187,000 tonnes, resulting in total costs of €44 billion (Maffii et al., 2007).

ACCIDENTAL OIL SPILLS

While the amount of oil transported by sea has grown steadily – with a consequent increase in the risk of oil spills – the number of events involving oil tankers (as well as the amount of oil involved) has declined by about 90% since data-gathering began in the 1970s, see *Figure 15* (GESAMP, 2007; ITOPF, 2022). In the 2010s on average 16,400 tonnes were lost in accidental oil spills worldwide each year (ITOPF, 2022). For large spills – quantities over 700 tonnes – 60% are caused by collisions and groundings, followed by hull failures (13%), then onboard fires or explosions (11%) (ITOPF, 2022). Tankers transporting oil products are not the only vessels at serious risk of accidental spills. Any ship using oil-based fuel contains enough oil to do catastrophic harm. At particular risk are vulnerable coastal communities in developing states with ocean-based economies (UNCTAD, 2021).

The large reduction in accidental oil spills has mainly been achieved through the implementation of progressively tougher management measures in response to several massive oil spills in the 1960s and 1970s. The operational and construction regulations introduced by MARPOL (including double hulls), along with a range of other safety-related regulations – such as the introduction of traffic separation schemes, the designation of Particularly Sensitive Sea Areas, improved navigation equipment and international standards for seafarer training – have collectively and gradually lowered the risk. Meanwhile, initiatives by individual

countries have included updated hydrographic surveys (to make navigation safer), increased use of pilotage, and the pooling of resources to create regional response-management systems and infrastructure (Hassler, 2011).

In 1990 the IMO adopted the International Convention on Oil Pollution Preparedness, Response and Co-operation (OPRC Convention). Under this international co-operation and assistance framework individual states must develop national pollution-response systems and maintain the capacity and resources to tackle an oil pollution emergency (OPRC Convention, 1990).



Figure 14: 2019 oil spill from bulk carrier MV Solomon Trader in East Rennell, Solomon Islands, a UNESCO World Heritage site. Credit: Solomon Island Government / Greenpeace.



Figure 15: Decline in number of tanker spills vs. growth in crude and other tanker trade loaded, 1970-2020. Blue bars indicate number of oil spills over seven tonnes. The red line shows growth in crude and other tank trade loaded. Credit: ITOPE, 2022.

OPERATIONAL DISCHARGES

Ships produce a range of oily waste products during their routine operations, including: the cleaning of machine and engine spaces; sludge-type waste from crude-oil purification equipment; oil-contaminated ballast water when water has been carried in holds normally used for oil; tank-washing residues when oil tankers are cleaned using crude oil or a mix of oil and water.

PERMITTED DISCHARGES

The disposal of waste that contains oil is tightly regulated under MARPOL Annex I. Almost all ships are expected to store oily waste onboard in dedicated holding tanks, then dispose of it in port reception facilities. If a ship has equipment capable of filtering-out oil from its operational discharges to a maximum concentration of 15ppm then it is permitted to discharge it at least 50 nautical miles offshore. In Special Areas defined under Annex I, such as the Mediterranean and Baltic Seas, Antarctic waters and other areas around the world, restrictions are more stringent.

ILLEGAL DISCHARGES VIA 'MAGIC PIPES'

Intentional and illegal discharges of untreated oily waste are common nonetheless. To avoid detection most are done at night or in bad weather (Vollaard, 2017). The proper flow of effluents into holding tanks is 'by-passed' and waste piped directly overboard using a detachable 'magic pipe' (so called) which can be hidden when inspectors arrive (Figure 16). Alternatively, the ship's system is 'tempered' so that it fails to register when the waste being discharged is more than 15ppm oil. Both techniques require operators to falsify legally-mandated record-keeping (EMSA, 2012). Illegal disposals at sea are primarily motivated by the costs of maintaining treatment equipment and training staff, and the time and effort it takes to visit waste reception facilities (OECD, 2003; Interpol, 2007). One estimate puts environmental compliance costs at approximately 3.5% to 6.5% of a vessel's daily operating costs; a substantial potential cost saving across an entire fleet (OECD, 2003).



Figure 16: 40-foot flexible bypass hose ('magic pipe') with oil residue. Credit: Interpol, 2007.

Detection of illegal discharges is nowadays greatly facilitated by satellite radar surveillance. Visible traces of oil in the waters near a vessel suggest a possible violation of MARPOL Annex I (Interpol, 2007). Oil slicks can be traced back to sources other than ships (such as natural seeps or oil platforms). But these new techniques are now steadily unmasking a surprisingly large number of illegal discharges by ships, suggesting that the problem has been underestimated for a very long time (Dong et al., 2022; Evanisko, 2020). The 2007 GESAMP study estimated annual operational discharges of oil (comprising fuel oil sludge, bilge oil and oily ballast from fuel tanks) at 276,000 tonnes per year worldwide (GESAMP, 2007). But this estimate was based on an assumption of 100% compliance and is likely, therefore, to be a gross underestimate given the mounting satellite evidence of widespread non-compliance. The true scale of operational discharges (legal and illegal) thus remains unknown but ocean advocacy organisations believe it to be several times greater than the GESAMP estimate: 810,000 tons per year (MarineDefenders¹³); between 660,000 and 2.5 million tons (Oceana, 2010). Overall, and at a global scale, this suggests that the constant drip of illegal discharges might result in considerably more oil being released into the world's oceans every year than by the 'black tide' events that capture the attention of the media and general public."

EVIDENCE OF WIDE-SPREAD ILLEGAL DISCHARGES

Analysis of satellite data for coastal areas strongly suggests that illegal discharges are common in the world's shipping lanes, around large commercial ports, and in areas of significant energy infrastructure or heavy shipping congestion (Evanisko, 2020). Tell-tale signs include slicks trailing directly behind individual vessels. The aggregated data clearly shows the cumulative effect along the main shipping routes (*Figure 17*). The areas hit hardest (with the highest density oil slicks) are the Mediterranean and Black Seas, Persian Gulf and Strait of Hormuz, the Bay of Bengal, Strait of Malacca, the Java Sea, and the Yellow Sea (Dong et al., 2022). The Gulf of Guinea, the coast of Brazil and the Gulf of Mexico are also areas of concern (Evanisko, 2020). Because satellite monitoring scans some areas more often than

others, and because oil slicks dissipate more quickly in rough seas, the illegal discharges detected are likely to understate the problem (Dong et al., 2022; Evanisko, 2020).

It needs to be noted that ships are not the only source of oil in the marine environment. But together with the other industrial sources – oil platforms, pipelines, etc. – they are estimated to contribute 94% of the oil in the marine environment, with only 6% stemming from naturally occurring seeps (Dong et al., 2022).

PROSECUTION

As with other international regulations and standards, it is up to individual states to introduce national legislation with which to prosecute and punish offenders under port state control measures – or else they can refer the matter to the flag state of the ship in question. Enforcement of MARPOL Annex I regulations thus varies enormously around the world (OECD, 2003) and there appears to be no centralised monitoring and reporting mechanism with which to assess the effectiveness of MARPOL in tackling illegal oil discharges.

In the European Union, for example, prosecutions for illegal oil discharges are rare even though penalties (including criminal sanctions) have been introduced (EMSA, 2012). There is some evidence that increased surveillance of European waters has had a deterrent effect (Helcom, 2022). A 2011 study by the IMO found the average fine imposed by port states worldwide to be just €5,220 and by flag states just €2,680 (EMSA, 2012).

The US appears to lead the way in enforcing MARPOL Annex I, perhaps unsurprising given the strong public response to the Exxon Valdez disaster in 1989. In 2013 the Department of Justice (DOJ) reported on its enforcement activity over the preceding 10 years: criminal penalties totalled more than \$200 million; a total of 17 years of jail time for shipboard officers and shore officials; the vessels ranged from cruise ships to containers ships, tankers and bulk carriers (U.S. DOJ, 2013). A former assistant attorney general for the DOJ nevertheless observed at the time that these cases were probably only the tip of the iceberg (Greene, 2012).

13 <https://www.marinedefenders.org/oil-pollution-facts.html>

OIL SPILLS FROM SUNKEN WRECKS

Not all accidents result in immediate oil spills. Some vessels sink with their cargo and fuel tanks intact. Resting on the ocean floor, they become ecological time bombs. The question now is not if they will start leaking oil, but when. The rate at which a shipwreck deteriorates depends on its construction, time immersed and extent of burial in the seafloor, along with a variety of physical, chemical and biological factors. But eventually it will deteriorate to the point where it releases some, or all, of its oil cargo, fuels or other hazardous chemicals.

A 2006 study estimated that there are more than 8,500 shipwrecks containing oil – about 20% of them oil tankers – which together amount to as much as 20 million tonnes of oil. Wreck hotspots are in south Asia/ western Pacific and the North Atlantic (*Figure 18*) (Michel et al., 2006). A significant percentage are left over from World War II. Estimated corrosion rates suggest that after more than 75 years many might by now be at risk of structural collapse, posing an increasing risk to the marine environment (Carter et al., 2021). Long consigned to the ‘out of sight, out of mind’ category, this problem has received more attention in the last couple of decades as ‘mystery oil spills’ have begun to be recorded (Symons et al., 2014). For example, in 2021 a strong earthquake off Alaska is suspected to have triggered the release of diesel from a vessel sunk in the late 1980s (Associated Press, 2021). Within a month efforts to contain the spill had cost more than \$3 million (Resneck, 2021).

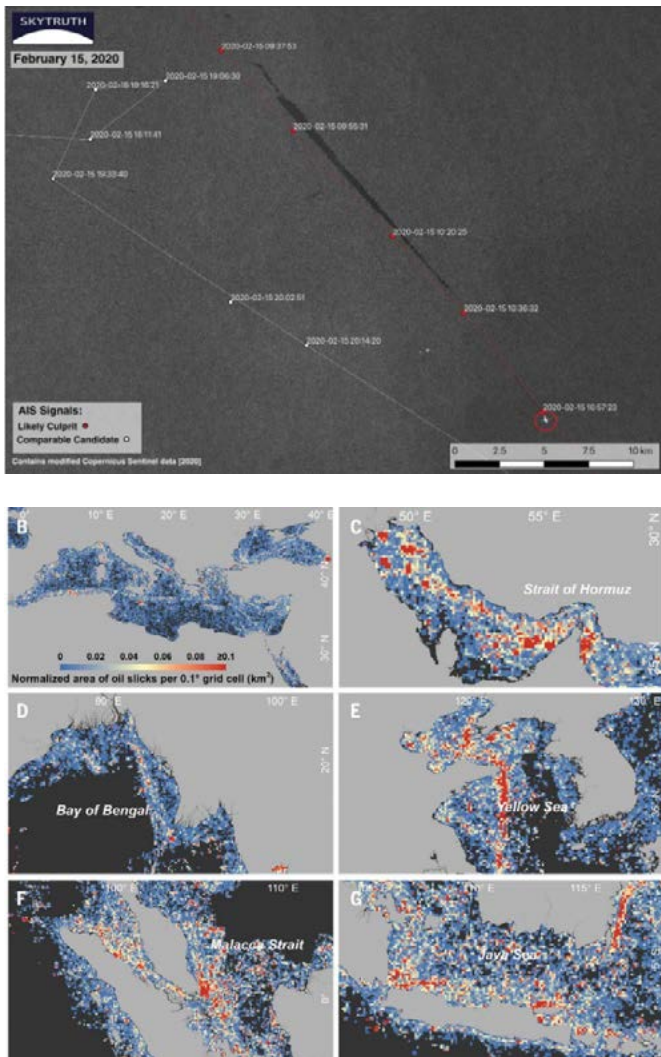


Figure 17: Top: suspected illegal discharge (black streak) in the Java Sea on February 15, 2020. AIS signals are shown for two potential sources. The likely source vessel is circled in red. Credit: Evanisko, 2020. Bottom: composite figure showing high density belts caused by oil pollution from ships, captured in satellite images between 2014–2019. The distribution of oil slicks overlaps with main shipping routes in these areas. From above left: Mediterranean Sea and Black Sea, Strait of Hormuz, Bay of Bengal, Yellow Sea, Malacca Strait and Java Sea. Credit: Dong et al., 2022.

ENVIRONMENTAL IMPACTS OF OIL

The severity of the damage done by a spill depends on the volume and composition of the oil, the location, prevailing weather conditions, and the vulnerability and resilience of the species and ecosystems affected. Catastrophic spills from shipping accidents – so called ‘black tides’ – often have fatal consequences for the many species exposed to the toxic oil compounds, whether by contact, direct ingestion or eating contaminated prey. Seabirds are particularly vulnerable; covered with oil, they can no longer fly and the loss of their natural insulation often results in hypothermia (Piatt et al., 1990). The harm done to seals, whales and dolphins is also well documented (Helm et al., 2015). Entire ecosystems can be damaged by the loss of oxygen when the water surface is entirely covered by an oil slick. Whilst in most cases environmental recovery is relatively swift, complete within 2-10 years, long-term environmental impacts can be observed decades later in areas in which conditions allowed oil to accumulate, or in particularly sensitive habitats such as salt marshes and mangrove swamps (ITOPF, 2011a; Kingston, 2002)

Techniques for containing and eliminating the oil, as well as strategies for treating oiled wildlife, have evolved continuously since the first major oil spills more than 50 years ago (Ghaly & Dave, 2011; Jørgensen et al., 2019; Prendergast & Gschwend, 2014). Workers and volunteers involved in the response still face a range of health hazards and risks from exposure to toxic chemicals and the handling of wild animals (Short, 2017). For local communities these events cause considerable suffering, with psychological trauma accompanying economic losses to a wide range of local industries, in particular fisheries and tourism (ITOPF, 2011b,c; Orellana, 2022). The effects on Indigenous Peoples can be especially profound (Afenyo et al., 2021; Inuit Circumpolar Council, 2014).

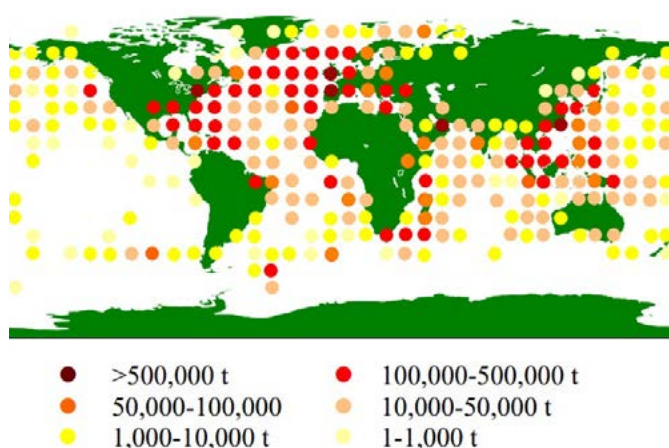


Figure 18: Estimated amount of oil still contained in shipwrecks (1890-2004). Credit: Michel et al., 2006.

Remediation of shipwreck risks is governed by the Nairobi International Convention on the Removal of Wrecks, which came into force in 2015. A state has the right to remove a wreck from its exclusive economic zone (EEZ) and recover the costs from the owner. It can cost more than \$100 million to extract oil from inside a wrecked vessel. However, the total clean-up, ecological and socio-economic costs for an equivalent spill (whether a large-scale disaster or a small-but-continuous discharge) can be several times greater (Lindgren et al., 2016). Some individual countries have been proactive in this area. The US, though not party to the Nairobi Convention, has developed systematic risk assessments to prioritise wrecks posing the highest pollution risk, with funding coming from a dedicated federal Oil Spill Liability Trust Fund (Symons et al., 2014).



Figure 19: Aerial view of the sunken Nathan E. Stewart which ran aground on the traditional territories of the Heiltsuk people in British Columbia, Canada, in 2016. Credit: Heiltsuk Tribal Council, 2017.

The impacts of the small-but-continuous quantities of oil associated with operational discharges are less well-examined and difficult to untangle from other human and natural sources (Farrington, 2013). Studies of naturally occurring hydrocarbon seeps, the consequence of geological processes along continental shelves, have shown both positive and negative impacts on species and ecosystems (Farrington, 2013). Unlike seeps, however, oily discharges can occur in areas with no previous exposure to hydrocarbons and affect species which are less likely to have natural adaptations (Farrington, 2013). Also, the composition of most fuel oils differs from out-of-well hydrocarbons because of the various additives used. Recent studies have sought to improve understanding of how the marine environment is affected by chronic pollution, whether from legal or illegal discharges. Initial tests indicate that even discharges of MARPOL-compliant oily waste can affect the feeding and reproduction of marine plankton. Even small, brief spills do immediate biological harm, it seems, with habitual, repeated discharges (even compliant ones) likely to affect the functioning of marine ecosystems (Brussaard et al., 2016; Tiselius & Magnusson, 2017).

OUTLOOK

Large, catastrophic oil spills dominate the public discourse on the environmental consequences of shipping. These disasters undoubtedly wreak havoc on coastal ecosystems, endanger public health and ruin local livelihoods and economies, often with long-lasting consequences. It is these high visibility events, like Exxon Valdez, that tend to trigger international action and then help maintain its momentum. Images of oiled animals and volunteers scraping oil from beaches still regularly make the world's news cycle, but the evidence indicates that the number of accidental oil spills has gone down sharply.

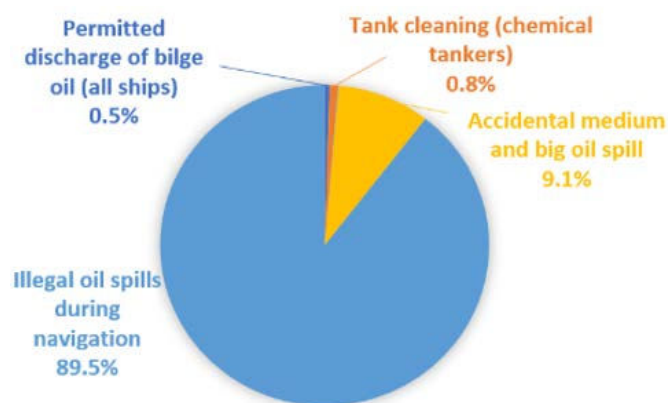


Figure 20: Contribution of permitted, accidental and illegal activities to total oil discharges from world fleet for 2006. Source data in Maffii et al., 2007.

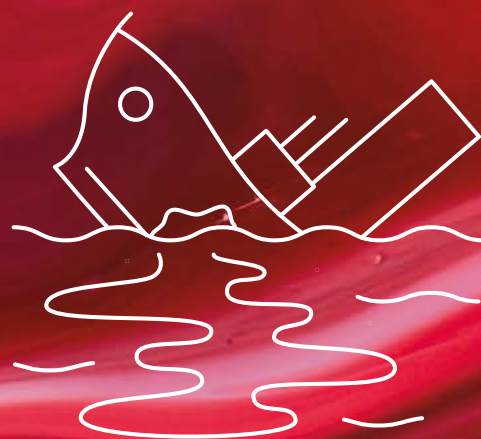
With maritime trade continuing to increase, and a shift towards emerging markets widely expected, questions are now being raised about oil spill preparedness in regions like Latin America (Taylor et al., 2021) and Africa (UNEP, 2020; Swanepoel, 2020). In the Arctic new trade routes are opening up as man-made global heating causes polar ice to recede. An accidental oil spill there would be catastrophic given the area's fragile ecosystems, remoteness and lack of emergency infrastructure. *(The Arctic's unique challenges are delved into further in Chapter 15).*

But in truth the high visibility of accidental oil spills and their aftermaths is masking the true scale (and source) of most of the oil discharged into the ocean from shipping. A staggering 90% of oil emitted by ships is attributed to deliberate illegal discharges at sea of the oil residues created during a ship's routine operations (Figure 20). Evidence of bilge dumping in EEZs is mounting as more and more is captured by satellite imagery (such as SkyTruth's Cerulean¹⁴) and whistle blowers reveal industry-wide illegal practices (Muller et al., 2022). Whether these practices extend to areas beyond national jurisdiction (the 'high seas') is not yet well-understood because current satellite imagery focuses mainly on coastal areas. While global estimates of illegal discharges vary widely, there is widespread agreement that this vastly-underestimated problem (Dong et al., 2022; Evanisko, 2020) deserves the attention of international policymakers.

¹⁴ <https://skytruth.org/cerulean/>

5

HAZARDOUS AND NOXIOUS SUBSTANCES SPILLS AND DISCHARGES



Dangerous chemicals and materials are among the many things regularly transported by sea. Collectively these are known as Hazardous and Noxious Substances (HNS). No single definition of HNS exists. Generally it applies to any substance (other than oil) which, if introduced into the marine environment, is likely to endanger human health, harm marine life, damage amenities or interfere with other legitimate uses of the sea.

HNS pollution can enter the sea as a result of an accident and via both permitted and illegal discharges. Major incidents are rare (and less frequent than oil spills) but the consequences for human health, the environment and local economies can be serious (Alcaro et al., 2021). The wide range of different products transported makes responding to an HNS spill more complicated than oil; the different physical and chemical properties, as well as their behaviour and effects once in the environment, can vary widely.

MARITIME TRANSPORT OF HNS

About 2,000 chemicals are regularly transported by sea (Purnell, 2009) – either in bulk (liquids and solids) or packaged form – with different types of ship required. Bulk carriers transport things like iron ore and rock phosphate. Bulk liquids travel by chemical tanker and can include acids, caustic soda, and petrochemical products. Gas carriers are used for liquified gases such as LNG and LPG. Smaller quantities of HNS, which tend to travel by container or in lorries on Ro-Ro ferries, are discussed in *Chapter 6*.



Figure 21: Chemical tanker Sten Aurora in 2019. Ships transporting dangerous goods are often painted orange as it is the most easy to detect colour against normal sea background colours. Credit: Niels Johannes / Wikipedia Commons.

Because of these widely different physical forms (gases, liquids, solids), behaviours (explosive, flammable, toxic) and operational implications (health and safety, ship design, spill preparedness and response), the transportation of chemicals (and in particular HNS) is governed by a complex web of international, regional and national regulations, codes and protocols.

The international regulations include:

- MARPOL Annex II for noxious liquid substances carried in bulk;
- the International Code for the Construction and Equipment of Ships Carrying Liquified Gases in Bulk (IGC);
- the International Maritime Solid Bulk Cargoes Code (IMSBC); and
- the International Maritime Dangerous Goods Code (IMDG) for packaged goods.

The volume of chemicals being shipped continues to grow, driven by rising demand for raw materials, the expansion of the global chemical industry, and the comparative cost-efficiency of ships for transporting large quantities over long distances (Lacoste, 2008; UNCTAD, 2022). About 165,000 million tonnes of chemicals (about half being petrochemicals) are transported every year (Cedre & Transport Canada, 2012; Galieriková et al., 2021). In 2021 the total global value of chemical exports was more than \$2 trillion. The majority of this trade is along the routes connecting North America, Europe, the Middle East and Asia (Cedre & Transport Canada, 2012; Lacoste, 2008). Both the number of chemical tankers and the volume of trade have roughly doubled in the last 20 years (Şanlıer, 2018). In 2020 there were 5,717 chemical tankers in operation worldwide (EMSA, 2022).

ACCIDENTAL HNS SPILLS

Among the types of HNS most likely to be involved in a maritime incident are the most commonly transported ones, such as acids, sodium hydroxide (caustic soda), LPG, LNG and ammonia (Galieriková et al., 2021). Estimates vary for the total amount spilled in an average year, ranging from about 9,000 tonnes (Galieriková et al., 2021) to 20,000 (Grote et al., 2016).

Most accidents happen at sea (rather than in or near a port) and nearly two thirds of them involve bulk carriers (Marchand, 2002). Vessel sinking is the most common cause (31% between 2005 and 2015), followed by collision (19%), grounding (17%) and leaks or other intakes of water (14%) (Cedre & Transport Canada, 2012). Between 2012 and 2021 a total of 42 chemical tankers were registered as 'lost' (Allianz, 2022).

