The multi-issue mitigation potential of reducing ship speeds

November 2019

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Environment and Sustainability
Consultants

This report was commissioned by Seas at Risk and Transport and Environment and part-funded by BMU/UBA and by the EU Life Programme

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Executive summary

This report was commissioned by Seas at Risk and Transport and Environment. Its primary objective is to review the mitigation potential of a modest reduction in vessel speed of between 10-20% globally or regionally for a range of environmental issues and safety of navigation, with an emphasis on the potential aggregate effect.

The impact of vessel speed reduction on the following issues is examined:

- GHG emissions
- Air pollutants (SO_X, NO_X)
- Black carbon
- Underwater noise pollution
- Collisions with whales and other marine wildlife
- Safety of navigation.

For each of the issues, the study:

- Summarises the status of any IMO or other regulatory process
- Examines the status of understanding of the issue
- Describes the status of understanding of the efficacy of speed reduction in tackling the issue
- Provides an estimate, where possible, of the impact on the problem of global or regional fleet-wide reductions in speed of 10-20%.

The overall potential impact of a modest (10-20%) reduction in speed on the shipping industry's environmental footprint is also examined.

The study consists of a preliminary review of existing information. No original analysis is undertaken. However, the review is supplemented by consultation with prominent individuals working in the various subject areas examined.

The reduction in fuel consumption of a ships' main engine and the proportionate reduction in CO_2 emissions within most speed ranges is well established. As a rule of thumb, a cubic relation between ship speed and main engine fuel consumption is assumed. When a ship reduces its speed by 10%, engine power is reduced by 27%, but since it takes longer to sail a given distance at a lower speed, the energy required for the voyage is reduced by 19%. Other factors will also influence the relationship between ship speed and engine power including weather conditions and, at a fleet level, the additional ships which may be required to provide the same transport work. As a consequence, the fuel and CO_2 emission reductions associated with slower ship speeds are likely to be lower.

Recent work by Faber et al estimated the CO_2 emission reduction potential for a 10, 20, and 30% speed reduction for the three major ship types for the period 2018-2030. Although the specific level of emission reduction was dependent upon ship type, overall the analysis indicated that the baseline CO_2 emissions could be reduced by around 13% and 24%, if ships reduced their speed by 10% and 20% respectively.

There is little empirical data which directly links ship speed and NO_X emissions. However, NO_X emissions will in general follow fuel consumption, as NO_X emissions and fuel consumption are related to power. For SO_X, since emissions are formed from the reaction between sulphur in fuel and oxygen in the combustion air, a direct relationship between SO_X emissions and fuel consumption exists. For simplicity, when assessing the impact of reduction in vessel speed on SO_X and NO_X emissions, the relationship between ship speed and fuel consumption/CO_2 emissions indicated above was utilised. Thus, a fleet wide reduction in vessel speed of 10% and 20% was assumed to result in a reduction in fuel consumption and NO_X and SO_X emissions of around 13% and 24% respectively.

Considering black carbon emissions, there is little detailed information on the efficacy of speed reduction in reducing black carbon emissions. However, there is general agreement that at full engine load, black carbon emissions are directly proportional to fuel consumption and a moderate reduction in speed will lead to reduction in black carbon emissions. When assessing the impact of reduction in vessel speed on black carbon emissions, similar route-level fuel consumption reductions to those identified above for CO_2, NO_X and SO_X were assumed; however, on account of the relationship between black carbon emission factors and engine load, an approximately linear reduction in black carbon with speed is conservatively estimated, although greater reductions may be achieved (Comer, 2019).

As regards the effect of reducing speed on the hydro-acoustic noise generated by merchant ships, for a ship fitted with a fixed pitch propeller, reducing speed is known to be an effective measure for reducing underwater noise, especially when it becomes lower than the cavitation inception speed. Although overall noise is reduced, it is not necessarily reduced across all frequency bands and a consistent relationship between speed and noise is not always apparent. For ships equipped with controllable pitch propellers, a relatively small proportion of the world fleet, there may be no reduction in noise with reduced speed.

Modelled data suggests significant reductions in underwater noise associated with reduced vessel speed. This is supported by measured data currently emerging from the Port of Vancouver-led ECHO (Enhancing Cetacean Habitat and Observation) Program, a voluntary commercial vessel slowdown and underwater sound measurement trial in shipping lanes overlapping critical habitat of the southern resident killer whale. The first slowdown trial in 2017 resulted in measured reductions in broadband noise exposure from all commercial vessel types, as well as noise reductions across most frequency bands. The biggest reductions in source levels were for container ships with more modest reductions associated with slower moving bulk/general cargo vessels.

Comparison of measured data from the ECHO Program with modelled data demonstrate that the well-established model of Ross (1976) which has been used for decades to estimate the relationship between sound energy and vessel speed aligns well with the results of the ECHO Program. This model indicates that a 10% reduction in speed would reduce underwater sound energy from shipping by around 40%; whilst a 20% reduction in ship speed would reduce underwater sound energy by around 67%.

Ship collisions with whales and other marine wildlife occur where there is an overlap between marine mammals and vessel activities. Unlike many of the issues identified in this study, the problem tends to be local or regional, and is particularly focused around marine mammal migration routes and other areas where significant numbers of marine mammals are likely to be encountered. On the east coast of the United States, the vulnerability of North Atlantic right whales to ship strikes is well documented. Other areas/populations that have been identified as high risk include the fin whale population in the Mediterranean Sea, blue whales south of Sri

Lanka, sperm whales in the Hellenic Trench off Greece, Bryde's whales in the Hauraki Gulf and sperm whales around the Canary Islands.

A number of studies have confirmed an increased ship strike risk with increased speed; however, there is still limited data to quantify the relationship between strike rates and vessel speed (Leaper, 2019). Much of the available data relates to North Atlantic right whales and investigations of the impact of the speed restrictions in the Seasonal Management Areas introduced on the east coast of the United States on the risk of whales being struck by ships. Initial work by Vanderlaan and Taggart (2007) has been built on by other researchers. Most recently, modelling of mortality risk for the North Atlantic right whale by Leaper, estimates both the probability of a whale being struck by a ship and the probability that, if a strike occurs, it will be lethal. Both probabilities are affected by speed. The probability of lethal injury at the time of impact is estimated as 50% when vessel speeds are reduced by 10% and 22% when vessel speeds are reduced by 20% as compared to "business as usual". The probability that a non-lethal strike will occur in relation to ship speed is harder to estimate and there is much more uncertainty.

Considering safety of navigation, there is little evidence to suggest that a general fleet wide reduction in speed would have an impact on safety of navigation. Most collisions are considered to happen through a combination of factors primarily related to watch keeping practices. Ship speed can be a contributory factor on occasion but it is understood to be only one factor in many to be considered. Local restrictions, however, can assist ship safety in particular situations, such as the requirement for oil tankers in congested sea areas such as the Straits of Singapore and Malacca (MPA, 2006) to slow down in order to reduce the risk of collisions. No data was able to be sourced to indicate the impact on navigational safety of fleet wide reductions in speed; however one P&I Association representative commented that "Whilst reduced vessel speeds may, and on balance probably would, help to reduce collisions and the impact, speed is only one factor in many to be considered in collisions" (Gillespie, 2013).

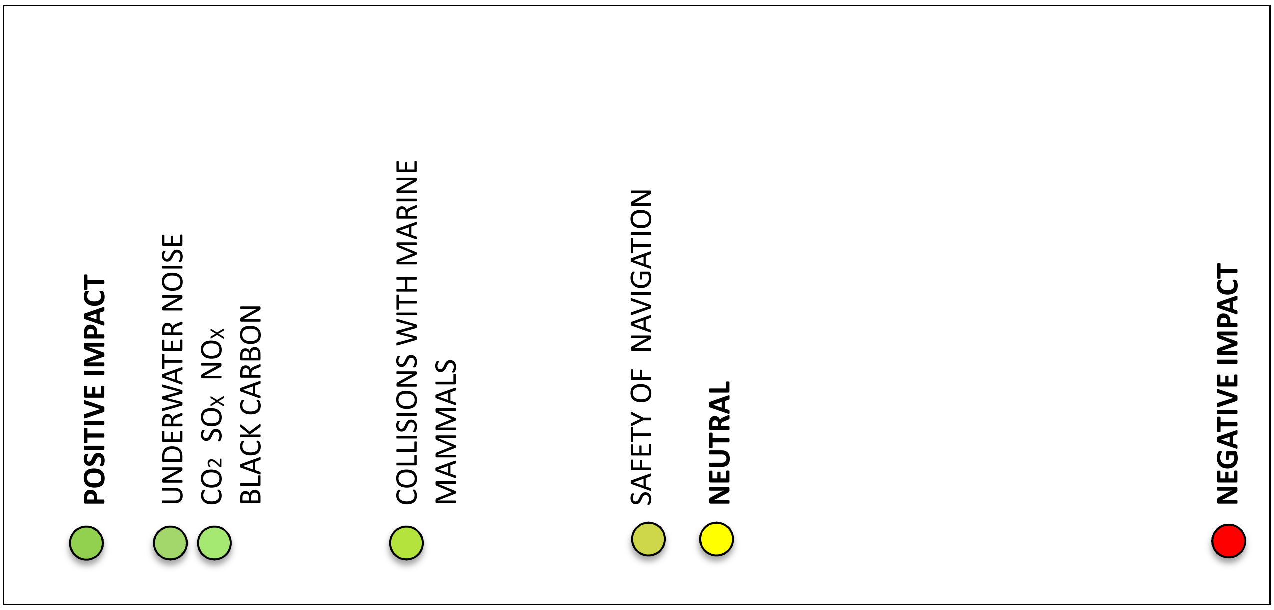


Figure: Overview of the mitigation potential of a 10-20% reduction in vessel speed for the range of safety and environmental issues reviewed

Given the preliminary nature of the review, the variability in data availability and the difficulty in comparing vastly differing environmental impacts such as NO_X emissions and the impact of underwater noise on marine mammals, it is difficult to quantify the *aggregate* safety and environmental benefits associated with a modest reduction in vessel speed of between 10-20% globally or regionally. However, differences in the mitigation potential of vessel speed reduction for the individual issues examined were apparent. These ranged from a highly positive potential impact on underwater noise, CO_2 emissions and the air pollutants, NO_X, SO_X, to what appeared to be a small positive impact on safety of navigation in most circumstances. Whilst significant benefits in terms of reduced collisions with marine mammals are present, these are less apparent since marine mammal collisions are generally a more local or regional issue and tend to require greater reductions in speed to give positive benefits (see Figure).

The suggested absolute and relative mitigation potential of vessel speed reduction for the different environment and safety issues examined are based on review of the data that was available to the author at the time the review was conducted. More detailed investigation would be required to establish more accurately the absolute and relative mitigation potential of a modest reduction in vessel speed of between 10-20% globally or regionally.

Chapter 1

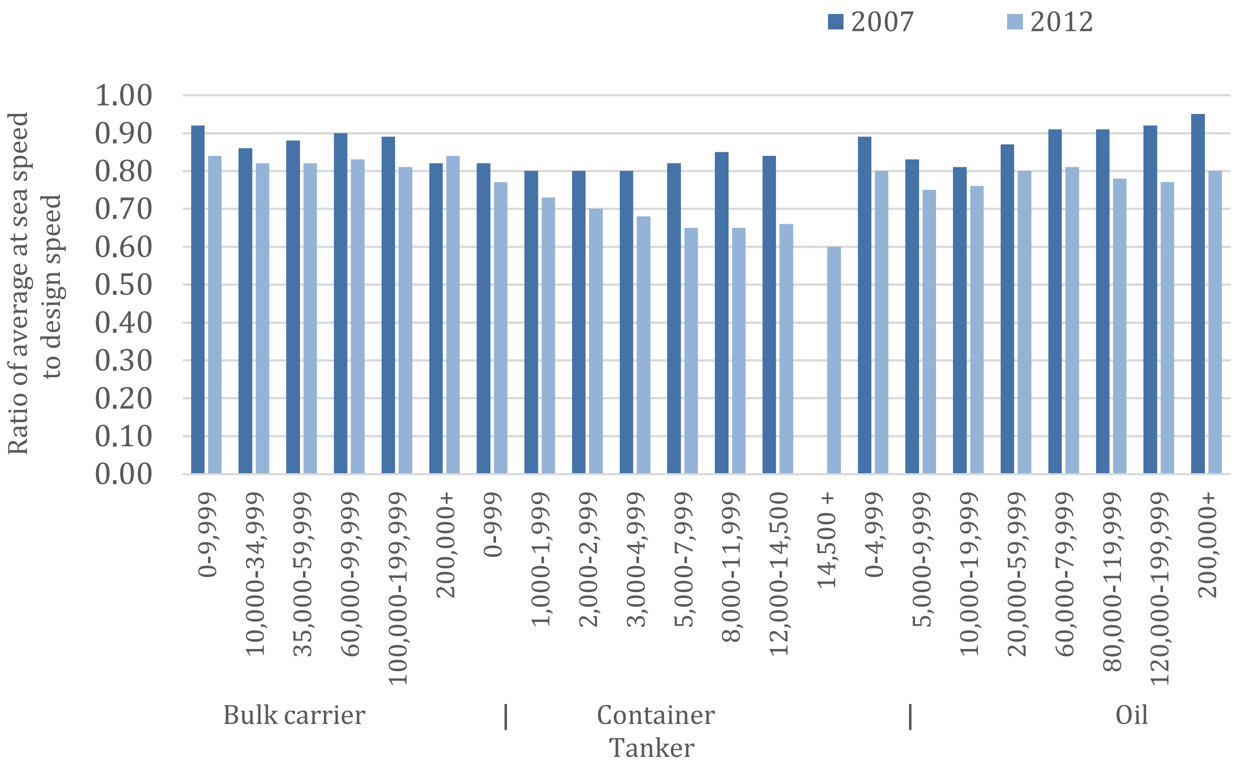
Introduction

1.1 Introduction

This report has been commissioned by Seas at Risk and Transport and Environment. Its primary objective is to review the mitigation potential of vessel speed reduction for a range of environmental issues and safety of navigation, emphasising the potential aggregate effect.

The study builds on industry experience of slow steaming which emerged following the financial crisis of 2008-2009 (Figure 1). Slow steaming helped many shipping companies, particularly the container lines, to absorb overcapacity and significantly reduce fuel costs since fuel consumption decreased significantly as ship speed decreased. Since CO_2 emissions are directly proportional to fuel use, reduced fuel consumption resulted in proportionately reduced CO_2 emissions. The relationship between ship speed and vessel fuel consumption/ CO_2 emissions formation as well as the potential of vessel speed reduction as a CO_2 abatement option has also been examined in various studies. The objective of this study is primarily to examine and raise awareness of other areas in relation to the environment and safety of navigation where vessel speed reduction may have a beneficial impact.

Figure 1: Change in average at sea speed between 2007 and 2012 for different size categories of bulk carrier, container ship and oil tanker (data from IMO, 2015a)



1.2 Objectives

The objective of this study is to increase awareness and understanding of the mitigation potential of reduced ship speeds for a range of environmental and safety issues including:

- GHG emissions
- Air pollutants (SO_X, NO_X)
- Black carbon
- Underwater noise pollution
- Collisions with whales and other marine mammals
- Safety of navigation.

For each of the issues, the study:

- Summarises the status of any IMO or other regulatory process
- Examines the status of understanding of the issue
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- Provides an estimate, where possible, of the impact on the problem of global or regional fleet-wide reductions in speed of 10-20%.

The overall potential impact of a modest (10-20%) reduction in speed on the shipping industry's environmental footprint is also examined.

1.3 Approach

The study consisted of a preliminary review of existing information. No original research was undertaken. The review was supplemented by consultation with prominent individuals (see Acknowledgements) working in the various subject areas examined.

1.4 Report outline

Chapters 2 – 7 examine the individual safety and environmental issues upon which vessel speed reduction may have an effect. The impact of vessel speed reduction on fuel consumption and CO2 emissions is the focus of many studies and is only briefly summarised in this study.

Chapter 8 draws together the individual estimations of the environmental and safety benefits of vessel speed reductions and examines the overall potential to reduce the shipping industry's environmental footprint as a result of speed reductions.

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Chapter 2

GHG emissions

Background

The term greenhouse gas (GHG) emissions covers a wide range of gases which influence climate such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O) and hydrofluorocarbons (HFC). Carbon dioxide is currently considered to be the GHG of prime concern in relation to shipping and this is where the majority of effort to control GHG emissions from ships has been focussed although other gases such as methane and HFC are also of concern. Additionally, black carbon is now understood to be a major contributor to shipping's climate impacts and is the second largest contributor to human-induced climate change, after CO_2 (Bond et al., 2013); however, it is not strictly a GHG and is dealt with elsewhere (Chapter 4).

The main approach to date to reducing CO_2 emissions is to improve energy efficiency thereby reducing the fuel burnt and thus the CO_2 emitted. However, there is now growing focus on the longer-term potential of low or zero carbon fuels to reduce GHG emissions from shipping.

2.1 Status of IMO or other regulatory process

Energy Efficiency regulations aimed at improving the energy efficiency of international shipping were adopted by the IMO in July 2011. These regulations were adopted as amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) and entered into force on 1 January 2013. The regulations apply to all ships of 400 gross tonnage and above and are composed of two main measures:

- The Energy Efficiency Design Index (EEDI) which requires new ships to comply with minimum mandatory energy efficiency performance levels, increasing over time through different phases to 2025. Amendments to MARPOL Annex VI to strengthen the existing energy efficiency mandatory requirements (EEDI) for some categories of new ships were subsequently approved in May 2019 for adoption at MEPC 75 in April 2020.
- The Ship Energy Efficiency Management Plan (SEEMP) which requires all ships, both new and existing, to develop and keep on board a ship specific Ship Energy Efficiency Management Plan, for improving the energy efficiency at sea and in port. 2016 Guidelines for the Development of a Ship Energy Efficiency Management Plan (Resolution MEPC.282(70)) provide Guidance on Best Practice for Fuel-Efficient Operation of Ships but include no mandatory requirements. There is no obligation for ships to implement their SEEMP.

In 2016, MARPOL amendments were adopted to require ships of 5,000 gross tonnage and above (representing approximately 85% of GHG emissions from ships) to collect and submit fuel oil consumption data, including proxies for "transport work", to their flag State from 1 January 2019 for aggregation and submission to IMO. The IMO Secretary-General is to report this information annually to MEPC.

Additionally, a Roadmap for developing a comprehensive IMO strategy on reduction of GHG emissions from ships was adopted in 2016. Subsequently an Initial GHG reduction strategy was adopted in April 2018 (Resolution MEPC.304(72)) which aims to reduce the international shipping sector's GHG emissions at least 50% below 2008 levels by 2050 and develop a programme of follow up actions (MEPC 73/19/Add.1 Annex 9). Amongst the candidate short-term measures (categorized as those which directly reduce GHG emissions from ships and those which support action to reduce GHG emissions from ships with potential for finalisation and agreement by MEPC between 2018 and 2023) identified is: "consider and analyse the use of speed optimization and speed reduction as a measure, taking into account safety issues, distance travelled, distortion of the market or to trade and that such measure does not impact on shipping's capability to serve remote geographic areas" IMO, Resolution MEPC.304(72), Initial IMO Strategy on Reduction of GHG Emissions from Ships, 2018.

A Revised IMO Strategy on reduction of GHG emissions from ships is due to be adopted in 2023.

During the course of the discussions at IMO a comprehensive series of GHG studies which focus on CO2 emissions from shipping have been undertaken (First IMO GHG Study on GHG emissions from ships, 2000; The Second IMO GHG Study, 2009; The Third IMO GHG Study 2014). A Fourth IMO GHG Study is to be undertaken for publication in autumn 2020. This additional study is expected to provide an update of GHG emissions estimates from international shipping from 2012 to 2018 and future scenarios for shipping emissions from 2018 to 2050.

Broader international efforts addressing GHG emissions include the Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC) adopted in December 2015. Under the Agreement countries have committed to reducing their GHG emissions to limit the increase in global average temperature to well below 2 °C above pre-industrial levels, and to pursue efforts to limit the increase to 1.5 °C, in order to reduce the risks and effects of climate change. There is no reference to international shipping within the Agreement. The development of international measures to address GHG emissions from ships has so far been limited to IMO, but national and regional initiatives to address shipping emissions are also starting to emerge.

In September 2015, The United Nations General Assembly adopted Resolution A/Res/70/1 Transforming our World: the 2030 Agenda for Sustainable Development, known as the "Sustainability Goals". A total of 17 Sustainable Development Goals with associate targets are included. Of key relevance is Goal 13: "*Take urgent action to combat climate change and its impacts*".

2.2 Status of understanding about GHG emissions

CO_2 emissions are currently considered the most significant GHG emitted by shipping. Total shipping CO_2 emissions were estimated at around 938 million tonnes or 2.6% of the total global emissions of CO_2 in 2012. This figure was somewhat reduced as compared to the previous five years on account of the financial crisis of 2008-2009 which led to a sudden reduction in international trade. An average annual total shipping CO_2 of 1,015 million tonnes and 3.1% of total global CO_2 emissions has been calculated for the period 2007-2012 (IMO, 2015a). Three ship classes accounted for 55% of the total shipping CO_2 emissions: container ships (23%), bulk carriers (19%), and oil tankers (13%) (Olmer et al, 2017).

2.3 Status of understanding about the efficacy of speed reduction in tackling CO_2 emissions

The voluntary practice of slow steaming which was adopted during and following the financial crisis of 2008-2009 helped many shipping companies, particularly the container lines, to absorb overcapacity and reduce fuel costs since fuel consumption decreased significantly as ship speed decreased. Since CO_2 emissions are directly proportional to fuel use, reduced fuel consumption resulted in proportionately reduced CO_2 emissions. In many cases, anecdotal evidence suggests that the practice of slower steaming is continuing. Research by Olmer et al also demonstrated that most ship speeds remained relatively unchanged between 2013 and 2015. However, the largest oil tankers (>200,000 dwt) and the largest container ships (>14,500 TEU) appear to have increased their speeds by approximately 4 and 11% respectively between 2013 and 2015 (Olmer et al, 2017). Many shipping companies thus have recent experience with slow steaming and the fuel economies associated with a moderate 10-20% reduction in speed, which is the focus of the broader environmental and safety impacts considered in this report, have become well understood.

2.4 Estimation of impact of global or regional fleet-wide reductions in speed of 10-20% on CO_2 emissions

CO_2 emissions are generated by the combustion of hydrocarbon fuel in main engines, auxiliary engines and boilers with the main engine consuming the majority of fuel and generating the major proportion of CO_2 emissions.

Speed reduction can lead to significant reduction in fuel consumption by the main engine, and by association CO_2 emissions, although at low speeds non optimal combustion and other effects can limit the fuel/CO_2 savings. As a rule of thumb, a cubic relation between ship speed and main engine fuel consumption ($P \propto k \times V_3$) is used. When a ship reduces its speed by 10%, main engine power demand is reduced by 27%, but since ships cover less distance when they slow down, the reduction in energy per unit of distance is 19%. Other factors will also influence the relationship between ship speed and engine power including weather conditions and, at a fleet level, the additional ships required to provide the same transport work. As a consequence the fuel and CO_2 emission reductions associated with slower ship speeds are likely to be lower than this.

Recent work by Faber et al estimated the CO_2 emission reduction potential for a 10, 20, and 30% speed reduction for the three major ship types for the period 2018-2030. Although the specific level of emission reduction was dependent upon ship type, overall the analysis indicated that the baseline CO_2 emissions could be reduced by 13, 24, and 33% if the ships reduced their speed by 10, 20, and 30% (Table 1).

	10% speed reduction	**20% speed reduction**	**30% speed reduction**
Container fleet	13%	23%	32%
Dry bulk fleet	15%	28%	38%
Crude & product tanker fleet	10%	18%	24%
Total	13%	24%	33%

Table 1 - Relative CO_2 emission reduction potential for alternative speed regimes (Faber et al, 2017)

Information on the relationship between ship speed and CO_2 emissions available to date tends to be derived from modelling exercises and will be influenced by a number of factors including the model used, input data, assumptions made and ship types examined. Little published empirical data on the relationship between ship speed and fuel consumption/ CO_2 emissions is available.

The requirement to measure and report fuel consumption/CO_2 emissions for EU MRV and IMO DCS compliance could assist in the provision of more data from ships in service to assist confirmation of the relationship between ship speed and CO_2 emissions.