Incidents involving HNS are less frequent than oil spills but can be considerably more dangerous (Purnell, 2009). This is partly because complex chemical behaviour and the associated hazards make spill preparation much less straightforward. HNS accidents at sea can result in chemical fires and explosions as well as the release of toxic substances and gases. The consequences for life and the wider environment can be grave.

The nickel ore trade vividly illustrates the surprising ways in which an HNS cargo can end up in the ocean. Nickel ore is mostly mined in south-east Asian countries (including the Philippines and Indonesia) and then transported all over the world by sea. If the humidity of the ore increases it can liquefy, threatening the stability of the vessel carrying it. Since 2010 nickel ore liquefaction has caused at least seven vessels to capsize, killing more than 100 crew members (Dao, 2019; IIMS, 2022), releasing unknown quantities of toxic material into coastal waters, and damaging marine life and coastal economies close to mining operations (Sawal, 2022).



Figure 22: By its nature, nickel ore is a cargo that can liquify and pose a severe risk to vessel stability. It is thought responsible for the loss of more than 100 seafarers and multiple ships over the last decade. Credit: Wee, 2019.

Accidental spills are a particular threat to the physical health and economic viability of fishing communities. The 2021 sinking off Sri Lanka of the MV X-Press Pearl involved at least 81 containers of 15 different products classified as dangerous goods (including 25 tonnes of nitric acid). The UN Special Rapporteur tasked with investigating the accident noted that HNS were likely to have been released into the environment, and emphasised the vital importance of understanding the fate and behaviour of these chemicals and their impact on marine life. To this end, samples were collected but the findings are yet to be published. The UN report did note plummeting seafood sales and consumption across the country (because of public concern about contamination) following a major spike in turtle and dolphin deaths and unconfirmed reports of dissolving fishing nets (Partow et al., 2021).



Figure 23: The X-Press Pearl sank off the Sri Lankan coast in June 2021 with 15 different chemical substances on board. Credit: Sri Lanka Airforce Media.

OPERATIONAL DISCHARGES

It is rare for a ship to carry two identical cargoes consecutively. Tanks and holds need to be cleaned to avoid cargo contamination. MARPOL Annex II requires that any tank cleaning water and washing agents (as well as ballast waters containing chemical residues) must be discharged into local port reception facilities or transported onwards to another port where facilities are available. Discharge of tank-cleaning effluents into the sea is allowed only in line with Annex II, which specifies cleaning procedures, maximum chemical concentrations and minimum distance from shore (beyond the 12 nautical mile territorial sea limit). In practice this means it remains legal to discharge about 75-300 litres of chemicals per cargo tank (this depends on the ship's construction year, as per Appendix 4 to MARPOL Annex II) (Honkanen et al., 2012). In today's chemical tanker fleet of about 5,717 vessels (EMSA, 2022), each vessel can be equipped with as many as 50 separate tanks (GESAMP, 2019). Even if each vessel made just a single voyage each year (cleaning its tanks afterwards), a rough calculation suggests that somewhere between 21 million and 85 million litres of HNS could be legally discharged. Over an entire year the total amount would of course be considerably higher when taking into account repeat voyages.

Liquids are not the only HNS that can be legally discharged. The cleaning of dry bulk residues left in tanks after unloading (managed by a suite of regulations under MARPOL and IMSBC) is estimated to result in about 78,500 tonnes of potentially hazardous solids being discharged into the sea each year (Grote et al., 2016).

As with other polluting substances, the decision to make any amount of HNS discharge 'legal' is largely based on the assumption that dilution by the sea renders the effluents harmless. There are no authoritative scientific studies to support this convenient notion (Cunha et al., 2015; Hermansson & Hassellöv, 2022; Honkanen et al., 2012; Tornero & Hanke, 2016). The cumulative impact of repeated discharges has not been studied either.

Concern about the Baltic Sea in particular has been growing. Limited water exchange makes it especially vulnerable to chemical (and oil) discharges. The IMO recognises the Baltic as a PSSA (particularly sensitive sea area). A study commissioned by the Swedish Agency for Marine and Water Management (Hermansson & Hassellöv, 2022) estimates that hotspots for chronic-but-legal discharges are close to a wide range of ecologically important areas (including Natura 2000 areas and Ecologically or Biologically Significant Marine Areas (EBSAs) under the Convention on Biological Diversity) as well as areas of importance for commercial fishing and aquaculture. The same study also found indications that mandatory pre-washing of liquid cargo residues is often avoided (using formal requests for exemption), probably because of the extra time and money (including higher berthing costs) involved.

OCEAN DUMPING

The deliberate ‘dumping’ of HNS at sea can even extend to whole vessels along with whatever remains inside them. In 2020 the bulk carrier MV Wakashio ran aground with 4,000 tonnes of bunker oil on board in an environmentally sensitive area off Mauritius. Some 3,000 tonnes of fuel were removed successfully but the vessel eventually broke up and was towed offshore and sunk along with the remaining fuel. In early 2023 the Brazilian authorities deliberately disposed of an entire aircraft carrier by towing it into deep water and sinking it, along with an estimated 760 tonnes of hazardous asbestos and more than 300 tonnes of material contaminated with highly toxic PCBs (Boadle, 2023; Shipbreaking Platform, 2023).

Any HNS cargo that remains inside a sunken wreck is likely to pose a risk of future release, whether suddenly and catastrophically or slowly and continuously over a long time. In 2021 the fertilisers and industrial reagents onboard a bulk carrier in the South African port of Durban became reactive and started to release toxic fumes. After three months of uncertainty an emergency authorisation allowed the material to be dumped overboard, 250km offshore in the Benguela Current Large Marine Ecosystem (Jordan, 2022; Vyawahare, 2022).

Dumping of hazardous vessels, waste or cargo is prohibited under the 1972 Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter (London Convention), but exemptions are available via special permits. The more restrictive 2006 London Protocol further bans the exportation of waste to other countries for dumping and the burning of waste at sea. There is no authoritative information on the number of exemptions granted or any details of known cases of illegal dumping.

Maritime shipping is also implicated in the illegal cross-border transportation of hazardous waste and the dumping of chemical products that can result (Amnesty International & Greenpeace 2012; Mead, 2021). To be legal (under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and Their Disposal) these shipments must include an appropriate disposal plan. Illegal shipments of hazardous wastes are often carelessly dumped in rivers, villages and seas (UNEP/SBC, 2010).

ENVIRONMENTAL IMPACTS

The effects of any chemical on the marine environment depends on a number of factors. Most significant is the toxicity of a given product or of anything that might result when two or more compounds interact. Some substances behave in a similar way to oil spills (they might be petroleum derivatives); others react very differently, including forming gases, evaporating into the atmosphere, dissolving in sea water or igniting (Tornero & Hanke, 2016). The extent of the impact will also depend on the quantities released, the resulting concentrations in the water column, their persistence in aquatic environments (heavy metals and pesticides, for example, do not break down easily), as well as the duration of exposure and the vulnerability of the receiving environment.

Whereas the short- and long-term environmental effects of oil spills have been widely studied, the lack of data for chemical spills is noteworthy. Most information is inferred from the effects on fresh-water species or relies on assumptions made about how particular chemical compounds behave in seawater. These things are very rarely measured under real-world conditions. (Cunha et al., 2015; Honkanen et al., 2012; Şanlıer, 2018; Tornero & Hanke, 2016).

Studies under lab conditions indicate bioaccumulating, acute and chronic effects of a variety of chemical and HNS products on a wide range of marine species, from primary producers (such as algae) to large, top-of-food-chain predators (Şanlıer, 2018). Even low doses of highly hazardous and noxious substances can have harmful (but perhaps not deadly) effects on marine organisms, with profound effects on individual species and entire ecosystems over the longer term (EMSA, 2012; Şanlıer, 2018). These findings highlight the threat posed by even the trace amounts released through tank washing.

Substances not traditionally considered polluting, such as vegetable oils or fish oils, can also kill certain marine species, including by damaging the insulation provided by a bird's feathers or by clogging an animal's digestive tract (Häkkinen & Posti, 2003). In recognition, these substances were classed as ‘noxious’ by an amendment to MARPOL Annex II which took effect in 2007.

OUTLOOK

The global maritime trade in chemicals, including the many considered hazardous and noxious, is growing (UNCTAD, 2022). A wide range of products are transported in bulk or packaged form, using general cargo vessels as well as chemical tankers and gas carriers. Concerns about the risks have helped to create an entire system of international, regional and national measures to reduce accidental oil spills and limit the amount of HNS that can be discharged legally.

And yet, in spite of all this, we still lack comprehensive and consolidated information to show how much HNS is being transported, the extent of the incidents in which it is involved, and the impact spills and discharges are having on the oceans (Hermansson & Hassellöv, 2022; Purnell, 2009). This is all the more surprising given the very grave situations that certain, particularly-dangerous compounds can cause; the August 2020 ammonium nitrate explosion in Beirut's port area produced one of the most devastating blasts in recent history, killing more than 150 people.

Even though there is clear evidence that chemical spills of any kind are not as harmless as is generally assumed, a certain laissez-faire attitude persists. Of particular concern are the illegal discharges of liquid HNS cargo, of which much is still unknown. Accidental spills of HNS have been estimated at up to 20,000 tonnes a year (Grote et al., 2016), considerably less than the 78,500 tonnes thought to be discharged legally by dry bulk cargo vessels (Grote et al., 2016). Meanwhile, up to 300 litres per tank of cleaning fluids can be legally discharged in diluted form. As noted repeatedly, 'small' amounts quickly add up to environmentally-significant quantities, particularly if they are being discharged into ecologically sensitive areas.

Current international regulations leave so much room for interpretation (Hermansson & Hassellöv, 2022) that individual countries are now working to shed light on the impact of HNS discharges as well as considering the need for further limits on discharges (HELCOM, 2021).

It is also noteworthy that the IMO's HNS Convention – to incorporate the 'polluter pays' principle so that the shipping and chemical industries must compensate the victims of HNS incidents – is still not yet in force. (It would also regulate liability in the event of accidents and discharges, in addition to creating stricter reporting requirements for countries handling hazardous cargoes.) The convention has been open for signature since 1996 (and its updated protocol open since 2010) but by 2023 none of the major chemical exporting countries (including the US, China and Germany¹⁶) had signed and ratified it.

16 2020 Data https://wits.worldbank.org/CountryProfile/en/Country/WLD/Year/LTST/TradeFlow/Export/Partner/by-country/Product/28-38_Chemicals#

6

CONTAINERS LOST AT SEA



Containers are used to transport a vast array of packaged products, from consumer goods (produce, electronics, batteries, plastic pellets) to chemicals and other raw materials. In 2021 some 241 million containers were used to transport cargo worth more than \$7 trillion (WSC, 2022). The largest ships can now carry more than 20,000 TEU containers and the capacity of the container shipping fleet continues to increase each year.

LOSS OF CONTAINERS

Container vessels are designed to transport their cargo safely even in the most extreme conditions. Even so, severe weather, groundings, structural failures, collisions, running aground or the mishandling of cargo during loading can all still result in losses. An average of 1,629 containers are lost at sea each year and the numbers have increased significantly (by 18%) over the last decade (*Figure 24*). Individual containers are lost from time to time but the numbers are heavily influenced by rare but catastrophic events in which thousands are lost in a single incident. Examples include the MOL Comforting sinking in 2013 with 4,239 containers on board (WSC, 2022), and the 2020 loss of nearly 2,000 containers in the Pacific by the One Opus (Allianz, 2021). East Asia is most prone to accidents involving container vessels, followed by the coastal regions of Southeast Asia and Europe (*Figure 25*).



Figure 24: Containers reported lost at sea globally between 2008 and 2021. Credit: WSC, 2022.

Made of steel, most containers will sink quickly though some may take longer when the cargo is buoyant or the container has a foam wall construction. Floating containers can drift hundreds of kilometres before eventually sinking, breaking-up, or showing up on a coastline. Lost containers can pose a significant navigational hazard, especially to smaller vessels. The environmental impacts of submerged steel structures include localised shifts in seafloor communities, toxicity stemming from the container's paint and the potential to act as stepping stones for invasive species (Frey & De Vogelaere, 2014; Taylor et al., 2014). The release of containerised cargo can also have serious consequences, with risks that are often overlooked (Wan et al., 2022). The goods transported by container include many classified as hazardous and noxious (see *Chapter 5*) as well as raw plastics for the manufacturing industry (*more on plastics in Chapter 9*).

The environmental consequences of container losses at sea do not fit neatly into any national or international regulatory framework. Without an internationally-agreed way to measure or record losses, reliable and accurate data is hard to establish. Technological innovations – such as tracking devices to facilitate speedy recovery – are in development. The IMO is amending the SOLAS Convention to include mandatory reporting of containers lost overboard, and this should come into force in early 2026.



Figure 25: Geographic distribution of container vessel accidents from 2010 to 2020. Credit: Wan et al., 2022.



Figure 26: Grounding in 2007 of the MSC Napoli and, subsequently, containers washing up on England's southern coast. Credit: UK Environment Agency.

MIS-DECLARED CONTAINER CONTENTS AND CAR CARRIER INCIDENTS ARE A GROWING PROBLEM


It is estimated that around one in every 10 containers contains a dangerous cargo which has been properly declared. Another one in 20 (5%) are thought to contain dangerous goods which are undeclared either because of an administrative error or a deliberate act of deception (Allianz, 2022). In recent years a number of fires at sea have been traced to combustible or mis-declared container cargoes, including batteries, charcoal and chemicals like calcium hypochlorite (an ingredient in cleaning products) (Allianz, 2022).

Fires have become a consistent 'driver' of car carrier losses over the last decade (Allianz, 2022). Lithium batteries in particular are a growing concern because they are known to cause runaway thermal reactions when damaged or defective (IMO SSE 9/INF.6). In March 2022 the *Felicity Ace* sank south of the Azores with 4,000 cars onboard, some of them electric.

OUTLOOK

The worldwide container ship fleet has expanded most rapidly over the last couple of years, both in terms of the number of ships and the containers they can carry (UNCTAD, 2022). Container losses are only a small percentage of the millions of containers safely transported each year but they are of increasing concern nonetheless and the IMO is pursuing measures to make the reporting of container losses mandatory (IMO CCC 8/11/1). It remains to be seen how (or if) the new reporting system will help mitigate both the losses themselves and the associated navigational and environmental hazards. The thousands of containers already on the seafloor will probably have to stay where they are for many hundreds of years to come, to be joined by thousands more each year, leading to a considerable cumulative impact.

International efforts to mitigate the climate crisis, with the associated imperative to phase out traditional combustion engines, means that more and more vehicles with highly flammable lithium batteries (or some other alternative power source in development such as hydrogen fuel cells) will need to be transported by sea in future. Meeting global emission targets in line with the Paris Agreement could see 230 million electric vehicles manufactured by 2030 (IEA, 2021), underscoring the growing need to reduce the risk this trade poses to human health and the environment.



7

ANTIFOULING PAINTS



The colonisation of a ship's outer surface by organisms like barnacles, mussels and algae is known as biofouling. Preventing or reducing growth on a vessel's hull is important for two reasons. The accumulated growth on a hull causes hydrodynamic drag, raising fuel consumption and increasing GHG emissions by up to 55% (IMO, 2022). Secondly, managing biofouling is essential to managing the global spread of invasive aquatic species and mitigating the substantial environmental and economic consequences (see Chapter 12).

Antifouling paints contain a variety of toxic compounds which act as biocides and form a protective top layer on a ship's hull. It is estimated that worldwide around 80,000 tonnes of antifouling coatings are used each year (Maffei et al., 2007).



Figure 27: Example of extreme biofouling on yacht in Picton Harbour, New Zealand. Growth of mediterranean fanworm (*Sabella spallanzanii*), native to northeastern Atlantic and Mediterranean and now spread around the world. Credit: Marlborough Sounds Marinas.

TBT AND OTHER ANTIFOULING AGENTS

During the 1960s the chemical industry developed efficient and cheap anti-fouling paints using metallic compounds. The organotin compound tributyltin (TBT) quickly became the antifouling agent of choice for most seagoing vessels. Equally soon environmental concerns began to emerge, in particular TBT's persistence in water, accumulation in sediments and toxicity for non-target marine species.

TBT is considered by some ecotoxicologists to be the most hazardous man-made chemical ever deliberately released in large quantities into the environment (Beyer et al., 2022).

Toxicological studies undertaken throughout the world have pointed to TBT as the cause of a wide range of impacts including: shell deformation in oysters; sex changes in whelks; immune, neurotoxic, genetic and reproductive effects in other marine species, including fish and marine mammals; as well as risks to humans from the consumption of contaminated seafoods (reviewed in de Mora et al., 2020 and Beyer et al., 2022). It was also found responsible for the commercial collapse of a shellfishery in at least one area of France in the 1970s and '80s (IMO, 2002).

Harbour and port locations are the main hotspots for TBT but other sources also contribute to the problem, including runoff from long-lasting house paints (Beyer et al., 2022).

The IMO started developing counter-measures in the late 1980s but a complete prohibition of TBT was not adopted until 2008 when the International Convention on the Control of Harmful Anti-Fouling Systems on Ships (AFS Convention) came into force. The trade in TBT is also prohibited, under the Rotterdam Convention.

Despite being banned for more than a decade, TBT remains prominent on toxicologists' radar. TBT-based biofouling paints are still found on the market (Turner & Glegg, 2014; Uc-Peraza et al., 2022). Monitoring in some places (such as the Baltic) shows an improvement in TBT levels in sediments and marine species, but TBT and its environmental effects are still being reported on all continents, suggesting profound long-term legacy effects (Abreu et al., 2021; Beyer et al., 2022; Uc-Peraza et al., 2022).

Alternative anti-fouling systems developed after TBT was banned use a range of copper- and zinc-based compounds instead (Figure 28).

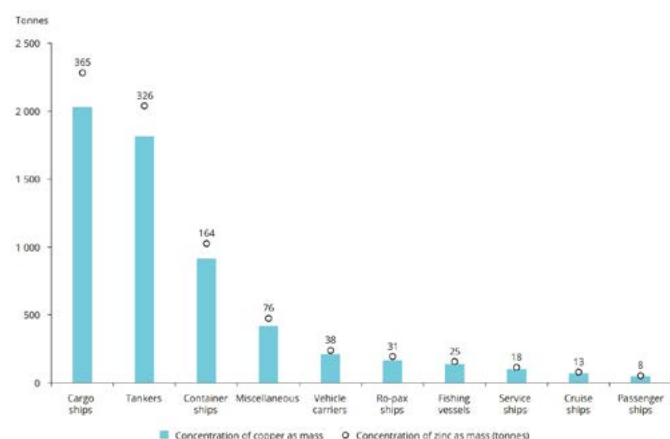


Figure 28: Estimated release of the main copper and zinc compounds from anti-fouling paints in European waters, 2019. Credit: EMSA & EEA, 2021.

Some species tolerate these so booster biocides are added – including Cybutryne (Irgarol), Chlorothalonil and many others – which all to some degree have toxic effects on the environment beyond their antifouling properties (Koning et al., 2020; Konstantinou & Albanis, 2004; Kyei et al., 2020). Cybutryne in particular has attracted much attention in recent years as research has shown it to be very toxic to aquatic life, with a tendency to be long-lasting in sediments once released (EMSA & EEA, 2021).

Following an EU proposal to the IMO in 2017 the use of Cybutryne was banned under the AFS Convention from 1 January 2023 – but only partially. The TBT ban applies to all ships but the Cybutryne control measures do not apply to any ship of any size that does not make international voyages or to smaller ships (400 GT or less) that do (IMO MEPC76). The reasons for these exemptions are unclear.

EMERGING ECO-FRIENDLY ANTIFOULING PAINTS AND SYSTEMS

A variety of eco-friendly antifouling paints are being developed to replace traditional, toxic coatings. These are being derived from the natural components produced by plants and marine organisms as part of their defence mechanisms against natural predators. Mostly of reduced or no toxicity, they act through a variety of physical and chemical control mechanisms to repel and prevent the attachment and growth on the surface of the ship's hull (Kyei et al., 2020).

Other possible biofouling management strategies include manual hull cleaning or the use of ultrasonic technology when vessels are in port (Zhong et al., 2022).

OUTLOOK

Biological growth on a ship's hulls has challenged seafarers and ship operators since humans first took to the sea. Antifouling paints have played an important role in reducing the risk of ship-mediated introductions of aquatic invasive species as well as improving the energy efficiency (and carbon footprint) of ships.

Nevertheless, the chemical compounds used in antifouling paints are as toxic for the marine environment as for the fouling species they are designed to prevent. With the global antifouling paint market projected to double by 2031 as the shipping fleet expands (Devashree et al., 2022), there is a growing need for effective and environmentally-friendly alternatives. Several reasons are given for why the market is not yet ready to shift to non-toxic hull coatings, including high initial costs and application difficulties (Kim, 2021). The prohibition in 2023 of yet another antifouling agent – Cybutryne – further highlights the need for viable and effective alternatives to be developed quickly and adopted widely.

Reducing the environmental impact of antifouling paints is not amongst the IMO's current priorities (IMO A 32/ Res.1149) but at least one regional initiative is looking into it. The Baltic Sea Action Plan describes the biocides from antifouling products as 'contaminants of emerging concern' and will seek to develop and implement management options (by 2026) to minimise the release of hazardous substances (and microplastics) from anti-fouling systems (HELCOM, 2021).

8

SEWAGE AND GREYWATER DISCHARGES



Ships generate several different types of wastewater during their regular day-to-day operations. The terms ‘sewage’ or ‘black water’ refer to drainage from toilets; ‘greywater’ refers to drainage from dishwashers, showers, laundries, baths and washbasins. As worldwide maritime traffic increases, the risks from wastewater generation and discharge are attracting more and more attention (Chen et al 2022; HELCOM, 2021; Shu et al., 2022; Ytreberg et al., 2020).

SEWAGE

Sewage generally contains wastewater not only from toilets, but also from medical facilities and the transportation of live animals.

Unsurprisingly, the amount of sewage produced on a ship is directly proportional to the number of people (or live animals) on board and the type of flushing system employed. People-carrying vessels, such as passenger and vehicle ferries (Ro-Pax and Ro-Ro cargo), collectively produce the most sewage – more than 16 million tonnes per year worldwide (*Table 3*). A single large cruise ship is a significant source of sewage; 3,000 passengers typically generate about 100,000 litres of human waste each day (about 33 litres per person, per day) (U.S. EPA, 2008).

Sewage can contain several contaminants of concern to human and marine health including: a range of pathogens (*E. coli*, *Salmonella*, other bacteria and viruses, as well as the eggs of intestinal parasites); organic matter; nutrients and heavy metals; as well as pharmaceutical residues (U.S. EPA, 2008).

MARPOL Annex IV aims to prevent sewage pollution by ships of 400 gross tonnes and above, or any ship certified to carry more than 15 people. The regulations prohibit discharge within three nautical miles of land (unless via an approved onboard sewage treatment plant), and the sewage discharged must first have been ‘comminuted’ (finely crushed and ground) and disinfected. Alternatively, sewage can be stored and offloaded at port reception facilities. Out on the open ocean, beyond the 12 nautical mile (nm) territorial limit, raw sewage can be freely discharged on the assumption that the ocean is capable of providing ‘treatment’ by

natural bacterial action. MARPOL Annex IV also prohibits the discharge of sewage from passenger ships within certain Special Areas (currently this means only the Baltic Sea) unless an approved and certified sewage treatment plant is being used.