Chapter 3

Air pollution (NO_X, SO_X)

Background

Oxides of nitrogen (NO_X) in marine diesel engine exhaust is formed as a result of oxidation of molecular nitrogen in combustion air or oxidation of organic nitrogen in the fuel. In the latter case, it would be expected that the bulk of the organic nitrogen will be oxidised during the combustion process. Dependent upon the fuel, this organic nitrogen may account for a significant proportion of the total NO_X emission, particularly for engines operating on heavy fuel oil. Oxidation of atmospheric nitrogen in combustion air will be influenced by local conditions in the combustion chamber with increased production of nitric oxide (NO), the primary reaction product, favoured at high temperatures and optimal air-to-fuel ratios. Later in the combustion cycle and during flow through the exhaust system, 5-10% of the NO_X formed will convert largely to nitrogen dioxide (NO_2) whilst at the same time a limited proportion of nitrous oxide (N_2O) will also be formed. Oxidation of NO to the more toxic NO_2 will subsequently continue at ambient temperatures after expulsion from the exhaust system. Adverse effects due to NO_X are diverse. Exposure to high levels of NO_2 has detrimental effects on human health and excess nitrogen deposition causes eutrophication with negative impacts on ecosystems and biodiversity as well as contributing to acidification. NO_X, together with volatile organic compounds is also involved in a series of photochemical reactions leading to an increase in tropospheric ozone which may adversely affect human health, crop yield and natural vegetation. In addition, secondary particulate matter is formed from chemical reaction of NO_X released into the atmosphere. At a global level, N_2O has a high global warming potential and may also play a part stratospheric ozone depletion.

Oxides of sulphur (SO_X) in marine diesel engine exhaust derives directly from the sulphur in the fuel used. In the combustion chamber the sulphur in the fuel is oxidised principally forming sulphur dioxide (SO_2) and to a much lesser extent, sulphur trioxide (SO_3). The use of alkaline lubricants to protect engine surfaces from acidic corrosion converts a small proportion of the SO_X produced by the combustion process to calcium sulphate; this is a relatively insignificant proportion and the sulphur emission from the engine will essentially be proportional to the sulphur content of the fuel. Concern over SO_2 emissions is associated with their detrimental effect on human health, primarily affecting the respiratory system and contributing to particulate formation. SO_2 emissions are also the main component of acid rain associated with acidification damage to sensitive ecosystems and contributing to corrosion damage to materials and historic monuments. Particulate sulphate makes a substantial contribution to regional background particulate levels.

3.1 Status of IMO or other regulatory process

Regulation of the exhaust emissions, NO_X and SO_X, is achieved through Annex VI to the MARPOL Convention together with other air pollutants including particulate matter, volatile organic compounds (VOC), various ozone depleting and global warming refrigerant gases and shipboard incinerator emissions. These other air pollutants are not the subject of this study and will not be discussed further.

MARPOL Annex VI on the Prevention of Air Pollution from Ships was adopted by the IMO in 1997 and entered into force in May 2005. Following entry into force, MARPOL Annex VI was revised to strengthen emission limits the in light of increasing awareness of the need to reduce emissions from the sector. The revised MARPOL Annex VI entered into force on 1 July 2010.

MARPOL Annex VI regulates SO_X through a global standard for fuel sulphur content with more stringent standards in regional Emission Control Areas (ECA) which respond to enhanced concern in certain regions over the health and environmental impact of SO_X (and in some areas NO_X) emissions. SO_X-ECAs currently include the Baltic Sea, North Sea/English Channel, North America and US Caribbean area.

Both global sulphur limits and regional limits within SO_X-ECAs have been progressively reduced over the years and limits are currently 3.50% m/m sulphur in fuel content globally and 0.10% sulphur in SO_X-ECAs. A further reduction in the global sulphur limit from 3.50% m/m to 0.50% m/m will become effective from 1 January 2020 (Figure 2).

As with other MARPOL Annexes, equivalent means of compliance such as alternative low- or zero-sulphur fuels or exhaust gas cleaning systems are allowable both globally and within ECA, subject to approval by the Administration.

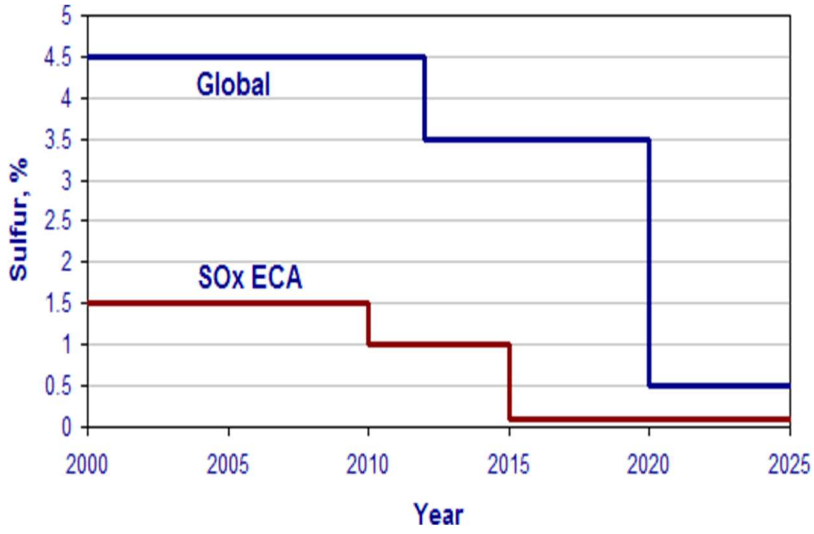
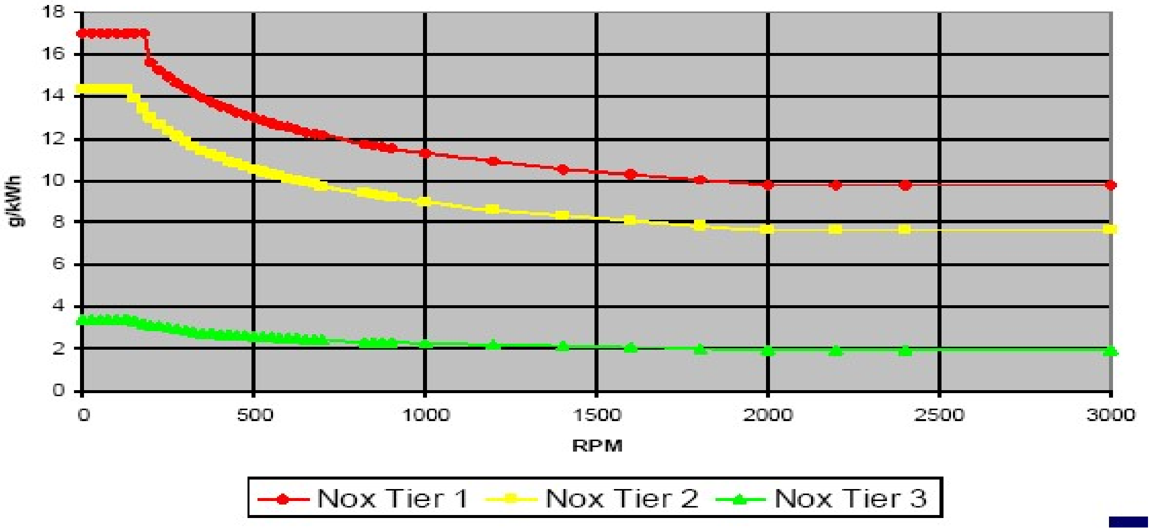


Figure 2 MARPOL Annex VI fuel sulphur limits

NO_X is regulated through diesel engine NO_X emission standards linked to rated engine speed with more stringent standards in (NO_X Emission Control Areas for marine diesel engines installed on ships constructed on or after 1 January 2016. NOx-ECAs are currently in place in North America and the US Caribbean Sea area. From 1 January 2021, the Baltic Sea and North Sea/English Channel ECAs will also become a NO_X Emission Control Areas in addition to regulating SO_X.

Progressive reductions in NO_X emissions from marine diesel engines installed on ships are in place (Figure 3), with a "Tier II" emission limit for engines installed on a ship constructed on or after 1 January 2011; and a more stringent "Tier III" emission limit for new engines installed on a ship constructed on or after a given date that is specified for each NO_X ECA, and applicable only when the ship is operating in the designated NO_X Emission Control Area. Marine diesel engines installed on a ship constructed on or after 1 January 1990 but prior to 1 January 2000 are required to comply with "Tier I" emission limits, if an approved method for that engine has been certified by an Administration.



Tier 1 - original global NO_X emission limit for new engines from 01.01.2000
Tier 2 - revised global NO_X emission limit for new engines from 01.01.2011
Tier 3 - NO_X emission limit in NO_X -ECA

Figure 3: MARPOL Annex VI NO_X Emission tiers

3.2 Status of understanding about the exhaust emission components, SO_X and NO_X

NO_X and SO_X were discussed at length during the 1990s in the period to 1997 when MARPOL Annex VI was adopted and again between 2005-2008 during the period when MARPOL Annex VI was revised. These emission components are thus relatively well understood in terms of sources and environmental impacts on air quality, acidification and eutrophication.

3.3 Status of understanding about the efficacy of speed reduction in tackling NO_X and SO_X emissions

The fuel economies associated with vessel speed reduction and the impact on CO_2 emissions are relatively well understood. Since SO_X emissions are formed from the reaction between sulphur in fuel and oxygen in the combustion air, a reduction in fuel consumed will lead to a proportionate reduction in SO_X emissions.

The situation with NO_X emissions is more complex since NO_X is formed primarily from the reaction between nitrogen and oxygen in combustion air. NO_X formation will depend on many factors and there may not thus be such a direct correlation between reduction in fuel consumed and formation of NO_X emissions, particularly at reduced loads, as may occur during slow steaming, when combustion is less optimal. There is also concern that at low engine loads, NOx emissions could increase as engine loads are reduced beyond a certain threshold (IMO, ISWG-GHG 4/2/9, 2018). Nevertheless, a survey of major operators including Third-Party Logistics Operators, Ship operators, Shippers and Beneficial Cargo Owners, and Major Port Authorities carried out by Faber et al in 2012 indicated that the operators surveyed had a clear understanding of the environmental benefits of slow steaming in terms of NO_X and SO_X emissions reduction as well as CO_2 emissions reduction (Faber et al 2012). The established practice of using NO_X emission factors in units of kg NO_X/tonne fuel consumed to calculate NO_X emissions would also suggest the presumption of broad linearity between fuel consumption and NO_X emissions.

3.4 Estimation of impact of global or regional fleet-wide reductions in speed of 10-20% on NO_X and SO_X emissions

There is little empirical data which directly links ship speed and NO_X emissions. However, NO_X emissions will in general follow fuel consumption, as NO_X emissions and fuel consumption are related to power – and measured as g/kWh (Gørtz, 2019). For the moderate speed reductions considered in this study, emissions of nitrogen oxides are thus broadly assumed to be reduced in line with fuel consumption and an approximately linear relationship between fuel consumption and NO is likely to be maintained. For SO_X, since emissions are formed from the reaction between sulphur in fuel and oxygen in the combustion air, a direct relationship between SO_X emissions and fuel consumption exists.

When assessing the impact of reduction in vessel speed on SO_X and NO_X emissions, the relationship between ship speed and fuel consumption/CO_2 emissions identified in Chapter 2, Table 1 was utilised. For simplicity, the data for total emission reduction was utilised. Thus, a fleet wide reduction in vessel speed of 10% and 20% was assumed to result in a reduction in fuel consumption and NO_X and SO_X emissions of around 13% and 24% respectively.

Chapter 4

Black carbon

4.1 Status of understanding about black carbon

Black carbon is a strongly light-absorbing carbonaceous material emitted as solid particulate matter. It is the product of incomplete combustion of organic fuels and is strongly light absorbing across the visible wavelength spectrum. Black carbon has both adverse human health and environmental impacts. It is amongst the smallest of particulate material and is associated with health problems including respiratory and cardiovascular disease and cancer. Black carbon may also operate as a carrier into the human body for a wide variety of chemicals of varying toxicity (Janssen et al, 2012).

Black carbon also has a significant impact on climate, absorbing incoming solar radiation and directly warming the atmosphere. It has a relatively short atmospheric lifetime, depositing on the Earth's surface a few days up to a few weeks after emission. However, when black carbon deposits onto light-covered surfaces, such as snow or ice, it reduces the albedo of the surface and continues to have a warming effect. Black carbon emitted in the Arctic (60°–90°N) has been found to warm Arctic surface temperatures nearly five times more than black carbon emitted in mid latitudes (Sand et al, 2013).

Black carbon emitted both within and outside of the Arctic region contributes to Arctic warming. Per unit of emissions, black carbon within the Arctic generally has a greater impact on climate change due to the wider global impact of Arctic climate processes. Thus, there is concern that as shipping in the Arctic increases as the Northern Sea Route and/or the Northwest Passage become navigable for a longer period in summer, more black carbon emissions will occur in the Arctic.