To help ships discharge treated sewage in compliance with MARPOL Annex IV, the IMO issued the 2012 Guidelines on implementation standards and performance tests for sewage treatment plants (IMO MEPC 64/23/Add.1). The adequacy of these guidelines to guide the development and deployment of fit-for-purpose treatment systems has been questioned in recent years. It is highly likely that ships are still using systems that consistently and regularly discharge pollutants (including the highly toxic disinfectant chlorine) into the sea, including coastal waters (IMO MEPC 71/14/2). A 2017 study of 127 effluent samples taken in the Netherlands indicated that 97% of the approved sewage treatment plants inspected did not meet all the discharge standards. The majority of the ships were discharging ‘virtually untreated raw sewage’ (IMO MEPC 71/INF.22). These findings have been corroborated by ad-hoc wastewater analyses done in Iran and China in recent years (IMO PPR 7/16/1; IMO PPR 8/7/4). Overall, these cases suggest that poor performance or failure of sewage treatment plants is commonplace.

In some countries, such as the US, legislative provisions allow federal regulations to be tightened selectively for the specific purpose of increasing environmental protection. This includes the creation of vessel sewage No-Discharge Zones, within which the discharge of both untreated and treated sewage is prohibited, forcing vessels to use port disposal facilities¹⁷. The designated range of these zones can be varied, from an individual harbour, bay or sound (such as Puget Sound) to the entire territorial sea of a state (such as California).

¹⁷ <https://www.epa.gov/vessels-marinas-and-ports/no-discharge-zones-ndzs-state>

Table 3: Estimates of worldwide sewage and greywater production by the world's fleet, by category (ships larger than 100 gross tonnes). Biochemical oxygen demand (BOD) of wastewater is used to indicate the short-term impact on the oxygen levels of the receiving water. Data from Maffii et al., 2007.

	Sewage		Greywater	
	<i>M tonnes/year</i>	<i>BOD (tonnes/year)</i>	<i>M tonnes/year</i>	<i>BOD (tonnes/year)</i>
TANKER (OIL, CHEM., OTHERS)	2.28	421	38.00	7,600
BULK CARRIER	1.25	232	20.89	4,178
GENERAL AND SPECIALISED CARGO	3.45	638	57.56	11,513
CONTAINER & REEFER	0.93	172	15.53	3,107
RO-PAX AND RO RO CARGO	12.76	638	76.49	15,298
CRUISE SHIPS	3.50	175	20.90	4,198
TOTAL	24.17	2276	229.37	45,894

The US State of Alaska has some of the most stringent regulations of this kind. For the past two decades it has developed a program which requires ships to obtain discharge permits and only operate when they meet strict effluent limits, use advanced wastewater treatment systems, and undertake performance monitoring to ensure that standards can be met consistently. In addition, both the State and the US Coast Guard undertake compliance monitoring; twice a month in the case of larger passenger vessels (White, 2021). Compliance reports and wastewater sample results for cruise ships are published annually¹⁸. The program stands as a good example of how sewage from ships, including large ones, can be successfully managed (IMO PPR 9/14/5).

One less prominent, but important, aspect of maritime sewage management flows from the activities of the livestock trade. Significant quantities of effluent solids, pathogens (*E. coli*, among many others) and nutrients (nitrogen, phosphorus and potassium) are all produced by the cattle, sheep and goats aboard large livestock vessels. The volume produced greatly exceeds the sewage output of a ferry loaded with a similar number of human passengers (Landline, Consulting 2003). Each day a cattle carrier transporting 20,000 animals produces organic matter equivalent to a city of 200,000 people (Landline Consulting, 2003). A livestock vessel prevented from disposing of raw sewage at sea would need an onboard waste treatment facility big enough for a small city. This graphically illustrates the scale of the on-board sewage treatment challenge. In reality wash-down practices ensure that raw effluent is continuously washed overboard from livestock pens (Landing Consulting, 2003). Analysis by the European Parliament recently estimated that livestock vessels discharge 214 million litres of cattle and sheep sewage into the Mediterranean and Black Sea each year (Boada-Saña, Kulikowska et al., 2021).

¹⁸ <https://www.epa.gov/vessels-marinas-and-ports/no-discharge-zones-ndzs-state>

GREYWATER

Greywater generally refers to waste from sinks, baths, showers, laundries and ships' kitchens (galleys). It does not include sewage or 'black water' (discussed above). Greywater is by far the largest part of all liquid waste generated by vessels (*Table 3*).

Most ships generate some greywater but passenger vessels and cruise ships produce the bulk (Ytreberg et al., 2020). One cruise ship with 3,000 passengers can generate about 706,000 litres of greywater each day, or some 235 litres per passenger (IMO MEPC 77/8/4). On a per-fleet basis, passenger and car ferries (Ro-Pax and Ro-Ro cargo vessels) account for the largest volume of greywater, followed by general and specialised cargo vessels (*Table 3*).

Contrary to its bland label, greywater can contain a wide range of contaminants: bacteria, pathogens, oil and grease, detergent, disinfectants containing chlorine, soaps, heavy metals (including zinc, copper, cadmium, lead and mercury), flame retardants, solids and nutrients (nitrogen and phosphorus) and microplastics. It can also be highly acidic (Holmberg, 2021; Nuka Research and Planning Group, 2019; Peng et al., 2022; U.S. EPA, 2008; U.S. EPA, 2011; Ytreberg et al., 2020). And the levels of contaminants in greywater are far from negligible; untreated greywater can show bacteria, nutrients, solids and pollutants at levels as high as raw sewage, or higher (U.S. EPA 2008, 2011; IMO MEPC 77/14/4).

And yet greywater is not subject to the same MARPOL regulations as sewage and can be legally discharged in coastal areas where sewage discharge is prohibited. This is largely based on the questionable assumption that greywater is quickly diluted if discharged by a fast-moving ship. To date, greywater regulations are in place only in a few places, such as Alaska and the Great Lakes (U.S. EPA, 2011).

Most recently, greywater has begun to attract attention as a significant sea-based source of plastic microfibres, the source being the industrial-scale laundry facilities onboard cruise ships. Preliminary calculations estimate the potential discharge of microplastics from cruise ships at 100,000 tons per year (Peng et al., 2022).

ENVIRONMENTAL IMPACTS OF SEWAGE AND GREYWATER DISCHARGES

The impact of a given wastewater discharge will vary according to its content and concentrations, and the nature of the surrounding environment. Generally speaking, the most vulnerable are confined waterways with slow water turnover (which includes bays, estuaries and fjords, and also the Baltic Sea) and which are already under pressure from contaminants flowing off the land (Holmberg, 2021; Huhta et al., 2007, Ytreberg et al., 2020). Areas of high environmental sensitivity (such as polar ecosystems) are also particularly vulnerable to the kinds of contaminants present in sewage and greywater (even when they have been treated) (Vard, 2018).

Sewage and greywater discharges into the marine environment are associated with a host of system-wide harms: oxygen depletion; the spread of pathogenic bacteria and viruses; increased nutrient levels (eutrophication), potentially leading to toxic algal blooms. Meanwhile, the consumption of contaminated fish and seafood can cause a range of illnesses in humans, with the risks especially high for indigenous and coastal communities who rely heavily on the sea for food (Nuka Research and Planning Group, 2019).

OUTLOOK

It is estimated that more than 250 million tonnes of sewage and greywater, with its payload of numerous contaminants and pathogens, are discharged into the world's oceans each year (Maffii et al., 2007).

The discharge of sewage is supposed to be regulated under MARPOL Annex IV but there is plenty of evidence that those restrictions are not being respected, with untreated sewage regularly discharged at sea, including into coastal waters (IMO MEPC 71/INF.22). As maritime traffic continues to grow so will this problem unless much more is done to develop stricter regulatory and enforcement mechanisms. The dramatic results achieved by Alaska with its wastewater program (described above) shows how fit-for-purpose regulations coupled with strict compliance monitoring can vastly reduce the contaminant load of the effluent ships discharge into the oceans (IMO PPR 9/14/5). The IMO is currently updating its existing sewage disposal guidelines with a view to requiring record-keeping and reporting on the lifetime performance of onboard sewage plants (IMO PPR 8/7), but such measures are unlikely to trigger the changes needed to tackle the main problem – ships discharging what is often raw sewage straight into the sea. At the time of writing it is also unclear if the updated guidelines will apply to existing ships, or only to new builds (IMO PPR 8/7).

As of 2023 there is no international regulation of greywater. This is particularly concerning given the long-standing evidence that contaminant levels in greywater can at times exceed untreated sewage. Discharge volumes of greywater are ten times greater than sewage and, unlike sewage, can be legally discharged into coastal waters.

However, some efforts are being made to manage greywater. As discussed, Alaska's state-led wastewater program – which succeeded in vastly improving contaminant levels from discharged sewage – also applies to greywater and has reduced those contaminants to levels safe for disposal in the marine environment (White, 2021). Furthermore, the Helsinki Commission will assess the environmental impacts of greywater and (by 2029) decide if and how to further limit greywater discharges into the Baltic Sea (HELCOM, 2021). Given the amount of microplastics discharged into the ocean in greywater and sewage (both treated or untreated), greywater might also come into closer focus as the new UN Treaty on Plastic Pollution is being developed (Kalnina et al., 2022).

9

PLASTIC AND OTHER GARBAGE POLLUTION



The pollution of the oceans by human litter is now recognised as a serious global environmental threat. Macroplastics (things like water bottles, fishing gear, plastic bags) and microplastics (fragments and particles generally five millimetres or smaller) can take many human lifetimes (if ever) to break down entirely in the marine environment. They pose significant long-term risks to marine biodiversity, human health and the marine economy.

Plastic enters the marine environment from a wide range of primarily land-based activities. To date there is no reliable estimate of how much plastic pollution comes specifically from marine-based activities like maritime transport, fishing, offshore oil platforms and aquaculture farms. A widely-adopted assumption is about 20% (UNEP 2009, Interpol 2018) but the latest studies suggest that some marine sources – in particular shipping – are contributing much more than previously thought.

ONBOARD PLASTIC GARBAGE

The intentional dumping of garbage overboard was routine practice until relatively recently. People acted as if the ocean could absorb anything thrown at it. Awareness of the environmental harm being done grew during the 1970s and eventually, in 1988, the discharge of garbage straight into the sea was prohibited under MARPOL Annex V. Ships of a certain size (100 gross tonnes and above or carrying 15 persons or more) must manage the plastic waste they create during normal operations and then dispose of it on land. Annex V also obliges countries to ensure that their ports provide adequate disposal facilities.

Inadequate monitoring of enforcement and compliance has made it hard to assess the effectiveness of the MARPOL Annex V regulations, but the evidence of failure is widespread. A 2010 study by the EU estimated that between 7% and 34% of predicted waste was unaccounted for at port disposal facilities, suggesting it had been thrown overboard (EC, 2018). The various types of litter observed in areas like the North Sea and Baltic Sea indicate that shipping, fisheries and offshore installations are responsible for nearly half of all the litter found on beaches (Fleet et al., 2017). The items observed floating close to major shipping routes off Portugal point to merchant vessels as possible sources (Sá et al., 2016).

Beach clean-ups over several decades on remote Tristan de Cunha in the South Atlantic suggest that the expanding traffic between Asia and South America is responsible for illegal dumping of waste (including Chinese-branded PET water bottles), which then washes ashore (Ryan et al., 2019). Anecdotal evidence also suggests that throwing trash overboard remains a common way to circumvent onboard management and avoid having to deal with disposal in port. Just a few years ago a well-known cruise company was fined \$20 million for environmental violations (including the discharge of plastic in Caribbean waters) even though it was still on probation after a previous conviction and \$40 million fine for illegally discharging oil-contaminated waste (U.S. DOJ, 2019).



Figure 29: Illegal discharge of plastic pipes. Credit: Interpol, 2018.

ABANDONED, LOST OR DISCARDED FISHING GEAR (ALDFG)

As on land, the versatility and durability of plastic has led to its widespread use at sea. These days all affordable, lightweight and durable maritime equipment is made of plastic (UNEP, 2021).

Abandoned, lost or discarded gear from fishing boats (ALDFG) is responsible for a surprisingly large amount of the plastic found in the ocean. Nets, ropes, buoys, pots and boxes amount to 39% of all beach litter by volume, making them the largest single category (UNEP, 2021).

A recent study on global ALDFG estimated that nearly 2% of all fishing gear is lost to the ocean annually; that means nearly 3,000km² of gillnets, 75,000km² of purse seine nets, 218km² of trawl nets, 740,000km of longline mainlines, and more than 25 million pots and traps (Richardson et al., 2022). The causes are numerous and vary by fishery, region and gear type (GESAMP, 2021; Gilman et al., 2022), the most common being when bad weather forces gear to be abandoned (Richardson et al., 2021). Even though MARPOL Annex V prohibits the sea-disposal of unwanted fishing gear (just like general trash), other reasons given for dumping gear at sea include the lack of disposal facilities for end-of-life gear and the expense of onshore disposal (Gallagher et al., 2023; GESAMP, 2021; Richardson et al., 2021).

Direct interactions between fishing boats and international shipping might be an added and previously unknown source of ALDFG in some places. In Sri Lanka, the overlap of high intensity shipping lanes and fishing grounds has reportedly led to the cutting of fishing lines and nets by passing ships, a matter of grave concern to fishers (Gallagher et al., 2023).

Potential mitigation measures, including the use of area-based management tools to avoid overlap between fisheries and ships, are reviewed in (GESAMP, 2021; Gilman et al., 2022).

MICROPLASTIC IN MARINE PAINTS, GREYWATER AND OTHER SHIP-BASED SOURCES

In recent years a growing number of studies have pointed to ships as a previously overlooked source of microplastic pollution. A trail of microplastic debris is often found along a ship's path. A significant (but long-underestimated) cause of this will be its antifouling coating (Dibke et al., 2021). These coatings (along with anticorrosion paints and coatings) commonly contain relatively high levels of toxic plastic polymers (such as epoxy, acrylic, vinyl) which are readily released into the surrounding environment during shipyard maintenance or in-water hull cleaning (*Figure 30*), by wear and tear or simply as a result of constant exposure to the elements (IMO, 2019). The latest available data suggest that 6-7% of marine coatings are lost directly to the sea during the lifetime of a vessel (GESAMP, 2020). In areas of high shipping traffic in the North Sea antifouling paint-derived microplastics have been found to outweigh land-based sources (packaging-derived microplastics) by between 20% and 80% (Dibke et al., 2021). Hazardous paint additives can make these micro-particles even more harmful than other microplastics (IMO MEPC 77/8/1). Of particular concern are so-called 'self-polishing' anti-fouling products which maintain their biocidal properties by sloughing-off during a ship's normal operations (IMO, 2019).

Onboard laundry facilities – and particularly the industrial-scale ones found on cruise ships – are another significant source of microplastics. Each year about 100,000 tonnes of microfibres are shed from synthetic clothing passing through cruise ship laundries, before being discharged into the ocean as unregulated greywater (Peng et al., 2022). Ropes (a variety of which are in regular use onboard all vessels) have recently been added to the growing list of potential sources of onboard microplastics (Napper et al., 2022). In particular, ropes older than two years produce substantial amounts of microplastics due to abrasion and fibre break-up in the harsh conditions.



Figure 30: Diver performing underwater hull cleaning.
Credit: IMO, 2019.

PLASTIC PELLETS

Raw material plastic is traded globally in the form of pellets, flakes and powders. Because these are often produced on one side of the planet but converted into finished products on the other, they are frequently transported in bulk, over great distances, by container ship. A single standard container can hold millions of individual pellets.

Pellet loss into the environment is recognised as a problem at every stage of the plastic supply chain. Since most water (rivers, stormwater and the like) will eventually make its way to the sea, pellet losses anywhere inland along the supply chain will eventually contribute to what is one of the leading sources of microplastic pollution in the oceans (Jambeck et al., 2015).

Pellet pollution from shipping disasters has been documented for more than a decade now. Since 2011 at least 1 trillion pellets have been lost at sea in eight maritime disasters (FFI, 2022). The MV X-Press Pearl brought this problem to prominence for the international community. In May 2021 it caught fire and dumped some 84 billion pellets (the contents of 87 containers), along with a variety of other hazardous and noxious substances, into the Indian Ocean off Sri Lanka (Partow et al., 2021). The scale of the environmental damage done by this event – described as the ‘single largest plastic spill’ in history by the UN investigators attending – was possibly compounded by contamination from other chemicals onboard (Partow et al., 2021).

In the immediate aftermath plastic pellets were found along a 300 km stretch of Sri Lanka’s coastline (*Figure 31*) even though most of the spilled pellets are believed to have remained at sea, transported by currents far across the northern Indian ocean (Partow et al., 2021).



Figure 31: Massive arrival of plastic pellets on the west coast of Sri Lanka following MV X-Press Pearl incident in 2021. Credit: Sri Lanka marine Protection Authority (MEPA), in Partow et al., 2021.

ENVIRONMENTAL, HUMAN HEALTH AND SOCIO-ECONOMIC IMPACTS OF PLASTICS

Whether the individual pieces are large or small, whether they originate on land or sea, the combined effect of the vast quantities of plastic now blighting the oceans can fairly be described as all-pervasive and, ultimately, potentially devastating for all life on Earth, including humans.

Once plastic enters the ocean it remains there for very many years, slowly being broken down into smaller and smaller pieces, and (if not deposited on the ocean floor) transported by ocean currents to even the most remote parts of the planet.



Figure 32: Plastic pellets found lodged in fish's gills and mouth following X-Press Pearl sinking in Sri Lanka in June 2021. Credit: Sri Lankan MEPA.

The effects are wide ranging; harming microscopic planktonic species and large whales alike by ingestion and entanglement; helping to transport invasive species; facilitating the direct destruction of seafloor habitats.

Lost or abandoned fishing gear can also result in so-called 'ghost fishing', with nets and other gear continuing to 'catch' and kill target and non-target species indiscriminately, degrading marine ecosystems for decades to come and worsening the threat to global food security and biodiversity conservation (GESAMP, 2021).

As plastics break down into microplastics they absorb contaminants such as heavy metals and organic pollutants, which are eventually transferred into marine food chains via plankton-eating and filter-feeding species (IMO, 2019; UNEP, 2021).

Contaminated fish and shellfish then expose humans to these bioaccumulated microplastics and contaminants. Even sea salt is now known to contain microplastics (UNEP, 2021). The precise ways in which exposure to plastic and associated chemicals damages health are not yet fully understood, but are strongly believed to include neurodevelopmental and hormonal disorders, metabolic disease, and reproductive health problems – with implications for offspring too (UNEP, 2021).

These ecological and human health arguments are compelling enough, but marine plastic pollution also entails hidden costs for the global economy, posing serious threats to the wellbeing and livelihoods of Indigenous Peoples and coastal communities, as well as marine-based industries (UNEP, 2022).

For example, direct economic losses are the result when ships' propellers become entangled (compromising navigational safety and endangering crew) or a coastal power station suffers from blocked cooling water intakes (FAO, 2016; UNEP, 2022). When marine litter washes up on land, and the coastline and beaches become unsightly or even unsafe, recreational and tourism value is lost. In 2016 the Asian-Pacific Economic Cooperation (APEC) estimated that marine litter (including plastics) cost its member countries \$1.26 billion each year in losses to shipping, tourism, fishing and insurance (APEC, 2016).



Figure 33: Impacts of garbage on marine wildlife. Credit: Interpol, 2018.

OTHER GARBAGE – ANIMAL CARCASSES

Under MARPOL Annex V, an animal that dies at sea during transport can be considered garbage and thrown overboard (except in the Mediterranean and Black Seas). Despite a lack of official data, the disposal of animal carcasses illegally (which means discharged inside special areas or without first having been prepared for sinking) seems to be common practice. Common justifications include problems with port reception facilities, the additional expense of carcass disposal on land, and the requirements of EU law (Boada-Saña, Kulikowska et al., 2021). An EU investigation found that 'the system in place seems incapable of guaranteeing [the levels of] animal welfare stipulated by EU legislation'.

As well as posing widely-reported animal welfare problems (Boada-Saña, Kulikowska et al., 2021), the livestock trade is generally risky for crew and cargo alike because most ships are old and were not originally designed for this purpose. Some 28 livestock transports have reportedly suffered major incidents, failure or even total loss (Robin de Bois, 2021). Ships used in the global livestock trade are the most frequently detained because of their regulatory deficiencies (Boada-Saña, Kulikowska et al., 2021).



Figure 34: Dead cow suspected to have been disposed overboard washed up on beach in Menorca, Spain, 2019. Credit: Es Diari Menorca, 2019.

OUTLOOK

Plastic pollution has captured the public's attention in recent years and many initiatives are now attempting to tackle the problem. Whilst it is currently not possible to estimate the total contribution of shipping to marine litter, a continuing upward trend is guaranteed given the increase in maritime shipping activity and trade over the coming decades and the mounting evidence of the shipping industry's contribution to the problem.

The creation of a new, legally-binding international agreement to address plastic pollution has begun under the auspices of the UN Environment Assembly, which notes 'with concern the specific impact of plastic pollution on the marine environment' as well as the importance of a full-lifecycle approach given the global, borderless nature of the crisis (UNEA, 2022). Formal negotiations began in 2022 with the ambition of completing a draft agreement by the end of 2024. How the treaty will address specifically marine-based sources of plastic pollution, such as from shipping, remains to be seen.

In 2018 the IMO also began to focus some of its attention on improving plastic management onboard ships by adopting its Action Plan to Address Marine Plastic Litter from Ships (IMO MEPC.310(73)). The plan aims to build on and improve existing policy and regulatory frameworks, and possibly to introduce new supporting measures such as a compulsory mechanism for declaring container loss (including location), reductions in marine plastic litter, and improved port reception facilities. Notably absent are specific proposals on microplastics, possibly because of the link to greywater, which is also unregulated (see page 54). Turning to ghost fishing and lost gear, mandatory marking of fishing gear, ways to encourage the reporting of lost gear, and improving onshore management facilities are all under consideration. The action plan should build on other measures either under consideration by the Food and Agriculture Organization (FAO, 2016) or already adopted (such as the 2019 Voluntary Guidelines on the Marking of Fishing Gear (FAO, 2019)), as well as the many local, ground-up initiatives and pilot projects spearheaded by the fishing sector (Cho, 2009) and NGOs in recent decades. The action plan is up for review in 2023 but it is unclear to what extent its ideas have been progressed and/or implemented.

10

UNDERWATER NOISE POLLUTION



Sound pollution from ships is increasingly shaping the underwater soundscape of the world's oceans. Today the global web of maritime traffic is the most ubiquitous and pervasive source of underwater human-made noise. Along the world's major shipping routes there has been a 32-fold increase in low frequency noise from maritime traffic over the last 50 years (Duarte et al., 2021). Although the long-term impact on marine life is not yet fully understood, extensive research is fuelling growing global concern about the cumulative effects of chronic noise on marine biodiversity and the knock-on social and economic consequences (UNGA A/73/68).

SHIPPING'S CONTRIBUTION TO THE MODERN UNDERWATER SOUNDSCAPE

Large commercial vessels produce continuous, relatively intense and predominantly low-frequency sounds, with most of this energy concentrated below 100 Hz (McKenna et al., 2012). In fact, low frequency ocean sound is dominated by shipping (Hatch et al., 2008; Hildebrand, 2009).

A ship's underwater sonic signature largely depends on its type, design, size and purpose (*Figure 35*). Generally, the larger the ship, the more sound energy and the lower the frequency. Faster vessels such as container ships and bulk carriers tend to produce the most noise (Jalkanen & Johansson, 2019; McKenna et al., 2012). Even when anchored some vessels create substantial amounts of underwater sound (Murchy et al., 2022).