Black carbon from all sources is the second largest contributor to human-induced climate change, after CO_2 (Bond et al., 2013) and is now understood to be a major contributor to shipping's climate impacts, representing 7% of total shipping CO_2-eq emissions on a 100-year timescale and 21% of CO_2-eq emissions on a 20-year time scale (Olmer et al, 2017). Since black carbon is a relatively short-lived climate pollutant, reducing black carbon emissions from ships has the potential to rapidly reduce shipping's impact on climate.

Understanding and awareness of the impact of black carbon is developing as information is gathered and more research is undertaken (eg. Lack et al, 2012; IMO 2015b, Comer et al 2017, Olmer et al 2017, IMO 2017a; ICCT, 2018). Reductions in black carbon are now more widely agreed to be required alongside other measures to limit global warming to 1.5.deg C. Reductions in black carbon emissions of at least 35% from 2010 levels are stated to be required by 2050 (IPCC, 2018).

4.2 Status of IMO or other regulatory process

Consideration of policy options to avoid or limit black carbon is at an early stage at IMO although significant work has been undertaken to gather information and develop understanding. Given the enhanced environmental impact on the Arctic, the initial focus has been "consideration of the impact on the Arctic of emissions of Black Carbon from international shipping". An initial work plan to gather information and develop understanding has recently been completed (IMO, 2019).

This included:

- Agreement and approval of a definition for black carbon emissions from international shipping
- Agreement of a Reporting protocol for voluntary measurement studies to collect black carbon data
- Identification of appropriate methods for measuring black carbon emissions from international shipping
- Identification and investigation of possible control measures to reduce the impact on the Arctic of black carbon emissions from international shipping, resulting in a list of 41 candidate control measures classified under the following groupings: Fuel type, Fuel treatment, Exhaust gas treatment, Engine and propulsion system design, Ship design, Operational measures (including slow steaming), Regulatory measures, and Other measures (PPR 6/WP.1).

Further work is planned including consideration of regulating or otherwise directly controlling black carbon emissions from marine diesel engines exhaust; further consideration of recommended black carbon measurement methods; and development of a standardized sampling, conditioning, and measurement protocol (MEPC 74/10/8, para 5), reporting back to IMO MEPC 77 in 2021.

Other regulations/bodies with interest in black carbon

The Arctic Council has substantial interest in the impact of black carbon in the Arctic. In 2015, a framework for action was established which commits the Arctic Council to take enhanced, ambitious, national and collective action to accelerate the reduction in black carbon and methane emissions and to provide black carbon inventories from 2015. An Arctic Council Expert Group was also established to periodically assess and report on progress of the implementation of the Arctic Council's Framework for Action on Black Carbon and Methane (Arctic Council, 2019).

The Climate and Clean Air Coalition and UNEP have recognised the substantial regional and global climate impacts of non-CO2 short-lived climate pollutants (SLCP) such as black carbon and the importance of addressing these pollutants as a way of slowing the rate of climate change. (UNEP WMO, 2011).

4.3 Status of understanding about the efficacy of speed reduction in reducing black carbon emissions

There is little detailed information on the efficacy of speed reduction in reducing black carbon emissions. However, there is general agreement that at full engine load, black carbon emissions are directly proportional to fuel consumption and a moderate reduction in speed will lead to reduction in black carbon emissions. At reduced engine load, or during inefficient operation of the engine, this direct proportionality is not likely to hold. (Lack and Corbett 2012, IMO 2015b).

Studies by Litehauz indicate that ship speed reduction without adjustment to the engine combustion process, can lead to increased black carbon emissions factors due to inefficiencies in combustion (Lack and Corbett, 2012, IMO, 2011, IMO, 2015). Real-time tuning, slide valves and de-rating of engines can counteract the increase in black carbon emission factors caused by operation of engines at lower loads. Theoretically, re-tuning and de-rating of engines to provide ideal combustion at all loads would reduce black carbon emissions in line with the reductions in fuel consumption (Lack et al, 2012; IMO, 2015). Slide valves can also contribute to significant reductions in black carbon emissions during slow steaming when re-tuning or de-rating is unavailable.

4.4 Estimation of impact of global or regional fleet-wide reductions in speed of 10-20% on black carbon emissions

The level of black carbon reduction associated with slow steaming is a function of engine type, fuel type and engine load, but generally the trend is for black carbon emission factors (g/kWh or g/kg fuel) to increase linearly as engine load drops from 100% to around 25% load. At lower loads, there is a sharper increase in emission factors as the engine load decreases towards zero (Figure 4). Assuming most ships operate at or above 25% engine load for most of their voyage, black carbon emission factors will increase linearly as engine load decreases. However, as ships slow down and engine load decreases, energy use (kWh) and fuel use (kg fuel) will fall exponentially thus it is unlikely that slow steaming will increase route-level black carbon emissions, especially if the engine is de-rated or tuned for low-load operations (Comer, 2019).

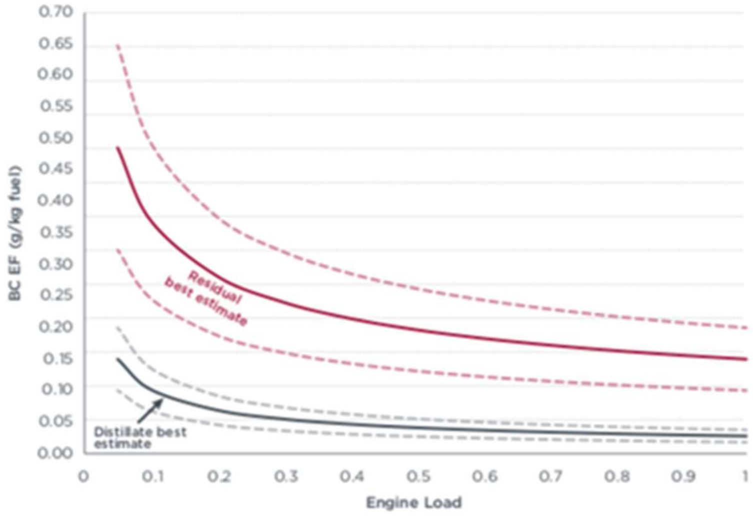


Figure G-3. Black carbon emission factors for 2-stroke main engines used in the analysis

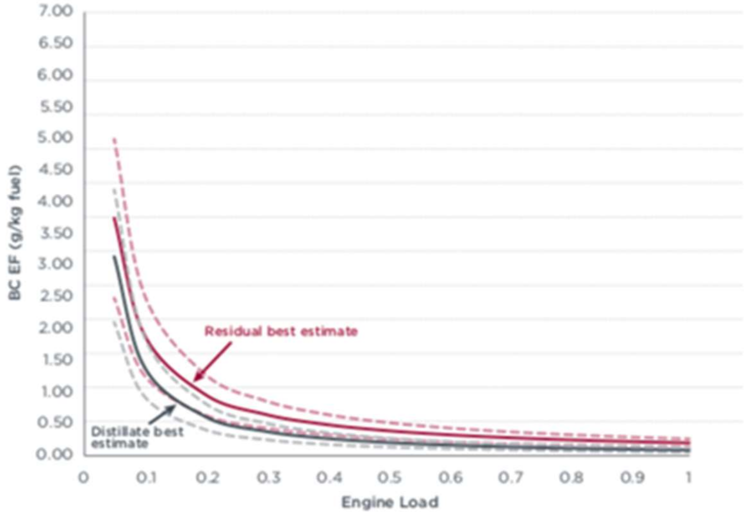


Figure G-4. Black carbon emission factors for 4-stroke main engines used in the analysis

Figure 4 Black carbon emission factors for 2- and 4-stroke main engines by fuel type (Comer et al 2017)

When assessing the impact of reduction in vessel speed on black carbon emissions, black carbon will in general follow fuel consumption (Comer, 2019). Similar route-level fuel/ CO_2 reductions to those identified in Chapter 2, Table 1 were assumed (ie. 10% speed reduction = 13% fuel reduction; 20% speed reduction = 24% fuel reduction); however, because of the relationship between black carbon emission factors and engine load (Comer et al, 2017), an approximately linear reduction in black carbon with speed is conservatively estimated, although greater reductions may be achieved (Comer, 2019).

Chapter 5

Underwater noise pollution

Background

Underwater noise originates from many sources, both natural and man-made including shipping, seismic exploration, industrial activities and construction, military and commercial sonar, acoustic deterrent devices, oceanographic experiments and explosions for underwater construction. While impacts have been reported for a range of noise sources, the largest contributor of anthropogenic noise to the marine environment is considered to be commercial shipping (IMO MEPC 73/INF.23).

There has been concern since the 1970s that noise from shipping could affect marine mammals due to the overlap between the main frequencies used by marine mammal species for communication and navigation and the dominant components of noise from propeller driven ships (Leaper & Renilson, RINA 2012). More recently, studies on the effects of shipping noise on marine life have demonstrated a broader range of impacts across taxa from invertebrates to cetaceans and underwater noise from shipping is increasingly recognized as a significant pollutant with the potential to impact marine ecosystems on a global scale (IMO, 2018b; Williams et al, 2015)

Both the loudness and the frequency at which sounds are produced will determine the level of impact on marine species. Whilst there is a broad range of signals produced by different marine species ranging from less than 20Hz to more than 100kHz, the frequency of shipping related noise clearly overlaps with frequencies used by many marine species (Figure 5).

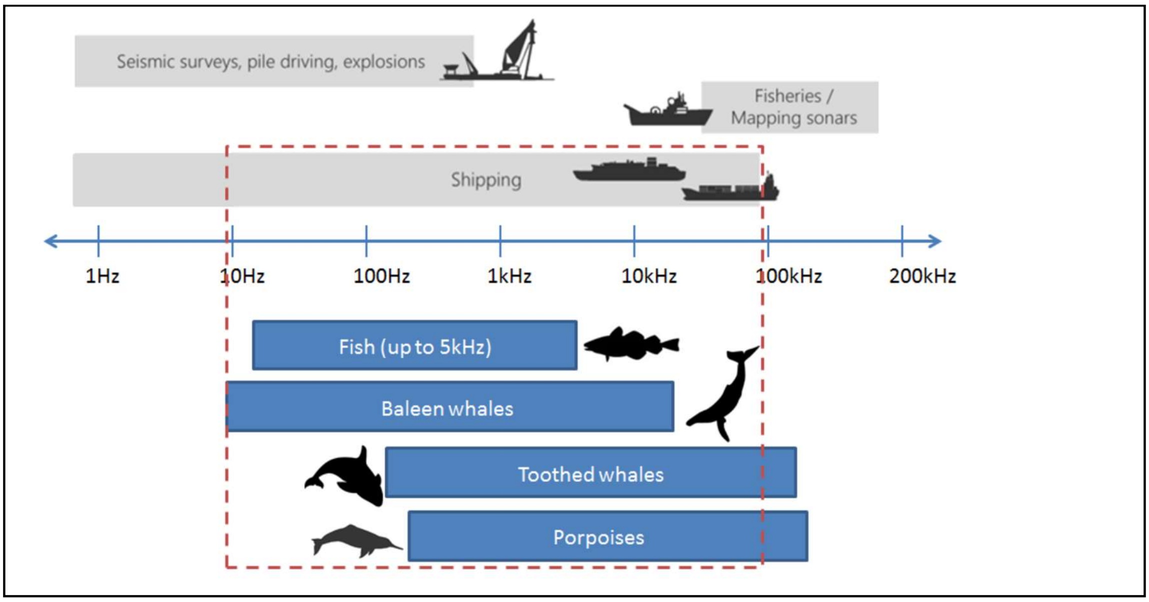


Figure 5: Overlap in the predominant frequencies of marine animal hearing and anthropogenic sources of underwater noise (IMO MEPC 73/INF.23 modified from Nikolopoulos et al., 2016; Veirs et al., 2015; and NMFS, 2016).

Many studies have explored the effects of anthropogenic noise on marine life. These include:

- Physical damage, from loss of hearing to death

- Masking communications, affecting mating and other interactions
- Reduced foraging activity, particularly where animals use sound to locate prey
- Increased stress levels, with overall adverse impacts on health, in a wide variety of species
- Behavioural modification, including avoidance of preferred habitats due to high levels of noise.

These adverse impacts are particularly acute for populations that are already under threat from habitat loss, over-harvesting, and other stressors (Kendrick and Terweij, 2019).