Most of a vessel's noise comes from its propulsion systems, in particular the formation and implosion of small bubbles (known as cavitation) as the propellers rotate. Engine noise and hull vibration add further to a ship's acoustic footprint (Hildebrand, 2009).

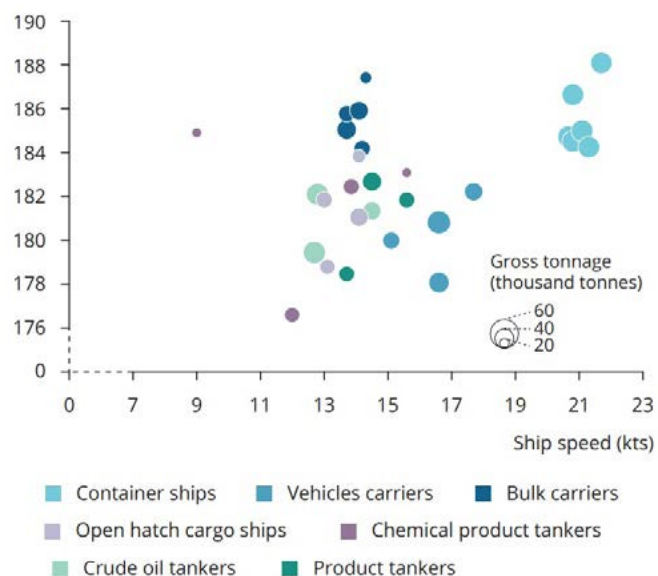


Figure 35: Broadband ship underwater noise source level of different ship types. Credit: McKenna et al., 2012.

Ship traffic is a dominant source of background, long-range and chronic undersea noise which persists far and deep across ocean basins, potentially affecting species very many kilometres from the individual ship or shipping lane (Hildebrand, 2009). This is because low frequency sound travels (propagates) very efficiently through water, allowing shipping noise to travel much further and longer underwater than it would through air. A further characteristic of sound propagation in water – the formation of so-called acoustic channels – enables sound energy to travel with little loss so that the noise from ships can project far from shipping routes and deep down into the ocean (*Figure 37*) (Dunn et al., 2021; Erbe et al., 2019; Hildebrand, 2009; Jalkanen et al., 2022; Kozaczka & Grelowska, 2004).

IMPACTS ON MARINE SPECIES

The wide-ranging threats to marine mammals from underwater noise has been extensively researched in recent decades (reviewed in Erbe et al., 2019). The findings show that shipping noise affects the behaviour and physiological responses of individual marine mammals, with potential implications at the population and wider, ecosystem level.

Sound plays a key role in the life of marine mammals. They use it to map their world, find prey and communicate, often across hundreds or even thousands of kilometres of ocean. The continuous low-frequency noise emitted by ships, capable of dominating and persisting across a range of frequency bands at considerable distances, overlaps with the typical hearing ranges of various marine species and interferes with the transmission of biologically-significant sounds (Figure 38).

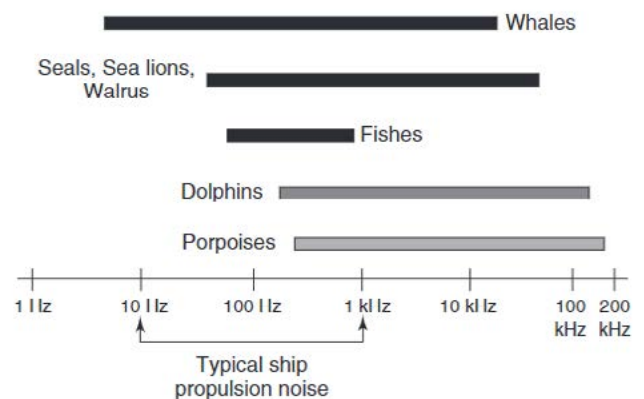


Figure 38: Typical hearing ranges of various groups of marine animals shown relative to the typical predominant frequencies of commercial shipping. Credit: Southall et al., 2017.

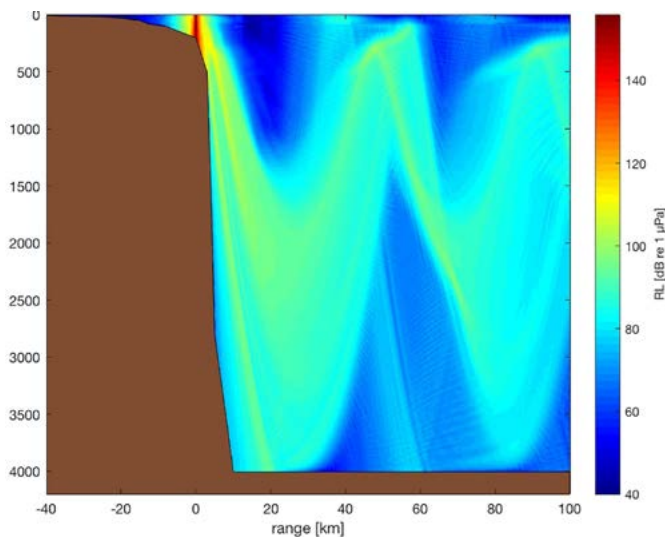


Figure 36: Representation of noise field produced by a cruise ship at the continental slope. Low frequency sound propagates with little loss in deep water and attenuates much more quickly in shallow waters. Adapted from Erbe et al., 2019.

Unsurprisingly, the geographical distribution of ship noise mirrors trade patterns, with greater shipping densities and noise found in the northern hemisphere (Figure 37) (Hildebrand, 2009). The main shipping lanes – including China to Europe via the Malacca and Suez Straits – are associated with the greatest noise levels. Other 'noisy' areas include the Gulf of Mexico and from the Malacca Strait towards Madagascar and Southern Africa. Even high up in the Arctic, both the Barents Sea and Kara Seas are increasingly experiencing significant noise from ships, most likely due to oil and gas extractive activities (Jalkanen et al., 2022).

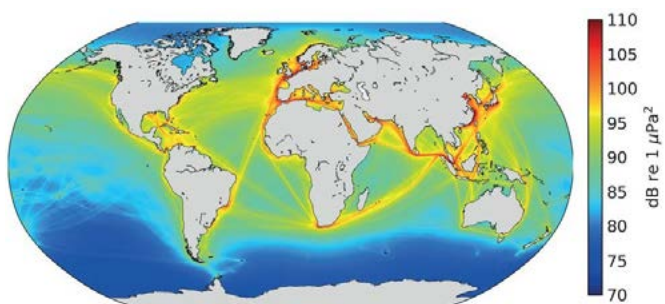


Figure 37: Average sound level estimated globally from marine traffic (at 100 Hz), based on average shipping activity, derived from AIS data for 2014. Credit: Duarte et al., 2021.

This masking of natural sounds disrupts co-operation, communication, navigation and more, causing increases and decreases in the rate of vocalisations (whistles and echolocation clicks); shifts in the frequencies used for acoustic signals; reductions in communication range; longer calls and even temporary uncharacteristic lapses into silence (Castellote et al., 2019; Erbe et al., 2018; Fouda et al., 2018; Luís et al., 2014; Melcón et al., 2012; Tsujii et al., 2018). Disruptions to foraging behaviour can include displacement from important habitats (Blair et al., 2016; Ilangakoon, 2012; Weilgart, 2007). Of particular concern are the effects of shipping noise on endangered species like the North Atlantic right whale, with increased levels of stress hormone found to be associated with ship traffic in the Bay of Fundy, Canada (Rolland et al., 2012).

Like marine mammals, fish also rely on sound to perceive and understand their world (*Figure 38*). The harm done to fish by underwater noise pollution includes increased levels of stress hormones, reduced group cohesion, poorer foraging performance and increased defensive behaviour, with these effects even being recorded in offspring as young as pre-juveniles (the larval stage) (Buscaino et al., 2010; Popper & Hawkins, 2019; Weilgart, 2018).

Crabs, lobsters, octopus and other invertebrates don't necessarily respond to acoustic stimuli through pressure changes, but they do perceive the associated motion of vibrating water particles (Popper & Hawkins, 2018). Changes in movement patterns, embryo development, mortality, settlement of larvae, defensive responses, stress hormone levels and rates of growth have all been detected in these species (Cruz et al., 2021; Weilgart, 2018).

The effect of ship noise on invertebrate larvae also turns out to be particularly relevant when it comes to addressing biofouling and ship-mediated propagation of invasive species. Underwater noise, such as the sounds produced by ships, has been shown to significantly shorten the time it takes for the larvae of some species to attach themselves to a ship's hull or other nearby surfaces such as marinas or port pylons. The stronger the underwater noise the faster the effect on larval settlement (McDonald et al., 2014; Stanley et al., 2016).

OUTLOOK

Global shipping noise is increasing in line with expanding global trade and, at the current rate, is expected to double every 11.5 years (Jalkanen et al., 2022; Kaplan & Solomon, 2016). Increased awareness of underwater noise pollution as a growing source of long-term and habitat-level pressure on marine environments has triggered renewed interest in this topic at the international level (EC, 2021; IWC 2022 CC/68/12.1.1/02; UNEP/CMS/Resolution 12.14; UNGA A/73/124).

While international regulations are in place to protect crew and passengers from shipboard noise, nothing similar currently exists to protect marine ecosystems from underwater noise. Numerous approaches to making ships quieter underwater do exist, however the most effective are during initial ship design (Audoly et al., 2017; Berkowitz & Dumez, 2017; Leaper & Renilson, 2012; Spence & Fischer 2017; Virto et al., 2021). Making existing ships quieter is less straightforward. The 2014 IMO Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life provide a range of technical considerations to guide ship design (propellers, hulls, onboard machinery), as well as tweaks for existing ships (such as propeller cleaning, managing biofouling, speed reductions, rerouting and other operational changes) (IMO MEPC.1/Circ.833). Unfortunately, the IMO guidelines are not mandatory and their adoption and implementation has been extremely limited. In Europe, for example, the recorded noise energy from some ship types (namely general cargo vessels, container ships and tankers) has nearly tripled since the IMO guidance was issued (*see Figure 39*) (EMSA & EEA, 2021).

Even though there is general agreement about the threat posed by underwater noise pollution, current discussions at the international level are largely focused on filling knowledge gaps and noise monitoring (UNGA A/73/68) rather than effective mitigation measures. International progress is further hampered by the fact that underwater noise is not explicitly recognised as a type of pollution under the United Nations Convention on the Law of the Sea (UNCLOS), the main international agreement on all matters pertaining to the sea (UNGA A/73/68).

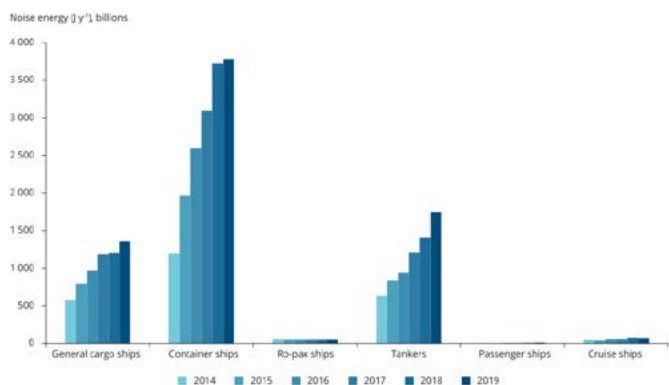


Figure 39: EU underwater noise energy (J) recorded since IMO's 'Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life' were adopted in 2014. Energy (J) at 125 Hz one-third octave band centre frequency by ship type, 2014-2019. Source: EMSA & EEA (2021)

The most successful example of noise mitigation – in the Port of Vancouver – will soon be a decade old. In 2014 a permanent noise monitoring system was introduced and since 2017 the port authority has been implementing a voluntary slow-down trial for commercial ships in areas of importance to killer whales. Vessels using quieting technology can claim harbour fee discounts of up to 50%. By 2020 preliminary data showed that more than 90% of vessels had joined the initiative and sound intensity had been halved. Incidentally, slowing down ships brings a number of additional benefits for shipping and the environment, including fewer whale strikes and reduced GHG emissions (Leaper, 2019).

There is clearly no one-size-fits-all solution to the problem of excessive ship noise. Key barriers to effective underwater noise pollution reduction include: the lack of a legally-binding management framework, the cost of retrofitting technology and the lack of agreed underwater noise thresholds to guide regulation and drive industry-wide uptake (Cruz et al., 2021; Vakili et al., 2020; IMO SDC 9/5/7). Nonetheless, the success of the Port of Vancouver initiative – not to mention the examples of fisheries research and naval vessels built to noise-quieting technical specifications (Cruz et al., 2021) – demonstrates that significant reductions are achievable. Furthermore, a recent pilot study looking at fuel efficiency gains and GHG reductions from retrofitting container ships also showed a reduction in emitted underwater noise as a co-benefit, further highlighting the potential synergies available in sustainability measures (ZoBell et al., 2023).

In early 2021 the IMO's Sub-Committee on Ship Design and Construction started to revise the 2014 guidelines (IMO SDC 8/14/2). It remains to be seen if and how the IMO will consider introducing integrated regulatory measures, which by general agreement are the only effective way to bring about sector-wide change (Cruz et al., 2021; Vakili et al., 2020).

11

SHIP COLLISIONS WITH WILDLIFE



The likelihood that marine species will come into direct physical contact with ships is increasing. The risks are greatest where areas of high shipping density overlap with areas of high species abundance. Most of our present knowledge relies on reports of whale and dolphin collisions with ships of all sizes but it is increasingly clear that these events are not restricted to marine mammals.

Seventy-five different marine species have been recorded struck by ships; as well as marine mammals these include fish, birds and sea turtles (Schoeman et al., 2020). A variety of factors may help explain the vulnerability of certain species or individuals to ship strikes: behaviour, physical and physiological traits, age, ambient noise at the time, and the overlap of migratory and seasonal movements with shipping lanes or other busy shipping areas. Typically, it is the larger, easy-to-spot species that are most often recorded, most of the rest having sunk unobserved and uncounted. The following sections focus on the most commonly-reported groups.



Figure 40: Top left: Juvenile North Atlantic right whale found with 20 large propeller cuts along the right side of its head off Georgia, USA, in January 2007. Credit: M. Zani, New England Aquarium. Top right: Pilot whale calf with half-severed fin, off Canarias. Credit: Photo Francis Perez. Bottom left: 39-foot dead whale wedged on the bow of a tanker arriving in 2021 into Mitzushima harbour, Japan. Credit: Mitzushima Coastguard. Bottom right: 10m long humpback whale pulled from the Cape Town harbour in December 2019. A ship's propeller had severed the back part of the whale just behind the dorsal fin. Credit: Cape Town ETC.

CETACEANS

Collisions between ships and cetaceans have long been understood as a major threat to these populations (Laist et al., 2001). Ship strikes are a leading cause of injury and death among whale populations, many of which are yet to recover from having been hunted to near-extinction.

IMPACTS

Ship strikes are forceful impacts by any part of a vessel (but most commonly the bow or propeller) and they often result in death or major injuries, with the physical damage inflicted sometimes internal and invisible (Cates et al., 2017; Laist et al., 2001). Fast and high-speed ferries cause the bluntest trauma on impact, with individuals found cut in two or caught on the bow (Carrillo & Ritter, 2010; Panigada et al., 2006). The massive injuries found on dead whales suggest that most, if not all, are being caused by large ships (Laist et al., 2001) (Figure 40). If a whale survives a collision the long-term consequences of their injuries are unknown (Panigada et al., 2006). The cetaceans most affected by ship strikes include large, fast whale species, such as fin whales (*Balaenoptera physalus*), but also slow-moving species which spend a lot of time on the surface, such as right whales (*Eubalaena spp.*) and sperm whales (*Physeter macrocephalus*) (Carrillo & Ritter, 2010). A recent analysis of the IWC Ship Strike Database (Winkler et al., 2020), which contains records for 36 species and subspecies, found that nearly half of fatalities involved just three species of large whale: fin (*Balaenoptera physalus*, 20%), humpback (*Megaptera novaeangliae*, 17.5%) and sperm (*Physeter macrocephalus*, 10.9%). In fourth place (6.9%) was the critically-endangered and declining North Atlantic right whale (*Eubalaena glacialis*), for whom ship strikes are a well-documented cause of death (Conn & Silber, 2013; Parks et al., 2012).

The collision of a small, fast-moving ship with a large whale can also put crew, passengers and the ship's structural integrity at risk. Such events are rare but passengers have died and vessels have suffered significant damage, including sinking (Ritter, 2012; Van Waerebeek & Leaper, 2008; Winkler et al., 2020).

WHY ARE CETACEANS VULNERABLE TO SHIP STRIKES?

Why do some species, and particularly larger whales, find it so hard to detect and avoid approaching ships? The reasons are not completely understood, but several factors probably increase either the probability of a collision or the severity of the outcome.

Vessel speed and size play a big part. The probability of a strike proving fatal increases from 21% to 79% as speed increases from 8.6 to 15 knots (Vanderlaan & Taggart, 2007). Most fatal injuries are associated with vessels of 80m or longer even though these often go unnoticed because of the limited visibility immediately in front of a larger vessel and its greater mass making the impact less likely to be felt (Laist et al., 2001). In nearly 40% of collisions involving vessels 120m and longer, crew members were unaware of the strike until they arrived in port and found a carcass wrapped around the bow (Laist et al., 2001).

Other factors also work against whales. Hydrodynamic studies of the forces they experience around ships indicate a strong suction effect from the propellers which can draw the animal into a collision even when it is at twice the depth of the ship's draught (Silber et al., 2010). Acoustic shadow zones, created immediately ahead of an approaching ship's bow, might also hinder timely detection and avoidance by the whale (Allen et al., 2012). Meanwhile, behavioural factors could include habituation to loud underwater noise, particularly in high traffic areas (Nowacek et al., 2004).

Information from the IWC Ship Strike Database further reveals that while virtually all vessel types have been involved in collisions, the highest numbers involve ferries, closely followed by sailing yachts, passenger vessels (including cruise ships) and motor yachts, then whale watching vessels, naval vessels, container ships and general cargo ships (Winkler et al., 2020) (Figure 41). Of the collisions for which vessel speed was logged, 50% occurred between 11 and 20 knots.

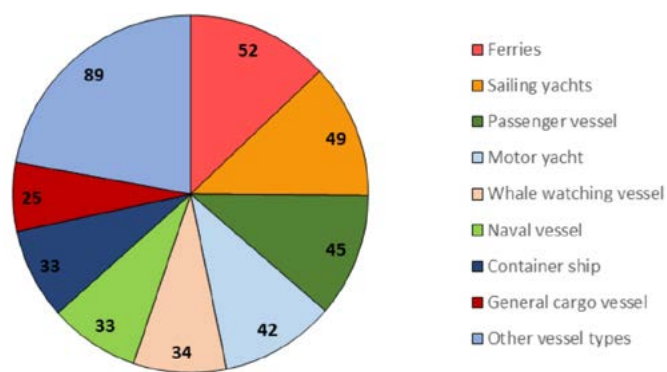


Figure 41: Number of ship strikes per vessel category, based on IWC Ship Strike Database (1820-2019). Credit: Winkler et al., 2020.

COLLISION HOTSPOTS

It is difficult to define the areas in which collision risks are highest due to a heavy reliance on stranding data and on the willingness of people (often crew) to report incidents (Carrillo & Ritter, 2010). The IWC Ship Strike Database is also understood to contain many (large) regional data gaps. With these caveats in mind, *Table 4* lists the populations known to be at risk (Cates et al., 2017).

Table 4: Populations at high risk because of their low numbers and the greater consequences of even a small number of ship strikes per year, as identified in the IWC Strategic Plan to Mitigate Impacts of Ship Strikes on Cetacean Populations 2017-2020 (Cates et al., 2017) and update for 2022-2032 (IWC, 2022). IUCN status information taken from IUCN (2022).

Area/population	IUCN Red List of Threatened Species status	Concern
Western North Atlantic right whale (<i>Eubalaena glacialis</i>)	Critically endangered	Species vulnerable to ship strikes and historically the victim in more than 50% of ship strikes. Ship strike rates have declined after Seasonal Management Areas (SMA) were introduced in 2008. However, there is concern that a shift in the summer distribution of the western community of North Atlantic right whales might have once more increased their ship strike risks in recent years (IUCN, 2022).
Eastern North Pacific right whale (<i>Eubalaena japonica</i>)	Endangered	Current estimates are in the low 100s, with the eastern community particularly small (~ 30 individuals). The projected increase in shipping through the south-eastern Bering Sea, as the Arctic Ocean becomes ice-free due to global warming, is a potential threat to the very small eastern North Pacific population (IUCN, 2022)
Eastern North Pacific blue whale (<i>Balaenoptera musculus</i>)	Endangered	Known overlap of heavily-used shipping lanes (into ports of Los Angeles and Long Beach) with feeding area.
Chile-Peru Southern right whale (<i>Eubalaena australis</i>)	Critically Endangered	Communities off Chile and Peru are still very small and not showing the same signs of recovery (following commercial hunting) as other groups of Southern right whale (IUCN, 2022).
Arabian Sea humpback whale (<i>Megaptera novaeangliae</i>).	Endangered.	The small Arabian Sea community is genetically highly distinct and non-migratory (Pomilla et al., 2014). Concerns include the high shipping density in the area.

Table 4: Continued.

Area/population	IUCN Red List of Threatened Species status	Concern
Western gray whale (<i>Eschrichtius robustus</i>).	Not assessed separately from Pacific population. Gray whales are classed as 'least concern'.	Shipping congestion throughout the migratory corridor(s) of this community represents a potential threat by increasing the likelihood of ship strikes, especially in China and Japan. Present and planned large-scale offshore gas and oil development, with associated increases in shipping traffic in the South China Sea, in close proximity to the only known feeding ground for western gray whales off northeast Sakhalin Island (Okhotsk Sea), is of particular concern.
Blue whale (<i>Balaenoptera musculus</i>) – Sri Lanka and Arabian Sea.	Endangered.	High shipping density along the southern tip of Sri Lanka, where shipping routes across the northern Indian Ocean converge and overlap with very high numbers of blue whales as well as locations in which blue whales are regularly reported struck (Priyadarshana et al., 2016).
Blue whale – Chile.	Endangered.	Overall number and trend for Chilean blue whales are currently uncertain (IUCN, 2022).
Sperm whale (<i>Physeter macrocephalus</i>) – Mediterranean.	Endangered.	Found throughout the Mediterranean and considered a distinct population. Areas of importance to sperm whales which overlap with increased shipping density include: Hellenic Trench, Crete, Balearic Islands, eastern Alborán Sea and Strait of Gibraltar.
Fin whale (<i>Balaenoptera physalus</i>) – Mediterranean.	Vulnerable.	High risk areas include the Pelagos Sanctuary between the French mainland and Corsica, the Balearic Islands, eastern Alborán Sea and Strait of Gibraltar.
Bryde's whale (<i>Balaenoptera edeni</i>) – Gulf of Mexico.	Least concern.	Latest research suggests this is a separate, undescribed species (Rosel et al., 2021).
Oamura's whale (<i>Balaenoptera omurai</i>) – Northwestern Madagascar.	Data deficient.	Research to date indicates this could be a resident, non-migratory population (Cerchio et al., 2018).
Sperm whale – Canary Islands region.	Endangered.	The inter-island ferry system is a known threat to sperm whales, and the area experiences one of the highest sperm whale ship-strike rates in the world. The ship strike rate currently exceeds the population's natural reproduction rate (Fais et al., 2016).
Bryde's whale – Hauraki Gulf.	Least concern.	The Hauraki Gulf is home year-round to fewer than 200 Bryde's whales. Ship strikes caused many deaths until voluntary speed reductions were introduced in 2013 (Constantine et al., 2015).

MANAGEMENT

As the risks for cetaceans have risen in line with the number, size and speed of ships, international concern has grown. Efforts to reduce this threat include vessel re-routing, mandatory ship reporting, and mandatory or recommended speed restrictions. In 2009 the IMO launched its Guidance Document for Minimizing the Risk of Ship Strikes with Cetaceans (IMO MEPC.1/Circ.674) which includes a number of national (operational measures and investments in new technology) and international (increased coordination) measures.

Southern California provides an interesting case study. Since mid-2005 there has been a seasonal, voluntary speed limit (10 knots) for vessels of 300 GT or larger crossing a 75-mile stretch of shipping lane in the Santa Barbara Channel, the objective being to protect blue and other large whale species. Compliance monitoring in the early years found the measure to be largely ineffective, even after the introduction of an incentive program (McKenna et al., 2012; Morten et al., 2022). After 2011, however, strandings of dead whales thought to have been killed by ship strikes began to decline sharply, but for other reasons. This sharp decline was preceded by the introduction in 2009 of new emission regulations within a 24-mile wide buffer zone along the Californian coast. Imposing the use of cleaner but also more expensive fuels in coastal waters changed vessel behaviour in ways that also helped whales. To reduce the additional costs associated with cleaner fuels, ships approaching the port of Los Angeles had begun to cross the low-emission zone – prime whale habitat – at the shortest possible distance and more slowly (Moore, 2018).

For the time being, ‘static’ measures – such as reducing the overlap of large whale populations and high-density shipping zones – are likely to remain the most pragmatic approach to reducing ship strikes, the next being speed reductions (Winkler et al., 2020). *Table 5* provides a general overview of the various mitigation measures that have been implemented worldwide so far.

Table 5: Summary table of ship strike mitigation measures implemented worldwide. Credit: submitted by the IWC to IMO in 2016 (IMO MEPC 69/10/3).

Measure	Situation to which it might be applied	Implementation process (and observations)	Examples
Keeping vessels away from whales			
Permanent routing measures through traffic separation schemes (TSS), areas to be avoided (ATBA) or port approach routes.	Long-term patterns of whale distribution are sufficiently predictable and well understood to enable a robust analysis of the risk reduction that might be achieved.	Implemented through IMO, or national regulation if within territorial sea. Proposals should follow the IMO process, including data on the problem, the risk reduction achieved and implications for shipping. (Generally well-respected by industry.)	Bay of Fundy, Canada. Boston and California, US. Panama Cabo de Gata, Spain.
Seasonal routing measures.	Similar requirements to permanent routing but applicable where there are strong seasonal patterns in whale distribution.	<i>As above.</i>	Roseway Basin, Canada. Great South Channel, US.
Recommended (voluntary) routes.	Similar requirements to permanent routing through TSS or ATBA but not mandatory.	Implemented by IMO or coastal state as a non- mandatory measure.	Península Valdés, Argentina. Hauraki Gulf, New Zealand. Glacier Bay, plus ports on US east coast.
Short-term (days – weeks) and dynamic routing measures.	Implemented in response to short-term observations of whale aggregations or known high risk areas. Need almost real-time reporting systems that can identify aggregations.	Voluntary measures need to be communicated to mariners. (Can be difficult to encourage compliance.)	Dynamic management areas (DMA) off US east coast. Gibraltar Strait, Spain.
Slowing vessels down			
Permanent speed restriction zones.	Long-term patterns of whale distribution are predictable and well understood but routing measures are not practicable.	Can be voluntary or mandatory if implemented in national waters.	East coast of US (mandatory). Glacier Bay, US. Hauraki Gulf, New Zealand.
Seasonal speed restriction zones.	<i>As above</i> but applicable where there are strong seasonal patterns in distribution.	<i>As above.</i>	Panama. California, US. Península Valdés, Argentina.
Dynamic Management Areas for speed restrictions.	Implemented in response to short-term observations of whale aggregations or known high risk areas. Need reporting systems that can identify such aggregations.	Voluntary measures that need to be communicated to mariners. (Can be difficult to encourage compliance.)	US east coast.

Table 5: Continued.

Measure	Situation to which it might be applied	Implementation process (and observations)	Examples
Avoidance manoeuvres			
Real-time alerting tools to warn vessels of the presence of whales or aggregations. Enabling vessels to alter course or slow down.	A rapid reporting network of whale sightings or acoustic detections alert all vessels transiting an area to the locations of whales so that they can alter course or slow down.	Individually designed and implemented reporting systems.	REPCET (on-board computer system to monitor whale positions), Agreement on the Conservation of Cetaceans in the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS), Mediterranean Sea Whale Alert. Boston, US.
Observations from the vessel that allow avoiding action to be taken.	Only effective for vessels capable of rapid manoeuvring to avoid whales (vessels of a few thousand GT or less).	Additional dedicated observers, education and outreach to mariners.	Many initiatives.

WHALE SHARKS

Whale sharks (*Rhincodon typus*) are migratory, filter-feeding fish which can grow to lengths of 18-20 metres, making them the world’s largest fish. They can be found worldwide, from the tropics to warm temperate seas, and they spend significant amounts of time feeding near the surface and attending seasonal gatherings in very particular locations (some of which coincide with heavy shipping traffic). Whale sharks are listed as ‘endangered’ on the International Union for Conservation of Nature (IUCN) Red List of threatened species. Their decline in several locations around the world is hard to attribute entirely to fishing and fishing-related threats. Scientists increasingly suspect that ship strikes might be a significant, largely-hidden cause of early death.



Figure 42: Whale shark showing signs of a propeller strike. Credit: Simon Pierce/marinemegafauna.org.

COLLISION HOTSPOTS

One recent study looked at 14 years of data collected from whale sharks carrying tracking devices to assess the overlap with AIS data for large vessels (Womersley et al., 2022). The overlap (in time and geography) is extensive across the species' entire range, including many of its important aggregation areas. Furthermore, potential collision risk hotspots were found in all major oceans but concentrated in gulf regions where dense traffic clashed with seasonal shark movements. A high degree of overlap was particularly evident with cargo and tanker vessel tracks. *Figure 43* shows the collision risk hotspots: Gulf of Panama, Baja California, Gulf of Mexico and between Haiti and Cuba; Red Sea and Arabian Gulf; between western Australia and Indonesia, and the Perth Canyon area; and New Guinea's northern coast, the Coral Sea and Solomon Sea confluence.

Nearly a third of areas with high-density whale shark populations were also identified as areas of high collision risk. When sharks 'disappeared' their last recorded location coincided with the busier shipping routes more often than expected, suggesting an untimely death. Depth-recordings of tagged animals also provided evidence of sinking after a likely strike, suggesting that the animal was indeed killed by the collision. The Arabian Gulf has the highest frequency of confirmed whale shark deaths following collision with a large vessel (Womersley et al., 2022). Incidentally, some of the areas identified in the study – such as the Red Sea and Arabian Gulf – have also been identified as high-risk areas for other man-made threats to endangered whale sharks, such as pollution and fishing (Reynolds et al., 2022).

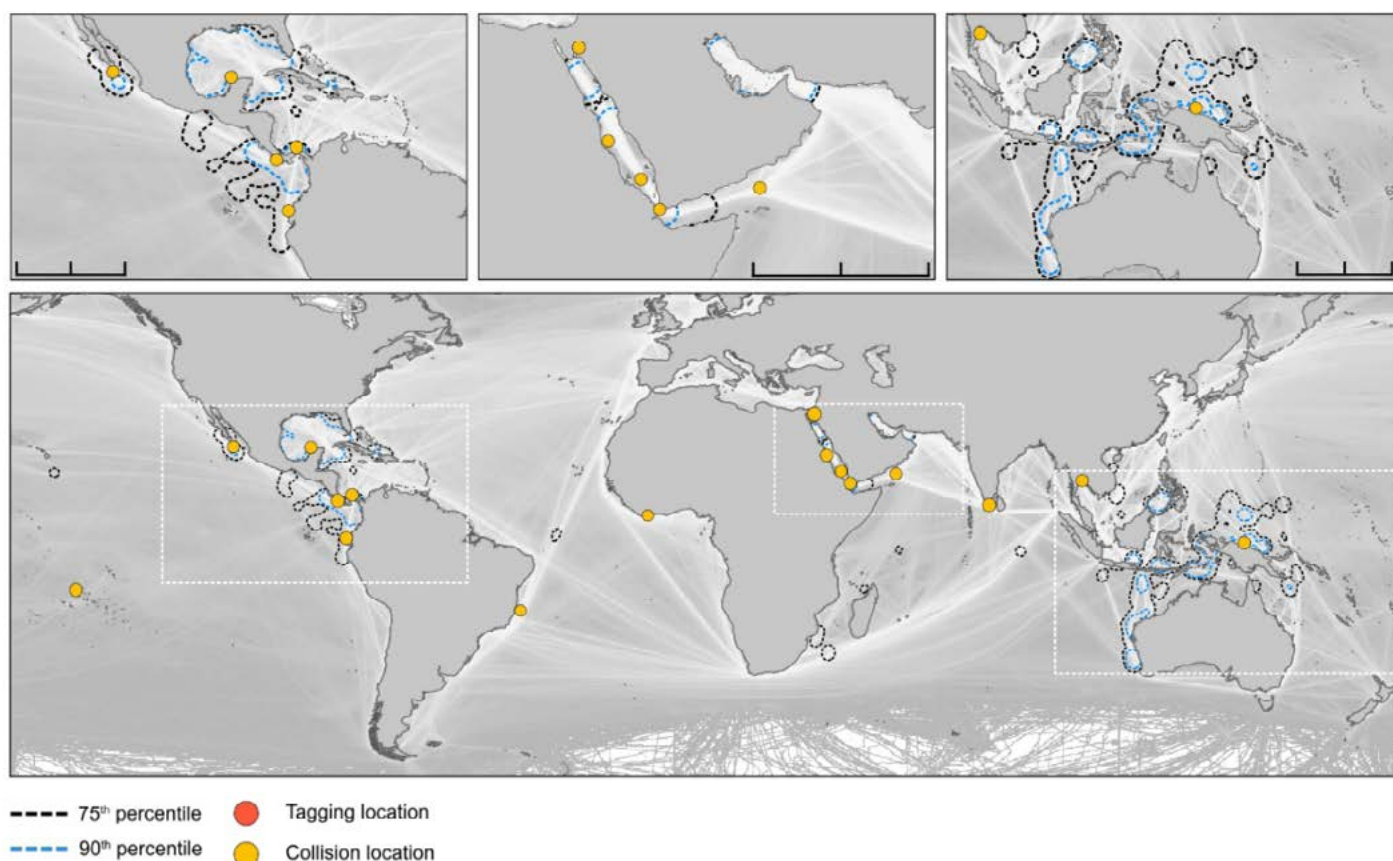


Figure 43: Location of risk hotspots for whale sharks from shipping. Orange circles denote the locations where fatal collisions occurred or where bodies of fatally injured whale sharks were first noticed on the bow of vessels. Collision risk hotspots are highlighted as the 75th (black dotted line) and 90th (blue dotted line) of the mean monthly relative collision risk index within $0.25 \times 0.25^\circ$ grid cells. Scale bars denote 1,000 km. Credit: Womersley et al., 2022 (supplementary information).

MANAGEMENT

Knowledge of the considerable threat to whale sharks from vessel collisions is relatively new and management measures are yet to catch up. Shipping is assumed to pose a similar threat to the basking shark (*Cetorhinus maximus*) – another large, slow-moving, filter-feeding fish – though no incident has been observed so far (Schoeman et al., 2020; Siders et al., 2013).

SEABIRDS

It is well known that light-polluted skies (from urban lighting and brightly-lit infrastructure) threaten the world's birds by disrupting key behaviours such as foraging and night-time navigation during migration. Light-induced ship strikes – when a seabird becomes disoriented at night, collides with a vessel and is unable to fly off (whether because of injury or disorientation) – is less well-known and understood. The full extent of these events and their impact on bird populations also remains largely unknown. However, the few published accounts suggest that these events are more frequent than previously thought and pose an additional threat to already-vulnerable species.

Most data on seabird ship strikes come from fishing vessels steaming to (or between) fishing grounds with fisheries observers or scientists on board. The recording of these events is not part of the standard data collection activities of fisheries observers (or of any other observers on other types of vessel), so the information collected has mainly been ad-hoc or anecdotal. The earliest accounts date back to the early 1990's when annual strikes involving thousands of seabirds were reported by the Tristan da Cunha rock-lobster fishery in the South Atlantic (Ryan, 1991). There have since been reports from fishing boats near remote sub-Antarctic islands (Black, 2005; Abraham & Richard, 2019; Coleman et al., 2022) and in Greenland (Merkel & Lambert Johansen, 2011).

Strikes have also been recorded onboard other types of vessel, such as coastguard and cargo ships (Merkel & Lambert Johansen, 2011). Brightly lit cruise ships also appear to pose a threat to seabirds and landbirds alike. Various accounts of mass bird strikes on cruise ships in the Caribbean have been reported. One account from 2004 describes a mass strike of north-American songbirds on a Caribbean cruise ship (Bocetti, 2011). A 2020 video shared on Twitter (*still images in Figure 44*) showed a major mass strike event (presumably somewhere in the Caribbean) with many hundreds of small birds strewn lifeless across a cruise ship's decks (Farnsworth 2020). In New Zealand a cruise ship coming into Auckland in 2019 saw 70 seabirds end up on its deck, nearly half of which subsequently died due to poor handling (Cropp, 2019).



Figure 44: Bird strike observed in April 2020 and assumed to have happened somewhere in the Caribbean. The event involved hundreds (or more) birds belonging to a variety of North American migratory species. Credit: Farnsworth, 2020.

IMPACTS

The consequences for individual birds are grim. Many are killed on impact. Others succumb to exhaustion having been unable to escape the strong wind draft of a fast moving vessel like a cruise ship. Some become waterlogged (or drown) in water-filled cavities on deck, or have their feathers contaminated by oil, resulting in hypothermia. Birds that survive and remain trapped on a fast-moving vessel can be severely displaced (Black, 2005; Bocetti, 2011). Not all victims necessarily land on deck; some land, or are lost, unnoticed in the sea (Merkel & Lambert Johansen, 2011). Timely and appropriate care of disoriented or injured seabirds – such as placing them in boxes to dry and get warm – increases their chances of survival (Coleman et al., 2022).

The number of birds involved in a single incident varies greatly, from an individual to several hundred (Black, 2005). Following the 2004 mass strike on a Caribbean cruise ship it was estimated that more than 700,000 migrating songbirds could die each year as a result of light-induced collisions with cruise ships in the Caribbean (Bocetti, 2011). For vessels operating in the Southern Ocean bird strikes are an almost nightly occurrence, though generally not fatal (Black, 2005). The proportion of birds that survive a collision also varies greatly, with reported mortality rates ranging from 5% (Glass & Ryan, 2013) to 25% (Black, 2005; Coleman et al., 2022). Survival rates for birds once rescued and released are poorly understood.

The effects of individual ship strikes on bird populations are not well understood but they clearly pose a serious risk to any group which is either naturally small or already endangered (Fischer et al., 2021).

WHY ARE SEABIRDS VULNERABLE TO SHIP STRIKES?

Particular families of seabirds seem to be most prone to colliding with ships, with vulnerability also changing with lifecycle stage and seasonal conditions. A ship's proximity to bird colonies, low visibility such as during dark nights (new moon or overcast skies) or particular meteorological conditions all increase the risk. Fog, drizzle or heavy rain all refract light, increasing the pool of light around a ship and potentially creating a greater attraction to seabirds (Montevecchi, 2006; Wiese et al., 2001).

Petrels, shearwaters, albatrosses and prions are the seabirds most often involved in ship strikes (Abraham & Richard, 2019; Black, 2005; Ryan, 1991). They are also some of the most threatened (Dias et al., 2019). Petrels and shearwaters seem disproportionately affected by ship strikes, especially during nocturnal migration and foraging outings, because their eyes are adapted to low light levels (Commonwealth of Australia, 2020) to help them search for bioluminescent prey (Imber, 1975).

Morphological and physiological traits might also be contributing factors. Fast-flying species with high wing loadings¹⁹ could be more likely to collide with vessels and sustain serious injury because they are less manoeuvrable and the force of the collision is greater (Glass & Ryan, 2013; Ryan, 1991). Both the intensity and colour of the light source also matter because the eyes of different species are sensitive to different wavelengths. There are no conclusive studies on what light types and colours play the biggest role in seabird strikes, but nocturnal seabirds adapted to seeing in low light are particularly sensitive to short wavelengths like white and blue (Lukies et al., 2021; Rodriguez & Chiaradia, 2017). Data for some species indicate lots of young being attracted to artificial light sources, suggesting they might be mistaking them for navigational cues like the moon and stars (Rodríguez & Rodríguez, 2009).

¹⁹ Relationship between wing area and body weight

The effects of individual ship strikes on bird populations are not well understood but they clearly pose a serious risk to any group which is either naturally small or already endangered (Fischer et al., 2021).



Figure 45: Night-time light display. Top: cruise ship. Credit: www.pxhere.com., Below: fishing vessel in Antarctica. Credit: Andrew McConnell/Greenpeace

COLLISION HOTSPOTS

The events in Greenland and the Caribbean show strikes can occur anywhere birds are active in the immediate vicinity of a brightly-lit vessel, but the Southern Ocean is generally understood to be a hotspot.

The extent to which seabirds are subjected to artificial light sources, even when out at sea and far away from their colonies, was demonstrated by a study tracking several New Zealand native species which had been kitted out with light sensors during their migrations (Petterson, 2022; *Figure 46*). The data revealed exposure to light out in the open ocean and close to major shipping lanes, and included instances in which the individual animal’s flight path was affected.

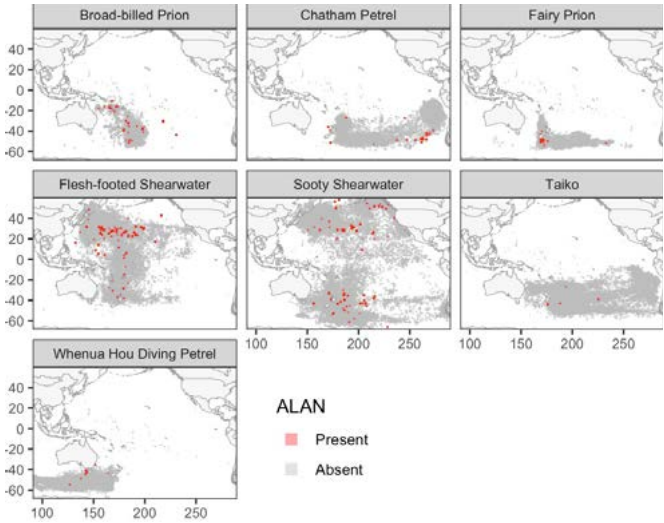


Figure 46: Estimated locations and prevalence of artificial light at night (ALAN) of 179 individuals of 7 native New Zealand species tracked between 2009-2018. Red points mark where tracked animals were exposed to light sources. Credit: Petterson, 2022.

MANAGEMENT

When it comes to understanding why some bird species are particularly vulnerable to ship strikes, many scientific questions remain unanswered. Nonetheless, experts have proposed a range of practical mitigation measures: ships avoiding known seabird colonies at night when visibility is poor, in particular during breeding; keeping light intensity low and shielding lights from above; switching off unnecessary lights and covering port holes; and finally, having effective rescue procedures to help the birds which are struck (Coleman et al., 2022; Commonwealth of Australia, 2020; Merkel & Lambert Johansen, 2011; Montevecchi, 2006). In polar regions the use of ice-lights is of particular concern. But these are a key navigational aid for which it is difficult to find alternatives (Merkel & Lambert Johansen, 2011).

The problem of bird strikes has been recognised by several management authorities in the Southern Ocean. Various strategies are being used to mitigate seabird ship-strike risks, including those posed by cruise ships (Commonwealth of Australia, 2020; New Zealand Department of Conservation, 2017, 2019; IAATO, 2010; Ryan & Glass, 2001).

OUTLOOK

Ship strikes are increasingly recognised as a threat to marine life all over the world (IWC, 2022; Schoeman et al., 2020). The most frequently-recorded species groups – the various large whales, seabirds and whale sharks – are among the most endangered species on the planet. Current scientific data indicate that globally ship strikes are a leading cause of human-induced mortality for several whale populations. Experts agree that for some endangered populations, such as the North Atlantic right whale *a*, deaths by ship strikes could be the difference between survival and extinction (IWC, 2022). Reducing the overlap of high-density shipping and areas heavily used by whales, in addition to speed restrictions, remain the most promising mitigation strategies (IWC, 2022). Incidentally, slower vessel speeds would also have immediate, tangible co-benefits, such as reductions in the GHG emissions and underwater noise pollution caused by shipping (Leaper, 2019).

Meanwhile, though our understanding of the risks to many non-cetacean species, such as whale sharks and seabirds, is just starting to emerge, it is already enough to cause concern – all the more so when the continued expansion of international shipping is considered.

Only concerted and integrated action can mitigate these risks.

12

TRANSFER OF INVASIVE AQUATIC SPECIES



Invasive aquatic species (IAS) are variously known as non-native, non-indigenous, marine pests and harmful aquatic species (among others), but are formally defined as: ‘aquatic organisms or pathogens which, if introduced into the sea including estuaries, or into freshwater courses, may create hazards to the environment, human health, property or resources, impair biological diversity or interfere with other legitimate uses of such areas’ (BWM Convention).

The global shipping network has proved to be a highly-efficient mechanism for spreading species across planetary distances, including between otherwise separate biogeographic zones. About 30% of newly-detected invasive species are now attributed to shipping – making it the most effective dissemination mechanism of all (Stranga & Katsanevakis, 2021).

As globalisation and expanding trade drive up invasion rates worldwide (Thomaz et al., 2015), the consequences for native ecosystems and local economies are often surprising, unwelcome and disproportionate. Invasive species now rank alongside climate change and pollution as a main driver of global biodiversity loss (WWF, 2022).

SHIPPING’S CONTRIBUTION TO TRANSFER OF IAS: BALLAST WATER AND BIOFOULING

There are two main mechanisms by which IAS are transported by ship: in ballast water within a ship’s hull, or attached to the vessel’s outer surfaces (also known as biofouling) (Costello et al., 2022).

While the hitchhiking of species on ships is a phenomenon as old as maritime trade (Carlton, 1999; Bax et al., 2003), it was not until the 19th century (when water started to be used as ballast and maritime trade took off) that the number of invasive events around the world began to increase substantially (*Figure 47*).

Water-as-ballast is now widely used by commercial vessels. Like ballast of any kind, it provides stability and manoeuvrability during a voyage and is an essential part of a ship’s operational safety. As a ship takes on ballast water a myriad of local species come along too. When the ship then ‘deballasts’ at its destination these stowaway species are released into a new environment. Each year about 3,500 million tonnes of ballast water are transferred in this way by merchant ships, and with it a wide range of marine species, from bacteria and plankton, to fish at various stages of their lifecycle (Bailey, 2015).

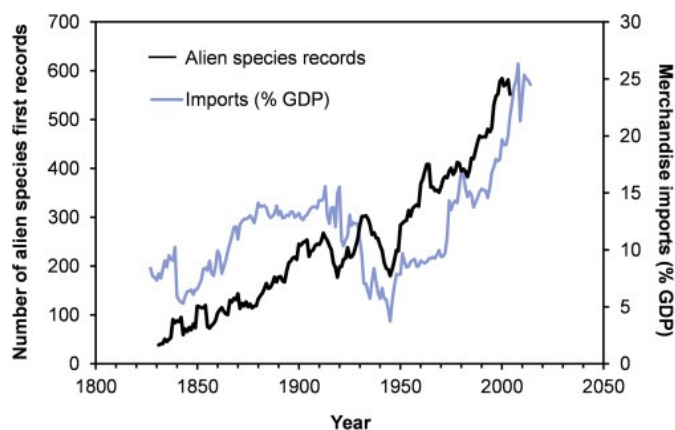


Figure 47: Annual number of new occurrences of alien species (ie. terrestrial and aquatic) recorded worldwide and growth of international trade since early 19th century. Credit: Hulme, 2021.