The increase in global shipping and other human activities in recent years have been associated with documented increases in ocean ambient noise levels (Andrew et al, 2002; McDonald et al, 2006 Hildebrand, 2007). Low frequency ambient noise in the oceans may have increased by around 15 decibels (dB) in the latter half of the 20th century due to human activities (Andrew et al, 2002). The high frequency components of shipping noise may also have increased due to the trend toward faster ships (Southall, 2005), since broadband cavitation noise, including the higher frequencies, generally increases with vessel speed (Arveson & Venditis, 2000).

5.1 Status of IMO or other regulatory process

In 2004, in response to the growing body of research that was emerging on the issue, the IMO Marine Environment Protection Committee (MEPC) commenced discussions on the harmful impacts of underwater noise from ships on marine life. By 2009, "Noise from commercial shipping and its adverse impact on marine life" was included on the MEPC agenda with the intention to develop non-mandatory technical guidelines, aiming to minimize incidental noise from commercial shipping operations in the marine environment and thus to reduce potential adverse impacts.

Guidelines for the Reduction of Underwater Noise from Commercial Shipping to Address Adverse Impacts on Marine Life were developed and approved by MEPC in 2014 (MEPC.1/Circ.833). The Guidelines are non-mandatory and provide general advice to designers, shipbuilders and ship operators. The focus is on the primary sources of underwater noise associated with propellers, hull form, on board machinery. Guidance on common technologies and measures for the reduction of underwater noise is provided for designers, shipbuilders and ship operators.

Operational and maintenance measures are also included as a means of reducing noise for both new and existing ships. Selection of ship speed is an important element of the measures included and for ships equipped with fixed pitch propellers, reducing ship speed is cited as an effective measure for reducing underwater noise, especially when it becomes lower than the cavitation inception speed. However, for ships equipped with controllable pitch propellers, a relatively small proportion of the world fleet which may include for example coastal ferries and service boats, there may be no reduction in noise with reduced speed.

The Guidelines are for application to commercial ships. They do not address the deliberate introduction of noise for other purposes such as sonar or seismic activities.

When adopting the Guidelines, MEPC considered that there were still significant knowledge gaps and setting future targets for underwater sound levels emanating from ships was premature. More research was needed, in particular on the measurement and reporting of underwater sound radiating from ships and interested Member Governments were invited to submit proposals for appropriate new outputs to future sessions.

The issue of underwater noise and its effects on marine life is also taken into account through IMO adopted "Particularly Sensitive Sea Areas" (PSSAs). These are areas which may be vulnerable to damage by ships and are considered to deserve special protection, due to their recognized ecological or socio-economic or scientific significance. The 2005 *Revised guidelines for the identification and designation of Particularly Sensitive Sea Areas* (resolution A.982(24), as amended by resolution MEPC.267(68)), recognizes that noise from ships can adversely affect the marine environment and living resources of the sea.

Additionally, The Polar Code includes provisions that relate to marine mammals and underwater noise with voyage planning (part I-A, chapter 11, Section 11.3.6) including the requirement that, in considering routes through polar waters, masters shall take into account "current information and measures to be taken when marine mammals are encountered, relating to known areas with densities of marine mammals, including seasonal migration areas" and "current information on relevant ships' routing systems, speed recommendations and vessel traffic services relating to known areas with densities of marine mammals, including seasonal migration areas".

Little further activity at IMO has taken place in this area until recently with a number of submissions, spearheaded by the government of Canada, being made to the latest MEPC sessions on this matter (e.g., IMO 2018c, IMO2019a).

Other regulatory developments

The European Marine Strategy Framework Directive (Directive 2008/56/EC) adopted in 2008 requires Member States to prepare national strategies to manage their seas to achieve or maintain Good Environment Status by 2020. Underwater noise has been adopted as one indicator of Good Environment Status (GES) based on ambient noise levels within the 1/3 octave bands centred at 63 and 125 Hz, which are dominated by noise from ships. Achieving GES may require reductions in shipping noise.

Related Standards

International Organization for Standardization ISO 17208-1:2016 Underwater Acoustics – Quantities and procedures for description and measurement of underwater sound from ships – Part 1: Requirements for precision measurements in deep water used for comparison purposes. Specifies the general measurement system, procedure, and methodology used for the measurement of underwater sound from ships under a prescribed operating condition.

ISO/DIS 16554 (2014) – Ship and marine technology – Measurement and reporting of underwater sound radiated from merchant ships – Survey measurement in deep-water specifies a method of measurement and reporting of underwater sound radiated from merchant ships in deep-water, where the depth of the water is equal to or greater than 1,5 times the horizontal distance between the hydrophone and CPA.

International Council for the Exploration of the Sea (ICES) Cooperative Research Report No.209 (CRR 209) explains the need for noise reduction in research vessels undertaking fishery resource surveys and makes practical recommendations for limiting underwater radiated noise, to assist those drawing up specifications for new vessels. This noise specification was designed for fishery research ships rather than as a commercial ship design standard. Nevertheless, certain design arrangements used to meet ICES CRR 209 may be useful for the reduction of underwater noise in commercial ships.

5.2 State of the art understanding about underwater noise pollution

Understanding has improved significantly in recent years and it is now recognised that underwater noise affects many marine species and that a significant proportion of the underwater noise generated by human activity is related to commercial shipping.

Substantial recent information relating to understanding the impacts of underwater noise on marine life has become available since adoption of the IMO guidelines in 2014 and has been summarised in a number of papers to MEPC (including MEPC 72 Inf 9 and MEPC 73 Inf 23). MEPC Inf 9 from IWC describes impacts of shipping noise on marine life; masking and population level effects on cetaceans; behavioural impacts; effects of noise on other marine life; monitoring studies evaluating the contribution from shipping to underwater sound; noise output from individual vessels; measures taken by industry that may reduce noise; and actions taken by international organizations and at the national level (IMO 2018b).

The Convention on Biological Diversity's Subsidiary Body on Scientific, Technical and Technological Advice has also published a Scientific Synthesis of the Impacts of Underwater Noise on Marine and Coastal Biodiversity and Habitats in 2016 (UNEP/CBD/SBSTTA/20/INF/8).

Different governments and IGOs have focused on this issue particularly in areas where ship operations are close to marine mammal migration routes or other areas where significant numbers of marine mammals are likely to be encountered.

The government of Canada has undertaken research to better understand the issue and to mitigate the potential negative impact of ship noise along the south-west coast of British Columbia where increased shipping including underwater noise has been potentially identified as having detrimental impacts on the killer whale population (Orcinus orca) (IMO, 2017b). This has been accompanied by various Canadian industry-led initiatives focused on vessel underwater noise such as the ECHO (Enhancing Cetacean Habitat and Observation) Program - a Port of Vancouver-led initiative aimed at better understanding and managing the impact of shipping activities on whales along the southern coast of British Columbia. The Government of Canada also hosted a technical workshop “Quieting Ships to Protect the Marine Environment” at IMO Headquarters in January 2019 to share knowledge and advance work on quiet ship designs and technologies to help protect the marine environment.

An extensive review of studies on anthropogenic noise in the Arctic Region has been compiled by the US National Oceanic and Atmospheric Administration covering: Compilation of Arctic Soundscape recordings in a number of Arctic and Subarctic regions; Research relating to the measurement of noise from vessels in the Arctic and Subarctic regions; Research related to the impact of vessel noise on Arctic marine life; and Research on management related research that proposes ways to reduce, maintain, or manage noise levels in Arctic waters (NOAA, 2018).

Additionally, the European Union has funded a number of collaborative research projects to develop understanding of noise energy in oceans including, Sonic (Suppression Of underwater Noise Induced by Cavitation, 2012-2015), Aquo (Achieve QUieter Oceans by shipping noise footprint reduction, 2012-2015), BIAS (Baltic Sea Information on the Acoustic Soundscape, 2012-

2016) and the current JOMOPANS (Joint Monitoring Programme for Ambient Noise North Sea) and JONAS (Joint Framework for Ocean Noise in the Atlantic Seas) projects.

In 2018, the focus topic of the United Nations Open-ended Informal Consultative Process on Oceans and the Law of the Sea was anthropogenic noise.

5.3 Status of understanding about the efficacy of speed reduction in tackling underwater noise pollution

Noise signatures emitted by ships are variable. They vary, amongst other factors, with the type and age of the ship, the ship's speed and the type of propulsor deployed. The actual signature produced by a ship varies considerably with the power absorbed by the ship and the propeller type (Carlton and Dabbs, 2008). Noise is also not propagated uniformly in the ocean and noise from ships in the deep sound channel will propagate more efficiently than noise in a homogenous water column, contributing to raised ambient noise levels in the ocean which can contribute to increased ambient noise levels (McDonald et al, 2006). Conversely, ambient noise in the oceans may be reduced by minimising the time spent by ships in locations where sound will propagate into the deep sound channel.

There are a number of different sources of noise from ships. The noise from the propeller will depend on whether it is cavitating or not (cavitation occurs when the local pressure is lowered to the vapour pressure of the water). Noise from a cavitating propeller dominates other propeller noise, other than singing, and all other hydro-acoustic noise from a ship. Generally, cavitation can be avoided at low speeds, however at typical cruising speeds this is not possible. Propellers will cavitate above a certain speed, irrespective of how well the ship and propellers are designed (Leaper and Renilson, 2012).

The lowest speed at which cavitation occurs is known as the Cavitation Inception Speed (CIS). Designers of warships and other specialised vessels such as research vessels try to ensure that cavitation does not occur at low operating speeds and the CIS for warships will typically be below 15 knots. However, normal merchant ships, which have not been designed to reduce cavitation, will experience cavitation and cavitation noise will dominate the underwater noise signature of large commercial vessels (IMO, 2010b).

For commercial ships, the CIS is likely to be around 10 knots or lower, and for many commercial ships, such speeds are well below normal operating speeds. Therefore, merchant ships will be exhibiting some level of cavitation (Leaper and Renilson, 2012).

There have been a number of recent studies which have investigated the effect of speed on the hydro-acoustic noise generated by merchant ships (e.g. McKenna et al., 2013; Simard et al., 2016; Veirs et al., 2016, MacGillivray et al., 2019). The recent study by MacGillivray et al (2019) was based on 1317 source level measurements from a voluntary initiative which provided an important experimental control for the speed comparisons. Their results indicated larger reductions in sound level with speed than some other studies (McKenna et al., 2013; Simard et al., 2016; Veirs et al., 2016) but were broadly consistent with the power relationship derived by Ross (1976). Ross(1976) had found that for merchant ships with fixed pitch propellers travelling above CIS, a general relationship between overall wide-band hydro-acoustic noise and ship speed is that noise expressed in dB will increase according to 60log(speed). In a review of the measured relationships, Leaper (2019) also found that the 60log(speed) was appropriate for general estimates across merchant fleets of the relationship between overall wide-band hydro-acoustic noise and ship speed.

This relationship will not hold for all vessels, but it provides a useful indication of the likely reduction in acoustic footprint associated with reduced speed. Although slower steaming will require more ships to be operated to carry the same quantities of cargo there should be an overall reduction in total acoustic footprint associated with slow steaming. For ships fitted with controllable pitch propellers, the situation is less clear and there may be no reduction in noise with reduced speed. Substantial cavitation can occur on controllable pitch propellers when operating at slower speeds resulting in higher noise levels; however, vessels with controllable pitch propellers are only a small proportion of the global fleet (Leaper, 2019).

5.4 Estimation of impact of global or regional fleet wide reductions in speed of 10-20% on underwater noise pollution

Preliminary calculations undertaken by Leaper and Renilson (2012) to estimate the impact of a ship's speed on acoustic footprint, suggested that for an individual ship at 12 knots, the acoustic footprint would be 10% of that ship at 16 knots. However, the number of ships required would increase by 33% for the same quantity of cargo carried. Thus, the total acoustic footprint at 12 knots would be 13% of that for the same cargo transported at 16 knots. Similarly, the total acoustic footprint at 12 knots would be 34% of that at 14 knots. Considering container ships travelling at 25 knots, total acoustic footprint would be reduced to 21% for slow steaming at 20 knots and 7% for extra slow steaming at 17 knots, allowing for the extra vessels required to transport the same cargo (Figure 6).