Biofouling species can be equally diverse but all share an ability to attach themselves to a ship’s surfaces. The biofouling process is extremely fast, kicking-in the very instant a ship is first immersed in seawater. Generally, it starts with the development of a microbial film (biofilm) which then provides the substrate for larger organisms, including algae, barnacles, mussels, sponges and associated mobile species such as crabs, shrimps and worms (Kanematsu & Barry, 2020). The severity of fouling depends not only on how long a ship remains in port and its cruising speed at sea, but also the environmental and seawater conditions (salinity, temperature, and so on) through which it passes.

IMPACTS OF IAS

Ships are not created equal when it comes to spreading IAS. Bulk cargo vessels (about 23% of the global fleet) pose the greatest risk of ballast-water introductions (*Figure 48, top*) because of their sheer size and ballast-water capacity (David et al., 2012).

The risk profile for IAS by biofouling, on the other hand, is thought to be markedly different; there is a more even distribution across ship types (*Figure 48, bottom*) and the amount of time spent in the source port is a key risk factor (Saebi et al., 2020).

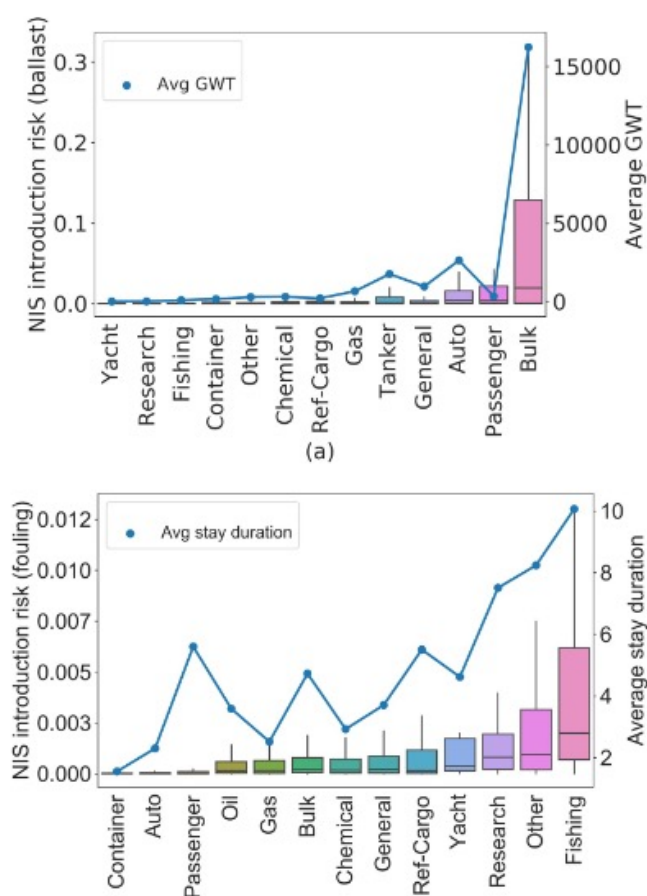


Figure 48: IAS introduction risk by different ship types for ballast water (top) and biofouling (bottom). Credit: Saebi et al., 2020.

Once introduced to a foreign port the ability of the non-indigenous species to colonise and spread depends on a range of factors, including: reproductive, survival, and dispersal rates; reproduction and growth cycles; and typical lifespan. Some species are able to adapt their lifecycle to their new surroundings (Bax et al., 2003); the most successful tend to be 'lifestyle generalists', able to tolerate a wide range of temperatures and salinities, as well as exposure to air and pollutants. Unfortunately, and precisely because of their adaptability, many of these species are predicted to thrive under climate change (Rahel & Olden, 2008).

Perhaps more surprisingly, the pressing problem of man-made underwater noise pollution (*Chapter 10*) has also been found to facilitate the settlement of some IAS species by significantly shortening the time their larvae need to attach themselves to a substrate. In general, the stronger the underwater noise (so, generally speaking, the larger the vessel) the faster the effect on larval settlement (McDonald et al., 2014; Stanley et al., 2016).



Figure 49: Water pipe choked with zebra mussels. Credit: www.seagrant.sunysb.edu

Once successfully settled, IAS have been found to pose grave threats to the ecological integrity of coastal environments as well as to the economic wellbeing of local communities and industries. Prominent examples of the most economically destructive IAS invasions include the zebra mussel (*Dreissena polymorpha*), a fingernail-sized freshwater mollusc native to Eurasia. It is thought to have been transported to North America some time in the 20th century but was first detected (in the Great Lakes) in the 1980s. By 1990 zebra mussels were found in their hundreds of thousands per square meter on virtually every submerged hard surface in the shallow waters of Lakes Huron and Erie. In addition to the damage done to native ecosystems, the removal of zebra mussels from coastal infrastructure (docks, locks and ship hulls), along with the unclogging of water intakes and filtration and monitoring systems, costs an estimated \$650 million a year (reviewed in Lovell et al., 2006).

Ballast water often contains micro-organisms and pathogens as well (Lv et al., 2018; Lympieropoulou & Dobbs, 2017). In the early 1990s a cholera epidemic (*Vibrio cholerae*), which killed 10,000 people in Peru (de Poorter et al., 2009) before spreading through Latin America and into Mexico, was traced back to ballast water from cargo ships (McCarthy & Khambaty, 1994).

In the Caribbean an as-yet unknown pathogen is killing a variety of coral species through something known as 'stony coral tissue loss disease' (SCTLD for short) (Figure 50). First discovered in the Florida Keys in 2014 (Precht et al., 2016), the disease has spread throughout the Caribbean (Kramer et al., 2019) and could potentially become the most lethal disturbance ever recorded in that region (Alvarez-Filip et al., 2022). The spread of SCTLD to geographically and oceanographically isolated reefs, along with its greater presence near ports, suggest that ships could be the spreading mechanism. While the causal link between shipping and SCTLD has not been fully proven yet, recent work (Studivan et al., 2022) showing that SCTLD pathogens can survive in UV-treated ballast water also suggests a role for shipping in spreading the disease.

The build-up of biofouling species is also a significant operational problem for the shipping industry itself because hull structures and propulsion systems can be damaged. Furthermore, the increased drag can reduce speed by up to 10%, requiring more fuel to compensate, which in turn means an increase in GHG emissions by up to 55% (IMO, 2022).

It is precisely because fuel is such an important component of shipping costs that modern antifouling paints have been applied to hulls since the 1960s. However, these coatings contain a variety of toxic chemicals which are themselves a source of serious environmental harm (see Chapter 7).



Figure 50: Stony coral tissue loss disease, identified by the patches of exposed white skeleton indicating quickly progressing lesions. Credit: Marilyn Brandt, August 2019 (in Mailing et al., 2020).

GLOBAL IAS HOTSPOTS

Today IAS are very nearly ubiquitous (Figure 51) but Europe and North America are known hotspots. This reflects the large volumes of trade involving those areas (Stranga & Katsanevakis, 2021), but also the greater surveillance and detection work done by these more affluent countries (Seebens et al., 2013). In countries with less well-funded surveillance systems, real invasion rates could be markedly higher than detected (Bailey et al., 2020; Cuthbert et al., 2021).

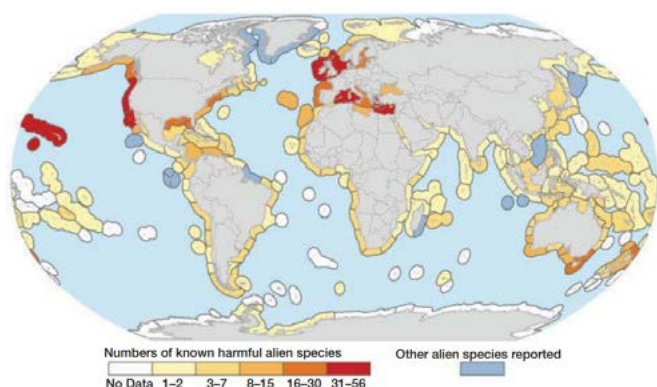


Figure 51: Number of recorded IAS by coastal ecoregion, with darker shades indicating a greater number of species with high ecological impact. Ecoregions in which only less harmful species have been observed are shown in dark blue. Credit: Molnar et al., 2008. Please note: this map depicts IAS attributed as originating in shipping and other dispersal mechanisms.

Because of these gaps in the surveillance data, network information on global shipping traffic patterns is often used to predict IAS risks for some ports and regions, and to identify which ports and routes might be central to the spread of IAS (Kaluza et al., 2010; Seebens et al., 2013). Generally speaking, the rate of biological invasion is considered to be highly dependent on shipping intensity, but other key factors include the distance between connected regions and their environmental similarity (Seebens et al., 2013). Network analyses suggest that invasion hotspots are concentrated in a relatively small number of ports in Southeast Asia, the Middle East and the US, with the highest invasion risks associated with Singapore, the Suez Canal, Hong Kong and the Panama Canal (Figure 52).

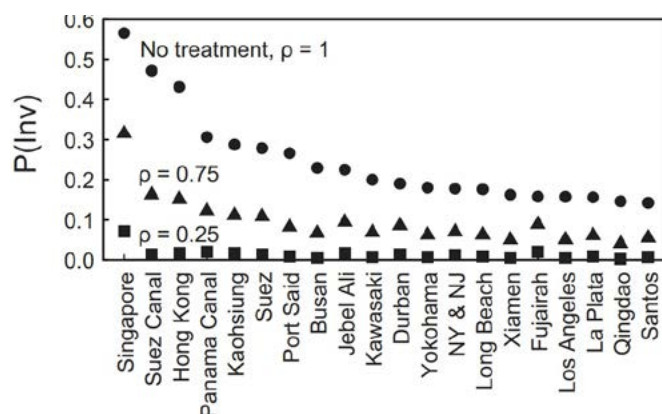


Figure 52: Estimated invasion probability $P(Inv)$ of the top 20 highest risk ports for three different levels of ballast water treatment p . Credit: Seebens et al., 2013.

At larger geographic scales, the most endangered ecoregions include the central Indo-Pacific, North-west Pacific, the Mediterranean and the North-west Atlantic – all because they combine a central role in world trade and short distances (environmentally-speaking) to adjacent ecoregions. By contrast the Western Indo-Pacific and North-east Atlantic also experience high invasion risks but from only a few source regions. The lowest risk areas are associated with low shipping intensities and remote locations, such as the tropical Eastern Pacific.

AN EMERGING RISK FOR POLAR REGIONS

As icecaps recede and polar waters become more accessible (including for tourism), special consideration needs to be given to the growing threat to fragile polar ecosystems from ship-mediated IAS (CAFF & PAME, 2017). This section focuses on the risk to Antarctica from IAS. More information on Arctic waters can be found in Chapter 15.

Antarctica is still widely thought of as one of the last pristine wildernesses, relatively unscathed by the relentless pressure of human expansion. The survival chances of 'natural' IAS arrivals (perhaps travelling on flotsam) are considerably reduced by the isolation and the icy and harsh waters of the Southern Ocean.

MANAGEMENT OF IAS

Invasive species travelling by ship, either in its ballast tanks or attached to its hull, can however make the journey in a matter of days. A recent study (McCarthy et al., 2022) of Antarctic-bound ships (*Figure 53*) shows the region connected to a network of more than 1,500 (and rising) ports worldwide, each a potential source of IAS. The South Shetland Islands and the Antarctic Peninsula are high-risk IAS hotspots because of the frequent landing of tourists and the various vessels that service the numerous research stations.

Most ships bound for Antarctica have also visited Northern Europe (including the Arctic regions), southern South America and the Northwest Pacific. Whether species originating in those areas could make it all the way to Antarctica would depend on several factors, including their ability to survive several ballast water cleanings and antifouling precautions. Unfortunately, biofouling surveys of Antarctic-bound vessels have already found temperate species from outside the Antarctic region (Hughes & Ashton, 2017; Lee et al., 2007, Lewis et al., 2005). Rising temperatures brought about by climate change will increase the likelihood that new introductions will settle and spread (Duffy et al., 2017).

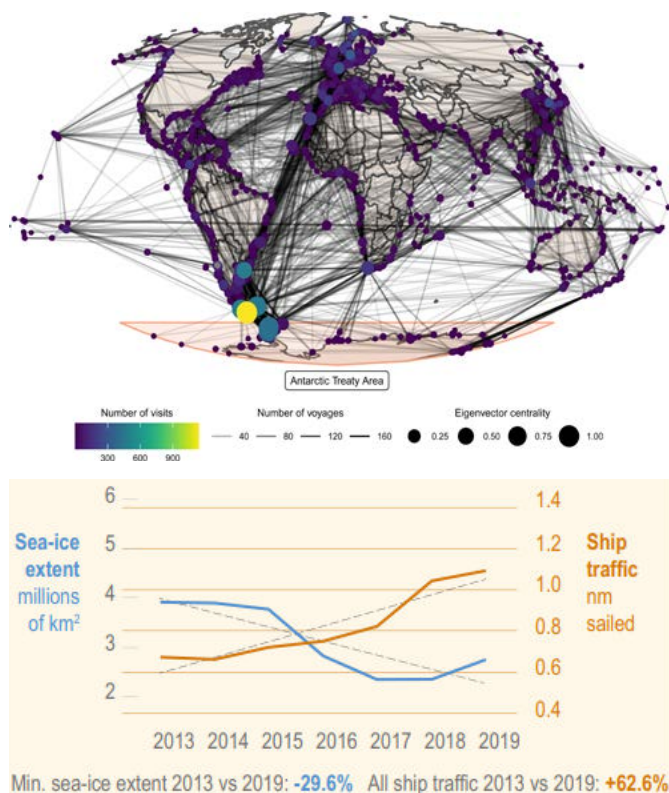


Figure 53: Top: Global port-to-port traffic network of all ships that visited Antarctica from 2014 to 2018. Credit: McCarthy et al., 2022. Bottom: Antarctica sea ice extent and ship traffic from 2012 to 2019. Credit: Constable et al., 2022.

Preventing the introduction of invasive species in the first place is by far the most practical and cost-effective solution, thus avoiding the heavy technical and logistical burden of detection and removal (Hulme, 2009). Control efforts and the associated costs can be shown to rise exponentially as an invasion progresses (Taylor & Hastings, 2004). In fact, once an IAS has established itself the damage it does to the environment is often irreversible. Nonetheless, the funding generally devoted to response management (after an invasion has begun) is 25 times greater than for preventative measures (Cuthbert et al., 2022).

Most prevention strategies target transport pathways. In 2017 the Ballast Water Management Convention (BWM Convention) came into force. By April 2023 its 95 signatories represented more than 92% of world merchant shipping tonnage. The BWM Convention requires vessels either to exchange at least 95% of their ballast water beyond the 200 nm limit and in waters deeper than 200m, or to perform onboard ballast water treatment (such as filtration, chemical disinfection, exposure to ultra-violet) in compliance with the parameters set out in the Ballast Water Performance Standard. By September 2024 all ships must have a ballast water treatment facility which meets the standard and have been developed and approved to IMO guidelines. Since June 2022 new ballast water management systems are also subjected to mandatory testing when installed to ensure they perform as required (IMO MEPC.325(75)).

The BWM Convention's rules include a range of exemptions including for safety reasons, search and rescue ships, and pleasure crafts under 50m with a maximum ballast water capacity of 8m³. Compliance is monitored by local port officials (Port State Control) and can happen in any port or offshore terminal of any country party to the convention. Monitoring may include verification of a valid certificate-approved ballast water management plan, inspection of the ballast water record book, and/or sampling of the ship's ballast. There is no official information published on BWM Convention compliance.

The uptake of onboard ballast water management systems is increasing (as intended) but the lack of any way to ensure that those systems remain efficient over time has been noted (Drillet et al., 2023; IMO MEPC 78/4/10)

Since 2011 IMO Resolution MEPC.207(62) has provided general guidelines on how to minimise biofouling risks for all types of ship. However, unlike ballast water, hull biofouling remains largely unregulated even though in European waters (for example) it accounts for roughly half of all new invasions (EMSA & EEA, 2021).

OUTLOOK

Invasive species are a leading global threat to biodiversity and pose a severe risk to current and future food security and livelihoods, particularly in countries without the capabilities to prevent and manage these invasions. The ecological and economic costs of invasive species are escalating rapidly (Cuthbert et al., 2021) and are now believed (across all realms) to be in the trillions of dollars (Cuthbert et al., 2022). International trade is a direct driver of biological invasions worldwide (Hulme, 2021).

At last this issue is high on the international biodiversity policy agenda (Essl et al., 2020; McGeoch et al., 2021; UNEP, 2021). The new Global Biodiversity Framework, adopted in December 2022 under the Convention on Biological Diversity, includes a target to 'eliminate, minimize, reduce or mitigate the impacts of invasive alien species on biodiversity' by preventing their introduction and establishment, and reducing introduction rates by at least 50% by 2030 (CBD/COP/15/L.25).

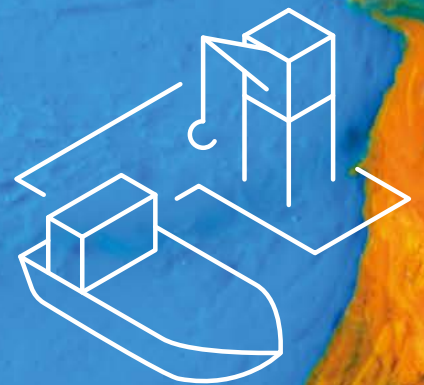
There is a general acknowledgement of the threats posed by IAS, but experts concede that the peak of the problem might not have been reached yet; international maritime trade continues to expand and there is mounting evidence that both the rate of IAS arrivals and the number of newly-affected areas are continuing to increase at an alarming rate (Bailey et al., 2020; Seebens et al., 2017). A recent study predicts that expansion of the global shipping network could far outstrip climate change as a driver of IAS, bringing a 3- to 20-fold increase in global invasion risk, with surges in middle-income countries and particularly in Northeast Asia (Sardain et al., 2019).

Despite the efforts made so far to reduce introductions via ballast water, new IAS continue to be discovered, demonstrating the epidemic-like spread of the problem and the extreme difficulty of containment. It remains to be seen whether the BWM Convention can succeed in reducing IAS introductions and bringing down the consequential ecological, economic and social costs. Full compliance with its protocols, along with perfectly-efficient ballast water treatment systems, are unachievable and unrealistic. As things stand, international measures to stem the tide of ship-mediated IAS might not be sufficient to keep up with expanding trade.



13

PORTS AND COASTAL DEGRADATION



Many of the environmental and human health impacts associated with shipping operations at sea described in previous chapters tend to accumulate in and around ports: higher levels of harmful atmospheric emissions and associated human health problems in nearby communities; higher levels of contaminants stemming from ship operation and maintenance activities (including toxic compounds from the biofouling paints used in shipyards); and increased underwater noise. Ports also play a central role in the distribution and establishment of aquatic invasive species. The sections below are an account of port-specific environmental and human health issues not covered elsewhere in this report.

PORT DEVELOPMENT

Port development has been very intense over the last two decades (EMSA & EEA, 2021) and demand remains for even more capacity to support further rapid growth in international trade and shifting global trade patterns.

The creation and continuing expansion of port facilities entail a wide range of environmental pressures on coastal environments and communities (extensively reviewed in Braathen, 2011). The need for sheltered waters often means irreversible degradation of natural harbours, estuaries and coastal wetlands; areas generally of high ecological value and relevance to national and international efforts to protect biodiversity. Land conversion and reclamation, breakwater creation, pile driving and extensive earthworks – all inherent in the siting and construction of port infrastructure – cause extensive damage, including: reduced water quality; changes to coastal morphology and hydrology; as well as the degradation of critical marine habitats (such as seagrass and mangroves, which act as fish nurseries) (ESCAP, 1992).

Socio-cultural impacts include: the degradation of the visual quality of coastal environments and with it the restorative effects of a once-untouched (or at least little-developed) coastline and seascape; the uprooting of local communities; and the generation of ethnic, cultural or tribal conflict with the associated loss of identity and place-based traditions (ESCAP, 1992).

DREDGING

Dredging is essential to the effective development and operation of ports and navigable waterways. Vessels (especially larger ones) require a certain depth of water to operate without running aground. In time sediments naturally reaccumulate in berths and channels; to maintain marine traffic, this must be excavated from the seafloor and disposed of elsewhere, generally offshore.

Sediments dredged from ports represent the largest volume of material dumped at sea (EMSA & EEA, 2021). The potential impacts of dredging and dumping include: the smothering of benthic species; clogging of the gills of fish and invertebrates; reduced light available to algae; nutrients and toxic trace metals released from contaminated sediments; the bioaccumulation of toxic contaminants in organisms and the food chain; depletion of the dissolved oxygen in the water column; and reduced water quality (Erftemeijer et al., 2012; ESCAP, 1992).

ANCHOR DAMAGE

Ships often lie at anchor while waiting to access port facilities. Anchors on large vessels can weigh more than 25 tons. A single anchor-chain link might weigh as much as 200kg (Davis et al., 2016). Depending on seafloor type, depth of water and sea conditions, this complete system of anchor and chain could be more than 100m long. As tides and sea conditions cause the vessel to swing around in a circular motion, the anchor and chain scour the seabed (Figure 54).

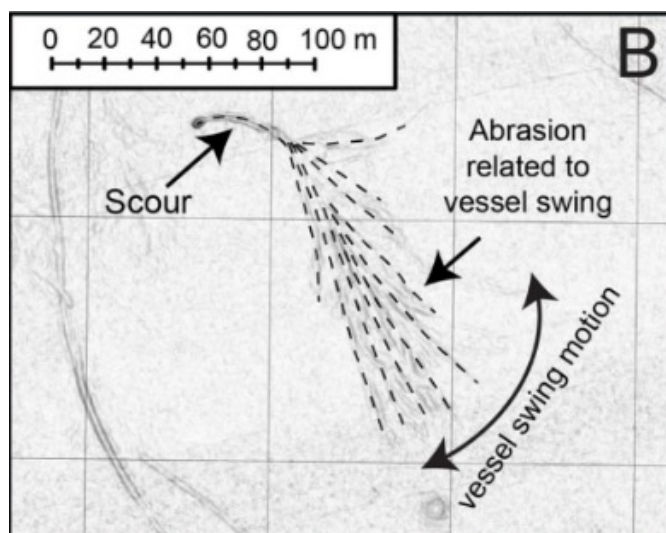


Figure 54: Evidence of abrasion related to vessel swing around a large anchor observed in multibeam bathymetry data image. Credit: Watson et al., 2022.

The localised impact on benthic habitats can be extensive, with the seafloor disturbed, radically altered or even eroded entirely to depths of up to 80cm (Watson et al., 2022). Subsequent vessels using the same location hinder the restoration process so that long-term recovery is substantially limited. Anchoring tends to occur within a narrow band of mostly shallow waters (80m or less) which often contain important and delicate ecosystems, such as seagrass meadows, biogenic habitats and coral reefs (Abdulla, 2008; Deter et al., 2017). Smith (1988), for example, described how in the Cayman Islands a cruise ship's anchor and chain destroyed 2,150m² of coral reef in a single event. A recent study by Deter et al., (2017)

estimated that the cumulative anchoring of high-tonnage and recreational ships along the French Mediterranean coast has damaged about 30% of the habitats in waters shallower than 80m. Then there are the secondary effects on water quality and turbidity, caused by sediment plumes and the churning-up of heavy metals and other contaminants.

The risks to coastal ecosystems are rising as more ships join the global fleet and increased port congestion along busy routes and at known bottlenecks (such as the Suez Canal) forces more and more vessels to anchor further out (Figure 55).



Figure 55: Large ships in anchorage off Singapore, waiting for their turn to unload cargo and refuel. Credit: The Nippon Foundation.

The damaging effects on marine environments are now well-documented and increasingly recognised. The worldwide threat to the health of benthic species and habitats clearly needs to be better managed (Abdulla, 2008; Argüello et al., 2022; Davis et al., 2016; EMSA & EEA, 2021; Watson et al., 2022). One recent study estimated the combined, global sea-floor 'footprint' of all anchoring high-tonnage vessels to be between 6,000 and 20,565 km² (Watson et al., 2022). Management strategies proposed so far include: the creation of designated anchorage sites; speed reductions approaching port (to avoid having to anchor at all); and restrictions on the time a vessel is allowed to sit at anchor close to port prior to loading (Steele et al., 2017).

WAKE INDUCED HABITAT DISTURBANCE

In shallow waters a ship's churning wake can cause turbulent mixing and re-suspension of sediments from depths of up to 30m (Nylund et al., 2021). As well as damaging the local physical environment, this has short- and long-term consequences for the associated marine species and ecosystems (reviewed in Gabel et al., 2017). For example, the re-suspended sediment increases seawater turbidity, which harms light-dependent organisms (such as phytoplankton, corals and seagrass). Without management these impacts can be particularly prevalent in coastal areas with high shipping traffic or busy shipping lanes nearby (EMSA & EEA, 2021).

OUTLOOK

A rapid increase in world trade is powering strong demand for more and bigger ports, particularly in emerging economies (Braathen, 2011; Lloyd's Register, 2013). As larger ships join the fleet – the draughts of megaships are projected to reach 20m – they are increasingly constrained by inadequate channel depths and berth lengths (ITF, 2015). Billions are already being spent worldwide deepening port channels to accommodate both increased trade and these megaships (Towey, 2022). The development of new and existing ports will put further pressure on coastal environments and communities as more land and waters are converted into port infrastructure. Port developments are already well-recognised as sources of political and social conflict, with land-grabs and threats to human rights predominantly affecting poor communities and Indigenous Peoples (Bartłomiejski, 2016; Gilbert, 2017; Lombard et al., 2021; Pearson et al., 2016). Numerous large developments – including a staggering number of completely new port developments – are either planned or already under construction in South America, Africa, Asia and the Arctic (Gadkari, 2016; Eboh 2022; Humpert, 2023; Mardones, 2022), most of them under China's Belt and Road Initiative (Figure 56).

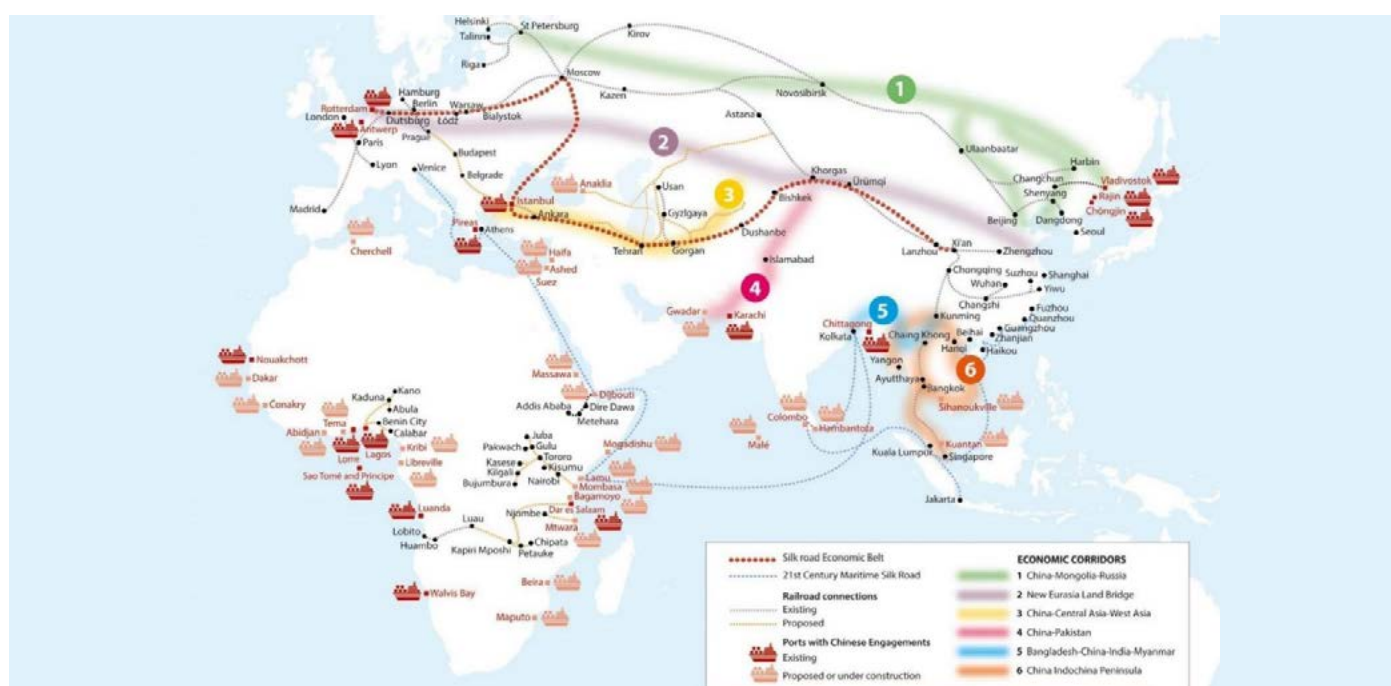


Figure 56: Proposed or under construction ports under China's Belt and Road Initiative. Credit: OECD, 2018.

14

SHIPBREAKING IN DEVELOPING COUNTRIES



Ships generally have a 30-year service life. Shipbreaking – sometimes referred to as ship dismantling, or recycling – is the breaking up of an obsolete vessel into its salvageable, reusable parts. Even though the majority of ships are owned by rich economies (the EU, US, South Korea, Japan), more than 80% of shipbreaking is done in the developing countries of South Asia (Bangladesh, India, Pakistan) and in Turkey, where wage rates are low, local markets exist for second-hand equipment and materials, and employment and environmental regulations are often lax (Barua et al., 2018; Rahman & Kim, 2020). High injury and casualty rates in many of these shipbreaking yards make this one of the most dangerous jobs in the world. International concern at the extremely poor working practices has been mounting for decades (Andersen, 2001; Misra, 2018; Ibeanu, 2009; Wan et al., 2021).

END-OF-LIFE SHIPS AS SOURCES OF TOXIC POLLUTANTS

Each year about 700 ships (mostly tankers, bulk and cargo carriers, and container ships) are sent to scrap yards worldwide (Wan et al., 2021). Among the various possible shipbreaking methods, ‘beaching’ is of particular concern; at high tide the ships are driven at full speed to strand them on mudflats or beaches, from where they can be dismantled over a period of six months or so (Hossain & Islam, 2006). Beaching is common in Bangladesh, India and Pakistan because it requires little infrastructure investment.

The ships themselves are unlikely to have been designed with end-of-life considerations in mind, such as to limit the use of hazardous materials or provide information to help them be dismantled safely (Andersen, 2001). They are delivered to the yards for dismantling ‘as is’, often without any inventory of whatever hazardous materials might be onboard. Up to 10% of a ship’s weight can be composed by toxic substances (Lin et al., 2022).

The bulk of a ship’s recyclable materials is steel coated with tons of paints containing heavy metals (like lead, mercury, zinc and arsenic). Oil, other metals and any insulation materials (including asbestos) are all reprocessed and sold even though they are all toxic to varying degrees.

Over the years numerous studies have documented the large amounts of solid waste and high levels of toxic materials that are released into the air, soil and coastal waters of South Asian shipyards, often at concentrations above safe levels (Barua et al., 2018; Demaria, 2010; Du et al., 2018; Hossain et al., 2016a, 2016b; Kakar et al., 2021; Nøst et al., 2015; Reddy et al., 2004, 2005; Tewari et al., 2001). *Table 6*, below, lists the main pollutants and their potential for harming human health and the environment.



Figure 57: Satellite image of yard in Chittagong, Bangladesh. Credit: www.cruisemapper.com

Table 6: Toxic and dangerous substances found on end-of-life ships. Based on Andersen (2001) and Du et al. (2018).

Pollutants	Source	Associated health and environmental impacts
Asbestos	Now largely banned but once widely used as thermal insulation and fire-retardant cladding.	Highly toxic. Remains in suspension for a long time, ultimately causing a variety of pulmonary diseases (including lung cancer, asbestosis and mesothelioma) and other cancers. Symptoms may not show for years after exposure. In South Asia workers often remove materials containing asbestos with their bare hands and no protective masks. In some facilities the asbestos is crushed manually before being sold to manufacturing industries.
Persistent Organic Pollutants (POPs)	Produced by burning waste, oil combustion and the use of cutting torches.	Compounds are carcinogenic. They accumulate in fatty tissues. Associated with a range of severe health problems including cancer, weakened immune systems, reduced cognitive and neurological function, damage to the immune system and birth defects.
Ozone-depleting substances such as chlorofluorocarbons (CFCs), hydrochlorofluorocarbon (HCFC), etc.	Refrigerants, fire-fighting systems, blowing agent (for making insulation foams).	When released into the atmosphere they contribute towards the destruction of the ozone layer.
Organotins	Paints	These toxic compounds accumulate in the blood, liver, kidneys and brain. Tributyltin (TBT) has been used in anti-fouling paints since the 1970s and is considered one of the most toxic compounds for aquatic ecosystems. See <i>Chapter 7</i> on antifouling paints.
Fibreglass	Insulation	A variety of volatile organic compounds. Toxicity similar to asbestos.
Heavy metals	Batteries, paints, electronics, light fittings, lamps, generators, cables, etc.	Includes lead, mercury, manganese, iron, cobalt, copper, zinc, cadmium, nickel. Highly toxic, heavy metals bioaccumulate in animals that ingest them, and remain in the environment for a very long time. Damage to neurological system, hearing, vision, reproductive system, blood vessels, kidneys and heart; especially harmful to the physical and neurological development of children.
Oil, fuel and sludge	Ships' pipes and tanks.	Onboard these may result in fire and explosion. Poisonous if inhaled. Often spilled and mixed with soil and water on the beach during shipbreaking, contaminating water and poisoning fish.
Bilge water	Stagnant water which has drained to the lowest part of a ship's hull.	Often contains a range of pollutants, including oil, inorganic salt and heavy metals. During dismantling activities bilge water is often released into the environment where it can cause widespread pollution of coastal waters and communities, poisoning anyone who consumes contaminated water or fish.
Ballast water	Used for ship's stability.	May contain bacteria and viruses, as well as invasive aquatic species (IAS – see <i>Chapter 12</i>).

Table 6: Continued.

Pollutants	Source	Associated health and environmental impacts
Polyvinyl chloride (PVC) / Plastic	Commonly found in cables, floor coverings and plastic devices.	PVC products pose serious threats to human health and the environment at every stage of their existence. PVC releases dioxin and carbon monoxide into the air when burned, and introduces hazardous chemicals into groundwater when buried. PVC also causes a variety of serious diseases including cancer and kidney damage, and may interfere with reproductive and neurological systems.
CO₂ and other gases	Trapped in ship's chambers.	Suffocation.
Radioactive material	May be present in liquid level indicators, smoke detectors or emergency signs.	Even low-level radioactive waste should be handled and disposed of according to existing best practice.

SYSTEMATIC HEALTH AND SAFETY, LABOUR VIOLATIONS

The workforce in shipbreaking yards is mainly composed of young, untrained, often illiterate people from poor rural areas, who have migrated to the coast looking for employment. They often live in shared shanties with no running water, electricity or sanitation. They work, without contracts or employment rights, for 12 hours a day, six days a week. In 2009 in India's largest shipyard daily wages ranged from \$3 to \$7 (Demaria, 2010). With no job security at all, a climate of intimidation prevails which prevents workers from exercising their rights to form trade unions and improve their working and living conditions (Ibeanu, 2009).

By any standards, ship decommissioning is a dirty and dangerous way to earn a living. Much of the work is done in tight, confined, and dangerous places. The handling of toxic and hazardous material is commonplace and frequently performed with bare hands and no personal protective equipment. Adequate health and safety protocols, occupational training, emergency response systems and medical facilities are all but non-existent (Gunbeyaz et al., 2019).

It is no wonder that work-related illness, injury and even death have become commonplace (*as Table 6 shows*) (Hossain et al., 2008, 2016a; Misra 2018). If a worker is injured, disabled (temporarily or permanently) or killed they are often not even acknowledged by the yard owners, never mind compensated.

A poignant reminder of the extreme risks endured by shipyard workers came in 2016 with the major explosion onboard a tanker being dismantled at a Gadani shipyard (Pakistan); 31 workers were killed and another 58 injured (Shipbreaking Platform 2016, 2017). Since 2009 there have been at least 440 deaths recorded in South Asian shipbreaking yards²⁰.

Long-term studies of shipyard workers' health are rare but one study in Taiwan showed that they have a significantly higher risk of developing cancer, and doing so earlier, when compared to the general population (Wu et al., 2015). A study tracking Indian shipyard workers estimated that about three out of every ten people directly engaged in ship recycling is killed by cancer of the lung lining (mesothelioma) (Singh et al., 2020). The average life expectancy of workers in Chittagong, the Bangladeshi port city with one of the largest shipbreaking yards in the world, is 40 years – 20 less than the average Bangladeshi man (ILPI, 2016).

²⁰ NGO Shipbreaking Platform. 2022 Shipbreaking Records. <https://www.offthebeach.org>

Child labour is still common in many developing countries including Bangladesh; as recently as 2019 13% of the workforce in Chittagong shipbreaking yards were children (Chowdhury, 2019). Constant harassment by adult workers (for making mistakes) and physical assaults are commonplace (Chowdhury, 2019). An investigation by the International Law and Policy Institute found that shipbreaking practices in Bangladesh, India and Pakistan arguably amount to serious or systemic human rights violations (ILPI, 2016).

ENVIRONMENTAL IMPACTS

Shipbreaking yards and their surrounding areas are regularly exposed to hazardous materials released during the dismantling work, making them among the most contaminated environments in the world (Reddy et al., 2005). Environmental concerns are low on the agenda of these shipbreaking yards and non-existent or inadequate downstream waste management often means that hazardous materials are just dumped or re-sold (Shipbreaking Platform 2017b; DNV, 2019).

The substances listed in Table 6 are all environmental pollutants that can contaminate drinking water, pollute coastal waters and damage ecosystems, with grave consequences for local communities which often rely on agriculture and fishing for their subsistence (Abdullah et al., 2013; Andersen, 2001; Ibeanu, 2009; Kutub et al., 2017).

Deforestation, forced land-use changes and illegal logging are all major subsidiary problems. In Bangladesh, for example, thousands of protected mangroves have been destroyed to free-up space for more ships (Hossain et al., 2016b).



Figure 58: Health and safety environment on shipbreaking yard, Bangladesh 2017. Top: Dangerous work without personal protective equipment. Bottom: Subsistence fisher mending nets near recycling yard. Credit: Studio Fasching.



Figure 59: Shipbreaking yard in Bangladesh, 2017. Credit: Studio Fasching.

OUTLOOK

The dismantling of end-of-life ships, mostly undertaken in developing countries in Asia and characterised by grave health and safety violations and extreme environmental degradation, continues to pose a major challenge for international governance. To mitigate the environmental and health impacts of shipbreaking several international legislative instruments have been developed over the last decades, but they have achieved little.

The IMO's Hong Kong Convention for the Safe and Environmentally Sound Recycling of Ships was adopted in 2009, but it is yet to be ratified by enough countries for it to come into force. The EU Ship Recycling Regulation (applicable since the end of 2018) expects EU-flagged ships to use recycling facilities vetted for compliance with strict rules on environmental protection and workers' safety. The 1992 Basel Convention on the Control of Transboundary Movement of Hazardous Waste and their Disposal, along with the EU's 2006 Waste Shipment Regulation, both seek to control export or cross-border movement of hazardous waste. Some national regulations on labour rights and working conditions have been introduced in shipbreaking countries, but none has so far proved effective in overcoming the numerous conflicts of interests within the governments responsible for enforcement (Ahmad, 2022; Rousmaniere & Raj, 2007).

In any case, no meaningful improvement is in sight because of the ease with which existing regulations can be by-passed using flags of convenience: the shipping company sells the vessel to a scrap dealer who gives it a new name, re-registers it under a black-listed flag, and uses an anonymous offshore company to cover their tracks. The authorities then find it very difficult to trace the scrap dealer and hold them to account, never mind the original owners. Flag states participating in these questionable end-of-life practices include Panama, Liberia, Palau, Comoros, and St. Kitts and Nevis²¹.

In the EU shipowners dodging regulatory oversight change flags so frequently that the Ship Recycling Regulation is now largely meaningless (Lin et al., 2022; Wan et al., 2021). In 2019 only 3% of EU-owned ships were dismantled in EU-vetted shipyards, the rest being recycled in Bangladesh, India and Pakistan under a different flag (Lin et al., 2022). If the purpose of the regulation was to ensure that European-owned vessels are decommissioned safely, then the initiative appears to have backfired. A review of the Ship Recycling Regulation will be completed by the end of 2023. Early submissions have highlighted the loopholes and ease of circumvention (see submissions by Danish Ministry of Environment, NGO Shipbreaking Platform, or International Ship Recycling Association²²).

The shipbreaking industry represents an extreme failure of global governance allied to seemingly boundless corporate greed, with no respect for human rights or even the basic ESG commitments many major shipping companies claim to live by. Ship owners obtain large economic benefits from selling their end-of-life ships to scrap dealers in South Asia because the prices they offer are up to three times more than regulated dealers in Europe. (Rahman & Kim, 2020). Meanwhile, an industry predominantly based in wealthy countries avoids the many external costs (environmental, human) and bad press associated with shipbreaking in developing countries.

A 2018 report by the UN special rapporteur on toxics and human rights detailed how the shipping companies work the system; greenwashing with sham safe shipbreaking accreditation schemes, hiding behind opaque end-of-life ship deals, and denying any knowledge of ships sold straight to shipbreaking facilities in South Asia with extremely poor human rights track records (UNGA A/HRC/39/48/Add.2).

As the special rapporteur says, '[this episode] underlines the considerable challenges of ensuring accountability in cases of beaching and the insufficient cooperation on the part of the private sector in that regard'. When interviewed, the special rapporteur added, 'the real Achilles' heel is always the possibility to swap flags. As long as the world allows shipping companies to choose the flag they fly, and thus the rules they want to abide by, regulation is all but impossible and players big and small will continue to dodge the rules and evade their responsibilities'.

21 NGO Shipbreaking Platform. 2022 Shipbreaking Records. <https://www.offthebeach.org/>

22 Available on the European Commission website: https://ec.europa.eu/info/law/better-regulation/have-your-say/initiatives/13377-EU-Ship-Recycling-Regulation-evaluation/feedback_en?p_id=30874925

Given the large number of active ships soon to reach the end of their service life, the need for safe shipbreaking practices is growing. Global ship recycling is projected to double by 2028 and quadruple by 2033 (*Figure 60*) (SSI, 2021). The implications are manifold. Many older, asbestos-laden vessels are yet to come of age (asbestos wasn't totally banned in shipbuilding until 2011). Environmentally sound and safe shipbreaking could be an inherently sustainable way to reuse materials that are otherwise highly polluting and energy intensive; 95% of a ship (including all the steel) can be recycled (Rahman & Kim, 2020). Meanwhile, decarbonisation goals already require a fundamental rethink of shipping – including ship design and the retrofitting of new technologies to old vessels – opening up new opportunities to incorporate circular economy principles across the lifecycle of ship-building and recycling (SSI, 2021).

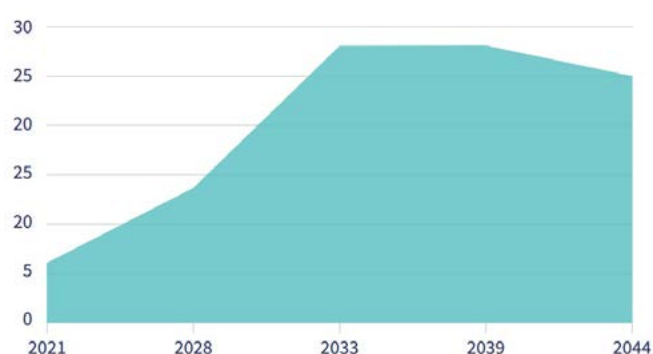


Figure 60: Projected annual ship recycling need in Idt (millions). Credit: SSI, 2021.

15

ARCTIC SHIPPING



There are few places on Earth where climate change is more visible than the Arctic. This region has warmed almost four times faster than the global average over the past 50 years, a trend that is set to continue (Rantanen et al., 2022).

Arctic sea ice is now less extensive and thinner than at any time since at least the 1850s. Climate science predicts at least one practically sea ice-free late summer before 2050 under all climate change scenarios (IPCC, 2021).

Unsurprisingly, the rapidly vanishing sea ice has stimulated interest in expanding commercial activities in the Arctic, including shipping and natural resource extraction (Bird et al., 2008; Constable et al., 2022; Tai et al., 2019).

INCREASED ARCTIC SHIPPING AND THE NEW TRADE ROUTES

With Arctic sea-ice retreating, previously unpassable shipping routes are expected to open more frequently and for longer, turning the region into a short-cut between the Pacific and Atlantic Oceans and reducing shipping costs by up to one third (Li et al., 2022). The Northwest Passage (NWP) – connecting the Far East with Northwest America, Canada and Northern Europe via the northernmost coast of North America – is about 7,000km shorter than the Suez or Panama Canal routes (Figure 62). The Northern Sea Route (NSR, also referred to as the Northeastern Passage), connecting the Atlantic and Pacific Oceans by following the northern Eurasian coast, is 40% shorter than sailing via the Suez Canal. A third route (not shown), known as the Transpolar Sea Route (TSR), offers the shortest alternative, over the Arctic High Sea and North Pole.

Estimates for how long ice conditions in the Arctic will allow these routes to operate vary but all models generally agree that even under strict emission-control scenarios Arctic routes (starting with the NSR) will become increasingly accessible, and navigable for longer, without the need for an icebreaker escort even for vessels with no, or moderate, ice strengthening (Melia et al., 2016; Stephenson et al., 2013, 2014; Wei et al., 2020). The TSR is projected to become feasible only under high-emission scenarios associated with global heating above 3°C (Crawford et al., 2021).



Figure 61: Summer 2022 Arctic annual minimum extent recorded on Sept 18, 2022, representing the 10th lowest extent in 44 years of observations. Yellow line shows 1981-2010 average minimum. Credit: NASA's Scientific Visualization Studio.

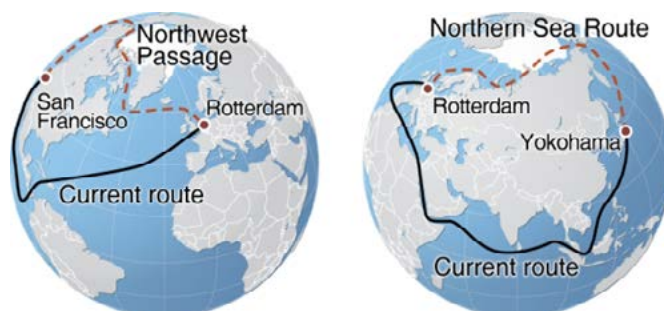


Figure 62: Northwest Passage and Northern Sea Routes and currently used routes. Credit: Hugo Ahlenius, UNEP/GRID-Arendal.