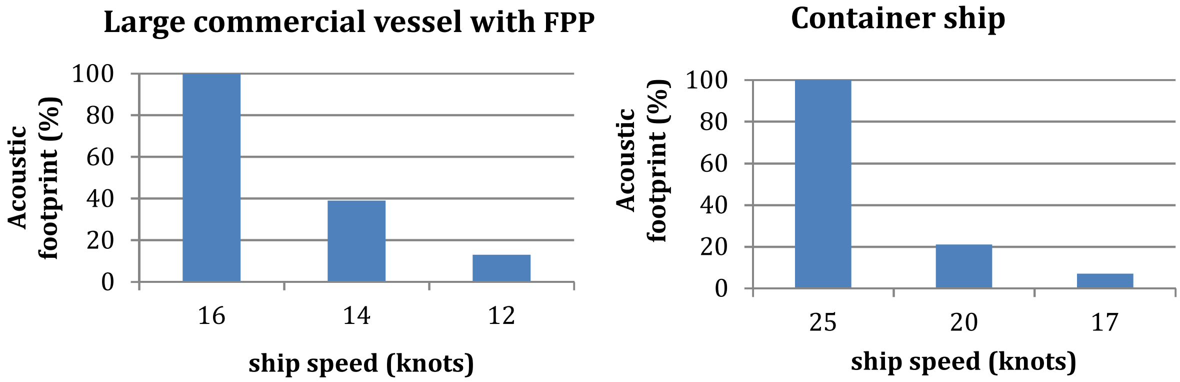


Figure 6 Estimated impact of ship's speed on acoustic footprint for a typical large commercial vessel with fixed pitch propeller (FPP) and a container ship (Leaper and Renilson, 2012)

Subsequent work by Leaper et al (2014) predicted the overall changes in underwater noise in response to slow steaming between May-September 2007 and June-August 2013 using shipping data from the eastern Mediterranean Sea on the main shipping route between the Suez Canal and the Sicilian Channel both for the fleet as a whole, and for individual vessels transiting the area during both time periods. Assuming all vessels had the same noise characteristics but source level followed the 60log10(speed) relationship then for the fleet as a whole the predicted acoustic footprint in 2013 was 34%-45% of that in 2007 (for the same number of vessel transits i.e., equivalent amount of cargo transported) dependent upon propagation loss assumptions. For the 91 individual vessels present in both 2007 and 2013 data sets, the ratio of total predicted acoustic footprint in 2013 as compared to 2007 showed that container ships showed the greatest reduction in mean speed from greater than 20 to around 16 knots and resulted in the greatest predicted reduction in acoustic footprint to 21-30% of 2007 levels.

Important measured data is currently emerging from the Port of Vancouver-led ECHO (Enhancing Cetacean Habitat and Observation) Program, a voluntary commercial vessel slowdown trial conducted through 16 nm of shipping lanes overlapping critical habitat of the southern resident killer whale (SRKW) and combined with underwater sound measurements. The first slowdown trial in 2017 in the Haro Strait resulted in measured reductions in broadband noise exposure from all commercial vessel types, as well as noise reductions across most frequency bands. The biggest reductions in source levels were for container ships that reduced their speed by 7.2 knots, corresponding to a 10.8 dB reduction in median source levels. More modest reductions of 5.0 dB are associated with slower moving bulk/general cargo vessels (MacGillivray et al, 2019; Joy et al, 2019). Further data is set to become available as results of the second trial are published.

Comparison of measured data from the ECHO Program with studies that estimate relationships between sound energy and speed show consistently that slower speeds produce less noise for ships fitted with fixed pitch propellers (Leaper, 2019). It has also been demonstrated that the well-established model of Ross (1976) which has been used for decades to estimate the relationship between sound energy and vessel speed aligns well with the results of recent studies and the results from the ECHO Program (Figure 7). Based on this model, Leaper (2019) estimated that a 10% or 20% speed reduction across the global fleet would be expected to reduce the total sound energy from shipping by around 40% and 66% respectively.

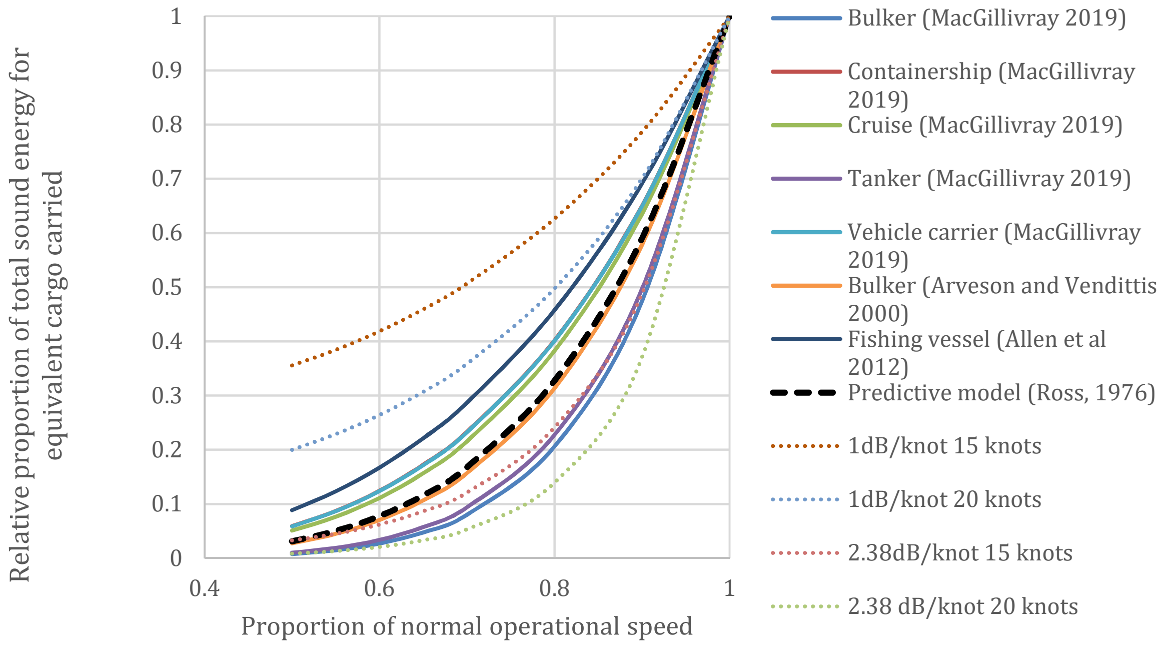


Figure 7: Relative proportion of total sound energy [also equivalent to the relative total acoustic footprint as defined by Leaper et al. (2014)] from a number of studies. Dotted lines indicate relationships that are dependent on the initial speed (Leaper, 2019)

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Chapter 6

Collisions of ships with whales and other mammals

Background

Ship collisions with whales and other marine wildlife are regularly reported worldwide (Laist et al, 2001). Collisions between whales or other marine mammals and ships occur where there is an overlap between marine mammal and vessel activities. Collisions involve a wide variety of vessel types and can result in damage to vessels including cracked hulls; damaged propellers, propeller shafts, and rudders; damaged port and starboard aft strut actuators; broken steering arms; and ruptured seawater piping (Waerebeek and Leaper, 2003). In some cases, particularly those involving large vessels, the crew may be unaware that a collision with a marine mammal has occurred.

Although the vulnerability among species varies, a wide variety of marine mammals have been involved in ship strikes (Glass et al, 2008) as evidenced by blood in the water; animals with cuts; propeller gashes or severed tailstocks; animals sinking after being struck indicating death; fractured skulls, jaws, and vertebrae; or haemorrhaging, massive bruising or other injuries being observed (Campbell-Malone *et al.*, 2007). Evidence of sharp and blunt trauma in such species as North Atlantic right whales, fin whales and sperm whales killed by vessels has been observed. The fin whale is most commonly recorded as being hit by ships worldwide (Laist et al., 2001). The North Atlantic right whale (*Eubalaena glacialis*) whale population which is found off the east coasts of USA and Canada suffers a particularly high rate of ship strikes which are a major cause of the failure of the population to recover from commercial whaling.

A 3- to 4-fold increase in the number of reported large whale–vessel strikes worldwide from the early 1970's to the early 2000's has been reported and attributed to increasing numbers, size and speed of ships (Vanderlaan et al, 2009). The global database of collisions between ships and whales developed by the International Whaling Commission (IWC) now has approximately 1,200 records of incidents. However, many animals killed by ship strikes are likely to go undetected or unreported because the ship strikes may occur in remote areas or the carcasses may sink or drift out to sea.

6.1 Status of IMO or other regulatory process

On account of the growing concern about collisions between marine mammals and ships, the IMO developed guidance for Member States which set out general principles and possible actions that may be taken to reduce the risk of collision between marine mammals and ships. MEPC.1/Circ.674 Guidance document for minimizing the risk of ship strikes with cetaceans was published in July 2009 (IMO, 2009a). Operational measures such as routeing and reporting measures or speed restrictions to reduce and minimize ship strikes of cetaceans are included as possible actions at both national and international level.

Some areas at high risk of collisions between marine mammals and ships may also be designated as PSSAs with associated routing measures or speed restrictions. Paragraph 2.2 of the Revised guidelines for the identification and designation of PSSAs (Assembly resolution A.982(24), as amended by resolution MEPC.267(68)), identifies ship strikes of marine mammals as a physical impact that may cause harm to such mammals. Paragraph 4.4.2 also identifies "critical habitat" for an endangered marine species as an appropriate criteria for PSSA designation.

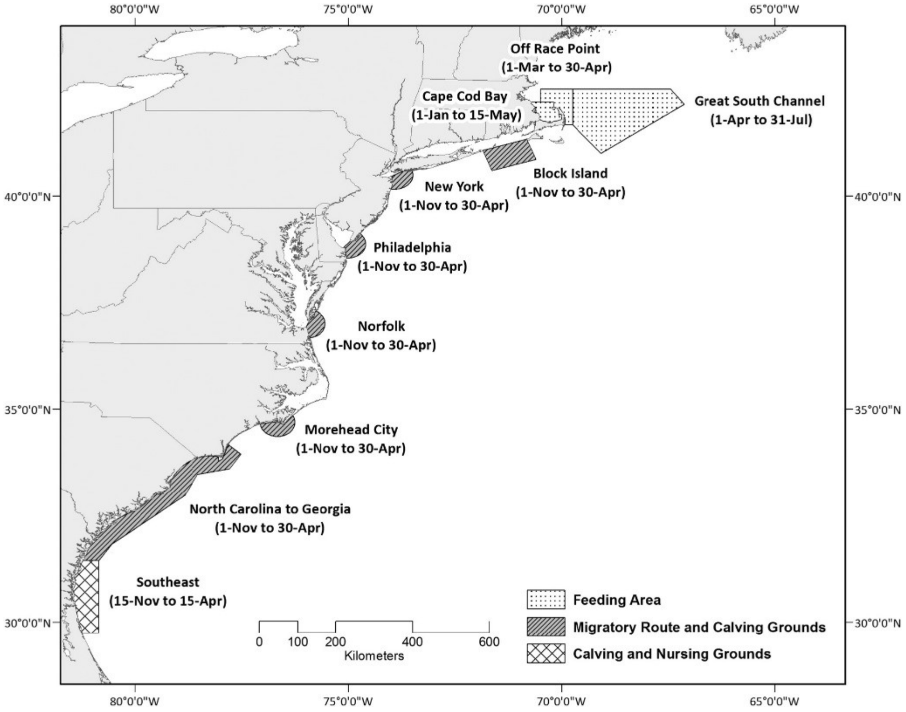
Since publication of the Guidance document for minimizing the risk of ship strikes with cetaceans in 2009, there has been little further action at the IMO on this issue. However, a joint IWC and UNEP-CEP-SPAW10 Ship Strikes Workshop hosted by Panama in 2014 recommended, with respect to IMO activities, development of an appropriate protocol to enable consideration of cetacean distribution and occurrences for proposed new or revised routing schemes or vessel speed restrictions (IMO, 2016).

Other regulatory developments

In areas where there is a high risk of collisions between marine mammals and ships, some national measures have been implemented which include operational measures such as routeing, reporting measures or speed restrictions to reduce and minimize cetacean strikes by ships.

On account of the relatively numerous, per capita, ocean going vessel strikes recorded for the North Atlantic right whale, the US National Oceanic and Atmospheric Administration (NOAA) established regulations to implement speed restrictions of no more than 10 knots applying to all vessels 65 ft (19.8 m) or greater in overall length in certain locations and at certain times of the year along the east coast of the U.S. Atlantic seaboard (Figure 8). The Endangered Fish and Wildlife; Final Rule To Implement Speed Restrictions To Reduce the Threat of Ship Collisions With North Atlantic Right Whales (73-FR-60173) was effective from December 9, 2008 to December 9, 2013.

Figure 8 Times and locations of vessel speed restriction seasonal management areas (SMAs) for North Atlantic right whales along the U.S. east coast (Conn & Silber 2013)



In the initial five years in which the mandatory 10 knot speed restrictions were implemented in the Seasonal Management Areas along the Atlantic coast of the United States, there were no right whale mortalities attributed to ship strikes either in, or within 45 NM in several Seasonal

Management Areas. The expiration date or "sunset clause" contained in regulations was subsequently removed and the seasonal speed restrictions remain in place (NOAA, 2019).