Economic activity and maritime transport are already increasing (Figure 63). Data collected between 2013 and 2019 shows a 25% increase in the number of ships and a 75% increase in total distance sailed (Arctic Council, 2020a). The majority of this activity is commercial fishing (41%), followed by icebreakers and research vessels, cargo ships and bulk carriers. Greenland and Svalbard dominate the Arctic cruise market, with one nuclear icebreaker even taking tourists to the North Pole.

Natural resource extraction in the Arctic is also driving up shipping. In 2014 one of the world's most northerly mines opened on Baffin Island (Canadian Arctic Archipelago), which involves the shipping by bulk carriers of 3.5 million tonnes of iron ore during the open water season. Traffic in and out of the mine site has led to a substantial (160%) increase in bulk carrier traffic between 2013 and 2019 in the IMO Arctic²³ area (Arctic Council, 2020a). In 2018 liquified natural gas (LNG) started being shipped to Asia from the resource-rich Yamal Peninsula (Northwest Siberia). Newly-built icebreaking LNG carriers can operate without icebreaker escorts so delivery should soon be possible year-round (Humpert, 2021).

A recent addition to the maritime transport and infrastructure of the Arctic is the development of towable floating nuclear power plants to provide energy for remote settlements and to drive new development. The first of its kind, the Akademik Lomonosov, started operating at the end of 2019 and is moored permanently in the far east of Russia's Arctic north.

Despite the publicity attracted by ships crossing the Arctic such voyages are not routine. Arctic maritime transport continues to be characterised by voyages to and from, not across, Arctic waters (Lasserre, 2018).

If (or when) trans-Arctic shipping will take off is anybody's guess. So far, the shipping industry's forays into the Arctic can be described as cautious, which can be put down to a number of economic limitations, practical navigation considerations and the wider risks of operating in a remote and hazardous environment. From a purely practical point of view most ships are not built, and crew not trained and certified²⁴, to operate in such challenging sea-ice conditions. Newly opened-up sea areas are generally poorly charted, posing additional risks to navigation (Li et al., 2022).

Meanwhile, the limited (or even non-existent) search-and-rescue infrastructure means that emergency response services can be a long time coming. And accidents do happen; 58 Arctic shipping incidents required a large rescue and escort operation in 2020, 17 (42%) more than the previous year (Allianz, 2021; Brigham, 2022). Insurance companies are reported to be pulling out of this market because of the uncertain risks being run by Arctic shipping (Saul, 2020).

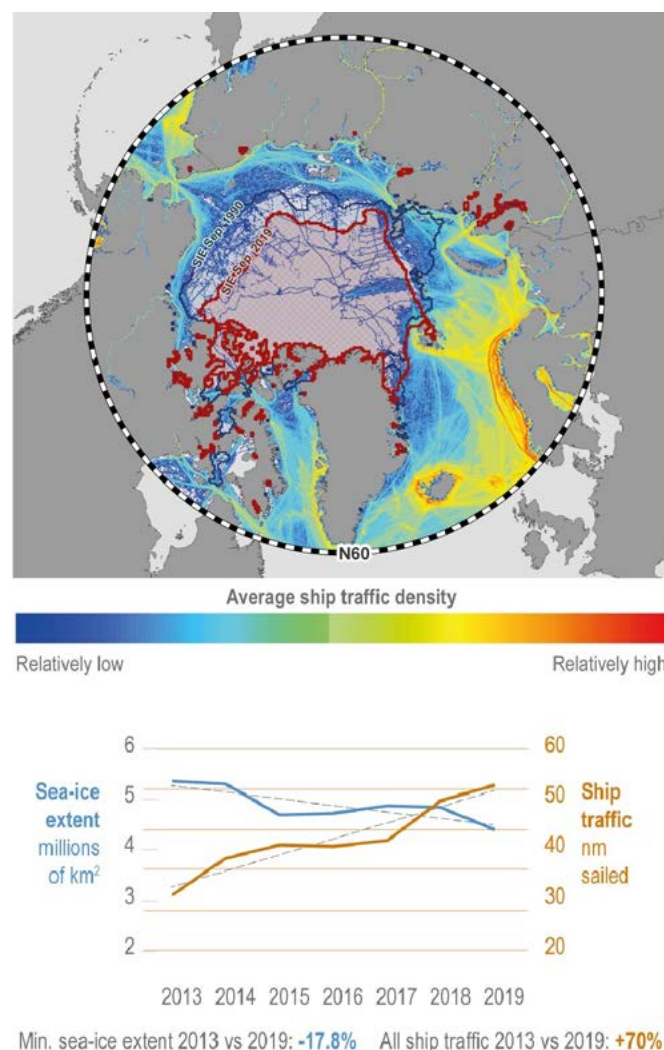


Figure 63: Top: Ship traffic from 2012 to 2019. Blue and red lines show minimum sea ice extent September 1990 and 2019 respectively. Bottom: Minimum sea-ice extent 2013 to 2019 and trend in shipping traffic. Credit: Constable et al., 2022.

²³ IMO Arctic denotes the area to which the Polar Code applies, roughly waters north of 60°N with deviations to include waters around southern Greenland, but excluding waters around Iceland, the Norwegian mainland, Russia's Kola Peninsula, the White Sea, the Sea of Okhotsk and Alaska's Prince William Sound.

²⁴ The IMO's Polar Code, a legally-binding catalogue of rules developed to ensure safe polar shipping, which came into effect in early 2017, requires ship and crew to be certified for operations in polar waters.

RISKS TO CLIMATE, THE ARCTIC ENVIRONMENT AND COMMUNITIES POSED BY INCREASED SHIP TRAFFIC

More Arctic shipping means greater risk for the fragile, already threatened Arctic ecosystems and the food security and livelihoods of the many Indigenous communities for whom the region is home (IPCC, 2019).

Accidental oil spills are widely considered the most significant threat. Once in the marine environment the effects could be severe because oil degrades and disperses slowly in freezing waters. Oil-spill responses – if feasible at all – could be further hindered by harsh weather conditions and long periods of seasonal darkness (Arctic Council, 2020b). A spill of heavy fuel oil (HFO) in particular would cause greater clean-up, socio-economic and environmental costs than other fuels (Comer, 2019).

Shipping is a significant producer of greenhouse gases (see Chapter 2). Black carbon (BC) emissions in the Arctic are of particular concern because once deposited on snow and ice BC reduces the amount of incoming radiation these reflect, effectively exacerbating the overall heating effect. BC in the high latitudes amplifies Arctic warming by up to five times when compared to lower latitudes (Sand et al., 2013). HFO – the most-used marine fuel by volume in IMO Arctic shipping – emits more BC than any other. Between 2015 and 2019 HFO use by all Arctic shipping increased by 75% (primarily driven by a very large increase by oil tankers) and combined BC emissions from all fuel types grew by 85% (Comer et al., 2020). Between 2015 and 2021 BC emissions in IMO Arctic waters doubled, with almost two thirds of total emissions coming from HFO (Osipova, 2023).

New IMO regulations ban the use and transportation of HFO in Arctic Waters from 1 July 2024, but a range of exemptions and waivers will probably result in a small (5%) reduction in BC emissions until the complete HFO ban comes into effect in mid-2029 (Comer et al., 2020). The total cost of switching all ships in the Arctic fleet to compliant fuels (like distillate) is estimated at between \$9 million and \$11 million (Roy & Comer, 2017).

In the Arctic underwater noise pollution from ships is now doubling in less than three years, faster than anywhere else in the world (Jalkanen et al., 2022). The impact here might also be more severe because of lower ambient sound levels and the greater sensitivity of Arctic species not used to competing with human-made industrial noise (IMO SDC 9/5/3). A review of the consequences for Arctic marine mammals describes a range of behavioural disturbances, including ‘freeze’ responses, avoidance and reduced vocalisations (Halliday et al., 2020). A study of Arctic cod (*Boreogadus saida*) – a key regional species – found that vessel noise led to displacement (among other behavioural changes) (Ivanova et al., 2020).

The risk from direct contact with humans include instances where seabird hotspots overlap with areas of increased shipping. All of the entry points into the Arctic have been identified as high-risk areas: Chukchi Sea (between Russia and Alaska), Davis Strait/Baffin Bay area (between Canada and Greenland), Greenland Sea, Norwegian Sea and Barents Sea (off Norway and Russia) (Humphries & Huettmann, 2014). Light pollution has led to bird strikes in Southwest Greenland (Merkel & Lambert Johansen, 2011). Arctic ice-breeding seals are also at risk of being struck by vessels at night while stunned by their bright lights (Wilson et al., 2017).

Amongst marine mammals, large whales such as beluga (*Delphinapterus leucas*), narwhal (*Monodon monoceros*) and bowhead (*Balaena mysticetus*), as well as walrus (*Odobenus rosmarus*), are all considered particularly vulnerable to a range of threats from increased Arctic shipping (including underwater noise, disturbance and ship strikes). Bottlenecks for both shipping and migrating whales – such as the Bering Strait – are areas of high conflict (Hauser et al., 2018) (Figure 64).

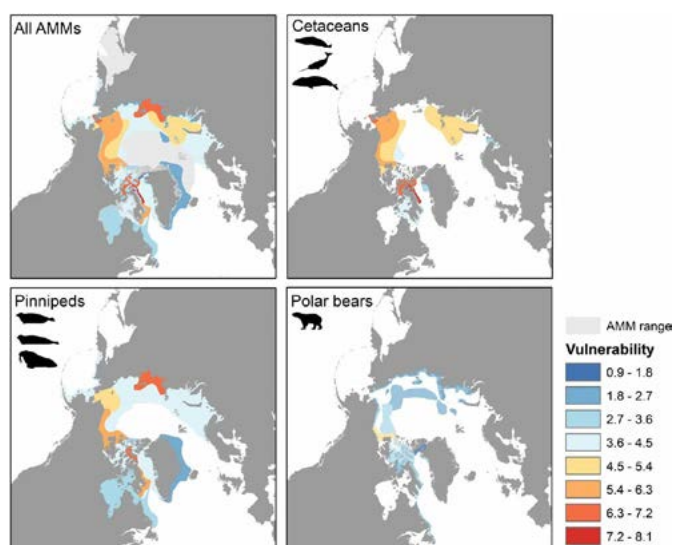


Figure 64: Maximum vulnerability scores for all Arctic marine mammals (AAM) and per taxonomic group exposed to Arctic Sea routes. Credit: Hauser et al., 2018.

Shipping has been found to be responsible for 48% of the invasive species brought into Arctic waters (Chan et al., 2019). A warming Arctic environment could also improve the survival and establishment chances of temperate species (Goldsmith et al., 2017). The cruise industry will create connections with ports further south (even Antarctica), opening up more routes for invasive species (McCarthy et al., 2022; Saebi et al., 2020). Expanding ship traffic also means more effluents (sewage, greywater, bilge water, etc.) discharged into fragile Arctic ecosystems. The amount of untreated greywater alone to be discharged in the Canadian Arctic is projected to double by 2035 (Vard, 2018).

Nuclear ships create their own particular problems. An incident involving a nuclear-powered icebreaker or floating nuclear power plant (whether towed or moored) could release radioactive contaminants, seriously threatening the Arctic marine environment, industries such as fishing, and local food sources.

Last but quite definitely not least, there are the Indigenous communities who make up about 10% of the 4 million or so people living in the Arctic. Their lives are deeply embedded in their icy homeland, making them the first to witness the rapid and profound changes being brought about by anthropogenic climate change (Inuit Circumpolar Council 2014).

A growing number of environmental conflicts across all Arctic countries have already been brought to a head by the extension of extractive industries into previously inaccessible areas (Hanaček et al., 2022). Shipping routes have also begun to converge on the seasonally unfrozen spaces Indigenous communities traditionally use for hunting, fishing and transportation. The problems these conflicts cause are frequently among the most dispiriting of the many negative consequences of expanding maritime commerce (Afenyo et al., 2021; Aporta et al., 2018; Downing, 2019; PEW, 2018), and are being met with varying degrees of concern and resignation (Inuit Circumpolar Council, 2014).

THE POLAR CODE

In an attempt to ensure that Arctic shipping develops safely and with respect for its unique environment, in 2017 the IMO's Polar Code entered into force governing the safety of ships operating in polar waters. The code establishes a suite of new mandatory measures, recommendations and guidance, designed to increase maritime safety and environmental protection in the high latitudes. The code's provisions are mandatory, having been applied through existing IMO regulations, including SOLAS and MARPOL.

The Code is seen as a good first step towards harmonising Arctic shipping safety and environmental protection, complementing country-based regulations which are, in places, even more stringent. But it also contains a number of notable regulatory holes, including disposal of greywater, air pollution, management of ballast and biofouling, underwater noise and the loss of packaged dangerous goods (Prior, 2022). The aforementioned ban on HFO use and carriage (as fuel) has also been adopted since the Polar Code arrived, but that ban does not extend to HFO as cargo.

Other regulatory developments include new and amended rules on routing through the Bering Sea and Bering Strait, as well as areas to be avoided in order to protect the marine environment from the higher risk of incidents that comes from increased shipping traffic (IMO NCSR 5/3/7).

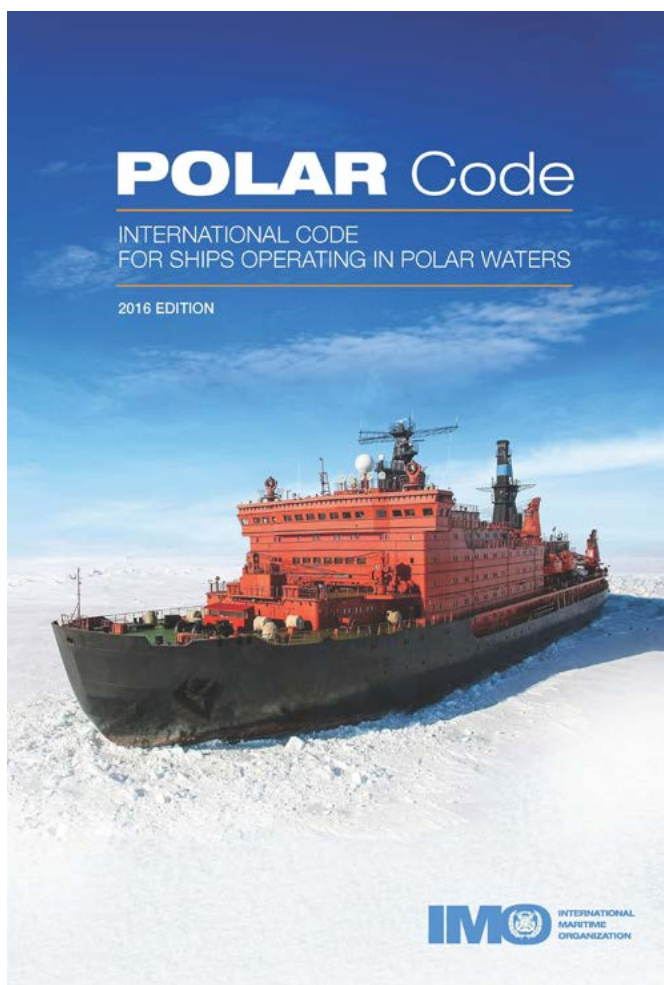


Figure 65: IMO's Polar Code

OUTLOOK

The Arctic is undergoing profound physical changes as a consequence of global warming. As Arctic ice recedes and emerging economic opportunities are seized, the region's unique and vulnerable ecosystems are increasingly facing the novel and cumulative pressures associated with shipping described in the other chapters of this report: accidental spills of oil or other hazardous substances; GHG emissions including black carbon; atmospheric pollution; underwater noise; sewage, greywater and scrubber effluents; invasive species, etc. These pressures are an additional threat to the rights, livelihoods and well-being of Arctic Indigenous Peoples and communities.

Newly-opened Arctic waterways are attracting maritime traffic in two distinct manners: into and within the region itself for the purpose of resource extraction and economic development; and as a shortcut alternative to traditional routes (Suez and Panama Canals) between northern hemisphere trade hubs. Within the Arctic, shipping is already increasing, driven mostly by commercial fishing. Polar cruise tourism is expected to reach mass-market dimensions (Nilsen, 2016), with up to 16 new expedition vessels, purpose-built for Arctic waters, joining the fleet (Nilsen 2016, 2019). Whether the prospect of maritime shortcuts will successfully divert notable trade volumes from traditional shipping routes – estimated at 5% of all global shipping by 2050 (Humpert, 2011) – remains to be seen.

In any case, shipping in support of extractive activities will continue to drive future Arctic marine activity (Arctic Council 2009). The region is estimated to hold as much as one fifth of the world's undiscovered oil and gas, most of it offshore (Bird et al., 2008). Despite the existential need to move away from fossil fuels, Arctic states like Norway, the US and Greenland continue to plan new activities (Arctic Council, 2021). Then there are the large deposits of rare earth metals and minerals found on land and deep under the sea (Hein et al 2017; Humpert, 2023; Reuters 2023; Rowe 2022). \$1 trillion is expected to be invested in the exploitation of Arctic resources over the coming decades (World Economic Forum, 2015).

Maritime transport and infrastructure is necessary for the exploitation of the Arctic's vast hydrocarbon and mineral resources. Russia is investing heavily in developing its infrastructure, with plans for a range of new nuclear-powered icebreakers, ice-class LNG tankers, more mobile nuclear power plants, new ports, and a network of emergency rescue centres along the NSR (Dalton, 2021; Humpert, 2017; Ship Technology, 2022). Responsibility for managing the NSR has also been assigned to the state-owned nuclear corporation, Rosatom, leading some to predict that the Russian Arctic will become the most nuclearised waters on the planet by 2035 (Goodman & Kertysova, 2020; Nilsen, 2019). In 2021 the Russian government announced its ambition to boost Arctic maritime trade on the NSR by 2,000% by 2030 (Staalesen, 2021).

Indisputably, the Arctic is heating up in more ways than one and even non-Arctic countries are increasingly taking an active interest in the region. The Arctic Council, the main diplomatic forum on Arctic issues, has a growing number of non-Arctic countries (including from Europe and Asia) seeking observer status (Bloom, 2022). China increasingly sees itself as a key Arctic power – often referring to itself as a 'near-Arctic state' – for whom maritime access to trade routes and natural resources are central (Doshi et al., 2021). The 2018 white paper laying out China's Arctic policy describes the expansion of its Belt and Road trade initiative with a 'Polar Silk Road' linking Asia and Europe (PRC, 2018).

As the Arctic is increasingly under tension from climate change and global economic forces, Arctic governance is coming to the forefront of debates about the future of the region. In 2009 an assessment by the Arctic Council's Protection of the Arctic Marine Environment (PAME) Working Group asked experts for their views on future Arctic governance arrangements (Arctic Council, 2009). At the time their assessment envisaged governance arrangements evolving in a fairly neutral manner, leaning towards a concerted and proactively sustainable management approach. The Arctic Council's 2021 Strategic Plan similarly sees the Arctic in 2030 as a 'region of peace, stability and constructive cooperation' (Arctic Council, 2021). Just over a year later the idea that foresight, precaution and multilateralism would guide the actions of Arctic nations seems less plausible.

It is safe to say that the Russian invasion of Ukraine in 2022 has done nothing to help growing geopolitical tensions in the Arctic region (Boulègue, 2023; Wall & Wegge, 2023). It is worth noting that, whilst international shipping has collapsed along the NSR as a result of sanctions, the traffic in oil and gas from the Russian Arctic to Europe and Asia has reached record levels (Humpert, 2023; Gavin, 2023).

Despite the evident scramble for Arctic resources, concerns for the Arctic environment are also mounting. Foremost are the calls by Indigenous Peoples to be heard and for a seat at the table shaping the policies and governance of Arctic shipping (Dawson et al., 2020; Inuit Circumpolar Council, 2020).

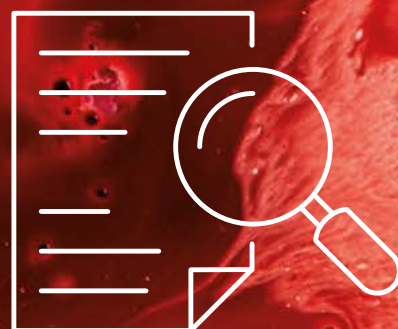
In the private sector a growing number of companies have signed up to the Arctic Shipping Corporate Pledge²⁵, declining to ship goods through the Arctic Ocean on environmental grounds. There are also partial moratoriums on hydrocarbon exploration in the Arctic (by US, Canada and Greenland). And in 2021, as part of its approach to Arctic engagement, the EU committed itself to ensuring that Arctic oil, coal and gas (but no mention of minerals) stay in the ground (EC, 2021).

In the six years since the Polar Code came into effect, numerous regulatory gaps and challenges have become evident (reviewed in Prior, 2022), and the IMO is looking at amending it in future.

25 <https://oceanconservancy.org/climate/shipping/arctic-shipping-pledge>

16

CONCLUDING REMARKS



Environmental degradation and loss of the ‘goods and services’ provided by a healthy environment (a stable climate, clean air to breathe, a thriving and productive natural world) is a tale of death by a thousand cuts. The current triple planetary crisis – climate change, pollution, and biodiversity loss – is largely driven by unsustainable production and consumption. As this report shows, maritime shipping’s central role in international trade results in a wide range of pressures that contribute to all aspects of the crisis.

Across the board, the findings in this report suggest that none of the environmental impacts associated with maritime transport are being tackled at scale. On the question of shipping’s contribution to climate change, there is a widespread consensus that current international ambitions under the IMO are woefully inadequate and will not bring about the transformational change needed for the industry to decarbonise and contribute its fair share towards ensuring that the Paris Agreement’s 1.5 degree Celsius temperature limit is not breached. Even if the industry were to embark on a timely pathway to full decarbonisation many of the associated pressures on the environment and human health would still persist. Admittedly some progress appears to have been made in the 50 years since MARPOL was adopted, primarily in reducing the number of accidental oil spills worldwide. But, by and large, most international regulations to tackle environmental and human health impacts from shipping are weak and poorly enforced, with any progress rapidly offset by the consistent growth in maritime trade. Too much store is placed in voluntary guidelines, which are routinely ignored, and many problems remain entirely unregulated.

When it comes to the environmental problems that shipping creates beyond its contribution to climate change, these are things the IMO and the industry prefer to gloss over. Developed in light of the 2015 UN Sustainable Development Goals (SDGs), the IMO’s Strategic Plan for the period 2018-2023 (IMO A 32/ Res.1149) does align with all the relevant environmental SDGs but chooses to focus on matters of secondary importance. With perhaps one or two exceptions, the environmental, social and governance (ESG) reports from major industry players narrowly define ‘sustainability’ primarily as a matter of decarbonising. Most fail to mention, let alone provide credible reduction targets for, the full range of environmental externalities their businesses entail.

Though the question of governance was beyond the scope of this report, the following insights spring naturally from its various chapters. As the main enabler of globalisation, shipping’s impacts are by nature transboundary, and require cooperation at international and regional level to develop and implement effective management measures. As the latest IPCC report notes, changes to the international and national governance structures of shipping might be required to course-correct its current unsustainable path. Whilst the IPCC is referring to shipping’s role in driving climate change, this report suggests that existing governance structures might not be up to the challenge of managing its many other negative environmental effects either. An issue-by-issue, piecemeal approach to regulation is always likely to be inadequate given the highly interlinked nature of so many of these pressures; something very clearly seen with, for example, the introduction of the IMO 2020 sulphur cap and the unintended consequences of scrubber wastewater, or the interdependencies between toxic antifouling paints, invasive species and climate change. These are highly complex problems that require a long-term vision to guide an integrated, ambitious and transformational agenda.

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