Seasonal mandatory speed restrictions for vessels 20 metres or longer have also introduced by the government of Canada for ships travelling in the western Gulf of St. Lawrence to protect right whales (Canada-news, 2019). Additionally, Panama has introduced restrictions on speed and maritime transit aimed at protecting cetaceans during their nearby seasonal migration. Between August 1 and until November 30 2019, a speed of not more than 10 knots has been introduced in specified areas in the approaches to the Panama Canal (Canal de Panama, 2019).

Further ship speed restriction measures implemented to mitigate ship-strikes have been implemented in Glacier Bay, Alaska, United States; Hauraki Gulf, New Zealand; California, United States and Peninsula Valdez, Argentina (IMO, 2016).

6.2 Status of understanding about collisions between ships and whales or other marine mammals

Whale –ship collisions have been recognised as a source of whale mortality for many years. Records indicate that fatal ship strikes involving baleen and sperm whales have been occurring at least since the late 1800s and have increased as ship size and speed have increased (Laist et al, 2001). Certain species have been shown to be more vulnerable to ship strikes (Figure 9) with the most frequently reported victims of vessel strikes being fin (*Balaenoptera physalus*), humpback (*Megaptera novaeangliae*), North Atlantic (NAR) right (*Eubalaena glacialis*), gray (*Eschrichtius robustus)* and other large whales (Laist *et al*. 2001, Jensen and Silber 2003).

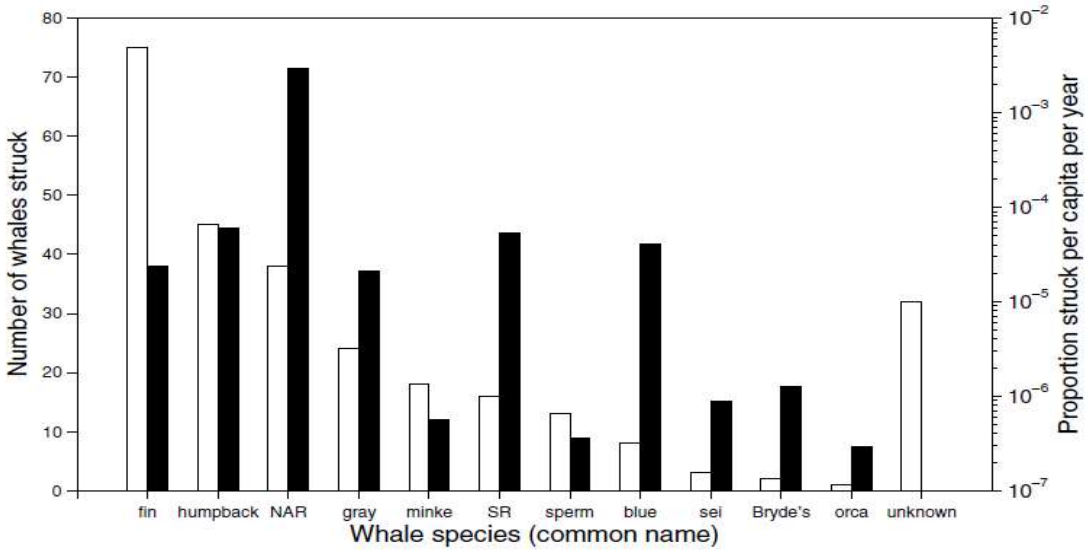


Figure 9: Frequency histograms of documented numbers of large whales reported worldwide being struck by vessels for the period 1960 - 2002 (open bars) and adjusted per capita rate (solid bars; log10 scale) using contemporary population size estimates for each species (source: Vanderlaan & Taggart, 2007)

The awareness of and seriousness with which the problem is viewed is often dependent upon proximity of a Member State and/or a ship operator's area of operation to marine mammal migration routes and other areas where significant numbers of marine mammals are likely to be encountered. On the east coast of the United States, the National Marine Fisheries Service has undertaken extensive efforts to increase awareness of mariners about the vulnerability of North Atlantic right whales to ship strikes and a number of studies have investigated the impact of the speed restrictions in the Seasonal Management Areas introduced on ship strike risks.

Other areas/populations that have been identified as high risk include the fin whale population in the Mediterranean Sea (Panigada et al, 2006), blue whales south of Sri Lanka (Priyadarshana et al. 2015), sperm whales in the Hellenic Trench off Greece (Frantzis et al. 2019), Bryde's whales in the Hauraki Gulf (Constantine et al., 2015) and sperm whales around the Canary Islands (Tejedor et al. 2013).

6.3 Status of understanding about the efficacy of speed reduction in reducing collisions of ships with whales and other mammals

Whale –ship collisions have been recognised as a source of whale mortality for many years. Analysis of historical records suggests that fatal ship strikes involving baleen and sperm whales occurred late in the 1800s, but remained infrequent until about 1950, and then increased between the 1950s to 1970s as the number and speed of ships increased (Laist et al., 2001). Records have indicated that all sizes and types of vessels can hit whales although most lethal or severe injuries involved larger ships and those travelling at 14 knots or faster. Whales usually are not seen beforehand or large vessels cannot manoeuvre to avoid a collision. There is clear evidence that whales avoid ships and it would be expected that this would be easier at slower ship speeds (Leaper, 2019b). Observational studies of whales close to vessels have also inferred greater collision risks with increases in speed (Gende et al., 2011; Harris et al., 2012).

An increased risk with increased speed of a strike being fatal and the relative risk reduction that might be achieved by speed restrictions have been confirmed by a number of studies. Several studies have focused on the impact of the speed restrictions introduced off the east coast of the United States in Seasonal Management Areas 2008-2013 to reduce ship strike risks to North Atlantic right whales. Amongst these, Crum el al 2019 quantified the risk of lethal collisions between endangered North Atlantic right whales and vessels before and after implementation of a vessel speed rule. The expected seasonal mortality rates of right whales decreased by 22% on average after the speed rule was implemented (Table 2). The effectiveness of the speed restriction rule was greatest where right whales were abundant and vessel traffic was heavy, and its effect varied considerably across time and space.

Year	Encounters	Collisions	Deaths	Mortality rate
2006-2007	23.37 (14-34)	14.05 (7-23)	9.02 (2-18)	0.044 (0.010-0.089)
2007-2008	36.20 (25-50)	21.72 (13-32)	13.12 (3-25)	0.043 (0.010-0.081)
2008-2009*	42.55 (30-58)	25.51 (16-37)	13.59 (3-28)	0.033 (0.007-0.067)
2009-2010	40.26 (28-55)	24.13 (15-36)	12.80 (2-26)	0.035 (0.005-0.071)
2010-2011	24.99 (16-37)	15.00 (8-24)	7.77 (1-18)	0.034 (0.004-0.079)

* Speed restriction implemented winter of 2008–2009

Table 2 Expected number of encounters and collisions between vessels and right whales and deaths and mortality rates of right whales (95% confidence intervals in parentheses) due to vessel collisions in and adjacent to the southeastern U.S. seasonal management area under scenario 1, the closest approximation to reality (Crum et al, 2019)

In the Mediterranean Sea, Panigada et al (2006) studying records for a relatively isolated population of fin whales from 1972 to 2001, suggested that the majority of whales were struck by ferries and that vessel speed and size influenced the frequency and severity of ship - whale strikes. Although yachts and motorboats could travel at speeds greater than 20 knots, they were generally small and readily manoeuvrable, and thus could more readily avoid collisions with whales. Where a collision did take place, the injury was less likely to be fatal. Panigada et al also observed that fast ferries had been involved in 42.9% of the whale strike incidents since they were introduced in 1996 and that this was likely to be attributable to their high speed and the increasing number of high-speed ferries in the area year on year.

6.4 Estimation of impact of global or regional fleet wide reductions in speed of 10-20% on collisions of ships with whales and other mammals

Although a number of studies have confirmed an increased ship strike risk with increased speed, there are still limited data to quantify the relationship between strike rates and vessel speed (Leaper, 2019) and much of the available data relates to North Atlantic right whales.

Following publication of the proposed rule by NOAA to implement vessel speed restrictions along the U.S. Atlantic coast, Vanderlaan and Taggart embarked on a study to estimate the probability of a lethal injury to a large whale as a function of the vessel speed at the time of the vessel–whale collision and provide an initial assessment of the usefulness of vessel speed restrictions to reduce whale-vessel collisions (Vanderlaan and Taggart, 2007). They demonstrated that cumulative percentage of whales killed or severely injured increased with speed as did the minor and no apparent injury classes, although these were at a lower level (Figure 10).

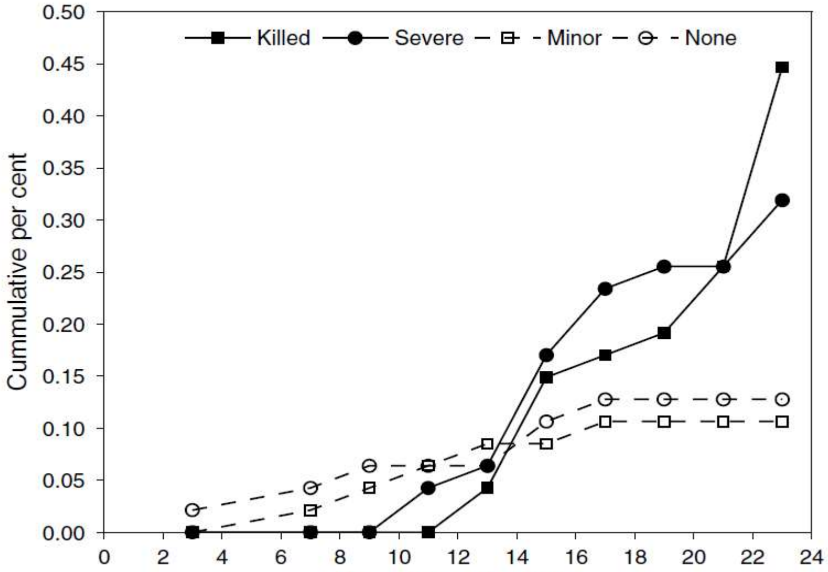


Figure 10 Cumulative percentage increase in each of four whale-injury classes as a function of vessel speed (Vanderlaan and Taggart, 2007)

Logistic regression modelling also demonstrated that the greatest rate of change in the probability of a lethal injury (defined as killed or severely injured) to a large whale, as a function of vessel speed, occurred between vessel speeds of 8.6 and 15 knots. Across this speed range, the chances of a lethal injury, if a collision occurred, declined from approximately 80% at 15 knots to approximately 20% at 8.6 knots. At speeds below 11.8 knots the chances of lethal injury following collision with a vessel dropped below 50%; above 15 knots the chances of lethal injury increase toward 100% (Vanderlaan and Taggart, 2007; Figure 11).

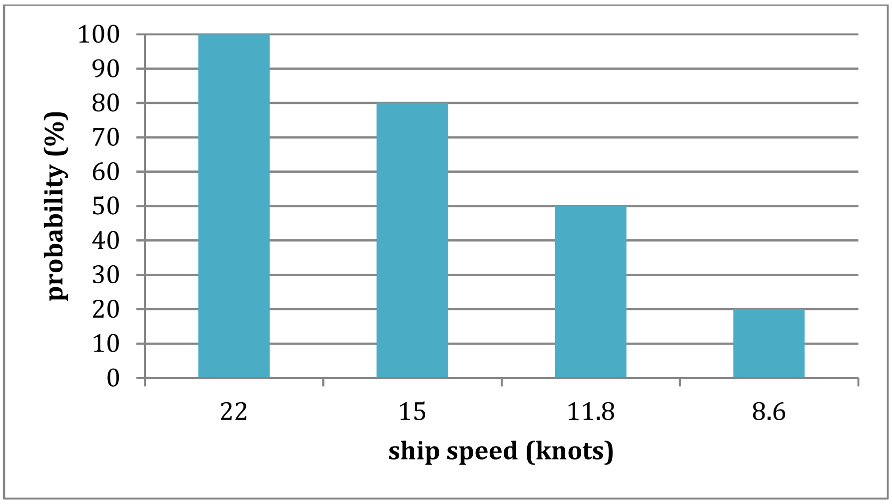


Figure 11: probability that if a collision occurs it will result in a lethal injury to a large whale, as a function of vessel speed (Vanderlaan and Taggart, 2007)

Vanderlaan and Taggart acknowledged that slow moving vessels would spend more time within a whale's domain than fast moving vessels and that this increased whale exposure to vessels navigating at low speed may have an impact. Modelling the changing encounter probability demonstrated that encounter probability increases slowly as speed decreases from 24 knots and then begins to increase more rapidly as vessel speed falls below 5 knots. They also recognised that the relationship between encounter probability and speed will become more complex as the size and shape of the domain or habitat change; as the number, sizes, and speeds of vessels and how they transit the domain change; and the number, sizes, and speeds of whales and how they move in the habitat changes.

Subsequent modelling of mortality risk for the North Atlantic right whale by Conn & Silber (2013) using additional data predicted the probability of a lethal whale strike at a given strike speed. The study also demonstrated the importance of accounting for both the effect of ship speed on the rate at which whales are struck by vessels and the probability of mortality given that a whale is struck.

Recently, Leaper (2019) has used the work undertaken by Conn and Silber (2013) for North Atlantic right whales to estimate probability of lethal injury at the time of impact for vessel speed reductions of 10, 20 and 30% as compared to "business as usual". Estimates may not be directly applicable to other species or populations since the relationship between speed and strike rate is likely to vary between species due to different responses to vessels, swimming speeds and ability to manoeuvre.

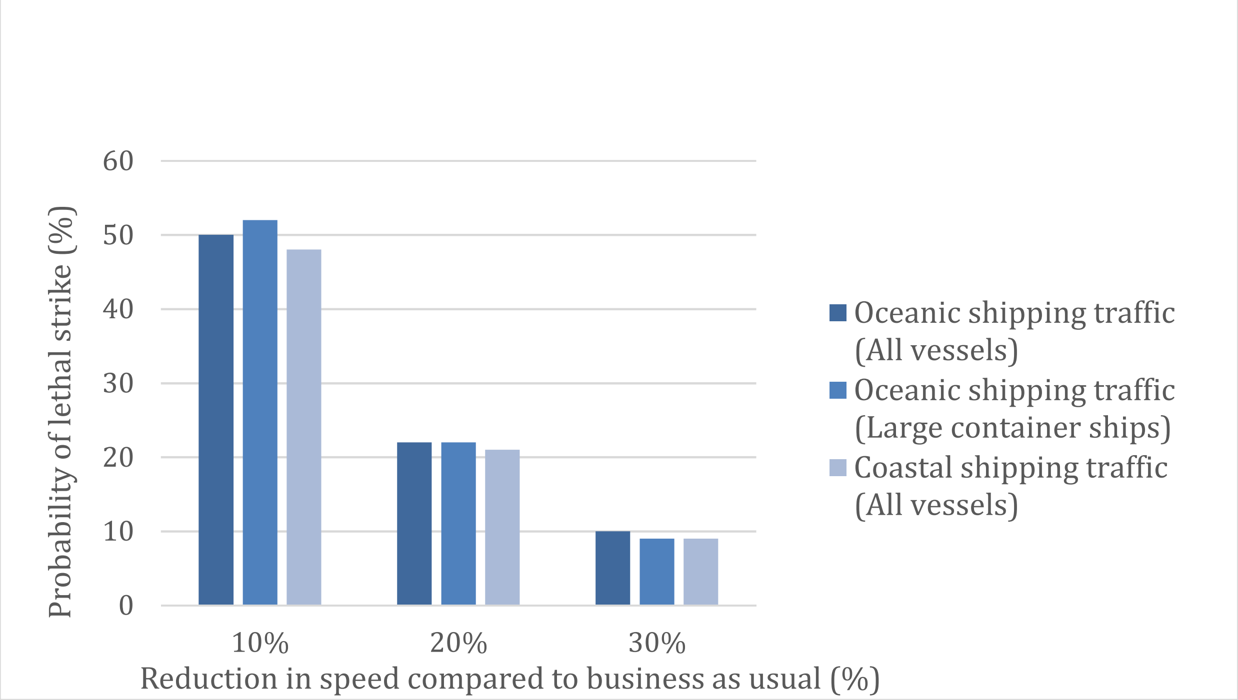


Figure 12 Probability of a lethal strike of marine mammals by a ship with 10%, 20%, 30% reduction in speed as compared to business as usual (adapted from Leaper, 2019)

Leaper estimates both the probability of a whale being struck by a ship and the probability that, if a strike occurs, it will be lethal. Both probabilities are affected by speed. The probability of a strike being lethal is easier to estimate since it is taken to be the proportion of observed strikes which resulted in death of a whale. The estimated reductions in risk of a lethal strike by a ship associated with speed reductions of 10, 20, and 30% are shown in Figure 12. The probability that a non-lethal strike will occur in relation to ship speed is harder to estimate and there is much more uncertainty.

Chapter 7

Ship speed and safety of navigation

Background

Ship speed has traditionally been considered in terms of ship safety and accident avoidance rather than as a measure with potential to reduce environmental impact; however, as is apparent from the preceding chapters, speed is increasingly being considered as a means to reduce environmental impact.

7.1 Status of IMO or other regulatory process

A series of measures to address navigational safety have been developed by the IMO. These include the International Convention for the Safety of Life at Sea, 1974 (SOLAS) and the Convention on the International Regulations for Preventing Collisions at Sea, 1972 (COLREG). More recently, interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions (MEPC.1/Circ.850/Rev.2) have been adopted.

SOLAS covers various aspects of ship safety, including construction, fire protection, life-saving appliances, radio communications, safety of navigation, the carriage of cargoes and safety measures for high speed craft. Safety of navigation is covered in Chapter 5. Ship speed is not specifically referred to. Regulation 34-1 reinforces the Master's responsibility for safe navigation and presumably for the speed of the ship, stating that "The owner, the charterer, the company operating the ship… .or any other person shall not prevent or restrict the master of the ship from taking or executing any decision which, in the master's professional judgement, is necessary for safety of life at sea and protection of the marine environment".

COLREG 1972, which replaced the 1960 Collision Regulations, was adopted in 1972 and entered into force in July 1977 with various amendments being subsequently agreed. Rule 6 addresses ship speed in general requiring that: "Every vessel shall at all times proceed at a safe speed so that she can take proper and effective action to avoid collision and be stopped within a distance appropriate to the prevailing circumstances and conditions." Factors which should be taken into account in determining safe speed are listed and include: visibility; traffic density; manoeuvrability of the vessel; presence of background light at night; state of wind, sea and current and proximity of navigational hazards; and draught of the vessel in relation to the available depth of water (IMO, 2003).

Rule 19 also addresses speed in the context of the conduct of vessels in restricted visibility and states that every vessel should proceed at a safe speed adapted to prevailing circumstances and conditions of restricted visibility. Additionally, "except where it has been determined that a risk of collision does not exist, every vessel which hears apparently forward of her beam the fog signal of another vessel, or which cannot avoid a close quarters situation with another vessel forward of her beam, shall reduce her speed to the minimum at which she can be kept on course".

Considering both the SOLAS and COLREG regulations, ship speed appears very much left to the Master's judgement, with the main requirement being that it is to be safe for the prevailing circumstances and conditions. This is understood to be tested rigorously during Master's examinations as is the appropriate course of action in various circumstances. Should an accident occur, the ship's speed will form part of the enquiry.

Additionally, following development of the Energy Efficiency Design Index (EEDI) requirements applicable to new ships within the MARPOL Annex VI regulations on Energy Efficiency for Ships, interim guidelines for determining minimum propulsion power to maintain the manoeuvrability of ships in adverse conditions (MEPC.1/Circ.850/Rev.2) have been adopted. These guidelines are intended to help ensure that ships complying with the EEDI requirements within MARPOL Annex VI regulations on Energy Efficiency for Ships, have sufficient installed propulsion power to maintain the manoeuvrability in adverse conditions (IMO, 2017c).

Polar Code

The International Code for Ships Operating in Polar Waters (The Polar Code, 2015c) has been developed to supplement existing IMO instruments in order to increase the safety of ships' operation and mitigate the impact on the people and environment in polar waters. It covers a range of shipping related matters relevant to navigation in Arctic and Antarctic waters: ship design, construction and equipment; operational and training matters; search and rescue; and protection of the environment. However, the major part of the code addresses ship safety. Chapter 11 – Voyage Planning aims to ensure that the Company, master and crew are provided with sufficient information to enable operations to be conducted with due consideration to safety of ship and persons on board and environmental protection. Voyage planning requirements require the master to take into account "… current information on relevant ships' routing systems, speed recommendations and vessel traffic services relating to known areas with densities of marine mammals, including seasonal migration areas". Guidance on the content of the Polar Water Operational Manual (PWOM) which must be carried recommends "The PWOM should contain guidance for the use of low speeds in the presence of hazardous ice". However, in general, there is limited discussion of speed in relation to safety of navigation in polar waters. Where thick ice is present, speed should naturally be restricted to a few knots. Navigational charts are often poor or non-existent in polar areas. This should also serve as a natural restriction to ship speeds. No consideration is given to ship speed in open waters. This may change as polar areas become more accessible and ship traffic increases as the polar ice melts due to global climate change.

Other regulations

Whilst there are no international ship speed limits, mandatory speed restrictions may be imposed by coastal states and may be encountered in coastal approaches, harbour areas, rivers and so on. Whilst speed restrictions are often maximum speed restrictions, minimum speed restrictions may also be imposed for example in some pilotage areas where a minimum speed may be required to make the tide, pass under a bridge and so on.

Maximum speed restrictions may be advised in coastal waters/port approaches as part of standardised information published by the coastal state. These restrictions may be for safety reasons, such as the requirement for oil tankers in the Straits of Singapore and Malacca to slow down in order to reduce the risk of collisions (MPA, 2006). Alternatively, speed restrictions may address environmental issues such as the problem of ship collisions with North Atlantic right whale along the east coast of the U.S. Atlantic seaboard.

7.2 Status of understanding about safety of navigation

Ship speed is generally not considered to be an issue in terms of safety of navigation. The ship's speed can be a contributory factor on occasion but is not considered to be a factor in most collisions. Maintaining or improving the training and professionalism of watch keeping officers is considered to more likely result in a material reduction in collisions (Gillespie, 2013).

7.3 Status of understanding about the efficacy of speed reduction in terms of safety of navigation

As indicated above, most collisions are considered to happen through a combination of factors primarily related to watch keeping practices. Ship speed can be a contributory factor on occasion but it is understood to be only one factor in many to be considered. Rule 6 of the COLREGS lists twelve factors to be taken into account by the watch keeper in assessing risk of collision. Most incidents in congested waters observed by one P&I Association are reported to be due to poor application of the collision regulations and particularly due to an ineffective look out (Gillespie, 2013).

7.4 Impact of global/regional fleet wide reductions in speed of 10-20% on safety of navigation

No data was able to be sourced to indicate the impact on navigational safety of fleet wide reductions in speed; however one P&I Association representative commented that “Whilst reduced vessel speeds may, and on balance probably would, help to reduce collisions and the impact, speed is only one factor in many to be considered in collisions” (Gillespie, 2013).

Chapter 8:

Overview of mitigation potential and conclusions

It is well established that within most speed ranges, speed reduction leads to a reduction of the fuel consumption of the ships' main engine and a proportionate reduction in CO_2 emissions. As a rule of thumb, a cubic relation between ship speed and main engine fuel consumption is assumed. When a ship reduces its speed by 10%, main engine power demand is reduced by 27%, but since it takes longer to sail a given distance at a lower speed, the energy required for the voyage is reduced by 19%. Other factors will also influence the relationship between ship speed and engine power including weather conditions and, at a fleet level, the additional ships required to provide the same transport work. As a consequence the fuel and CO_2 emissions reductions associated with slower ship speeds are likely to be lower than this.

Recent work by Faber et al estimated the CO_2 emission reduction potential for a 10, 20, and 30% speed reduction for the three major ship types for the period 2018-2030. Although the specific level of emission reduction was dependent upon ship type, overall the analysis indicated that the baseline CO_2 emissions could be reduced by around 13% and 24%, if ships reduced their speed by 10% and 20% respectively.

There is little empirical data which directly links ship speed and NO_X emissions. However, NO_X emissions will in general follow fuel consumption, as NO_X emissions and fuel consumption are related to power. For SO_X, since emissions are formed from the reaction between sulphur in fuel and oxygen in the combustion air, a direct relationship between SO_X emissions and fuel consumption exists.

For simplicity, when assessing the impact of reduction in vessel speed on SO_X and NO_X emissions, the relationship between ship speed and fuel consumption/CO_2 emissions indicated above was utilised. Thus, a fleet wide reduction in vessel speed of 10-20% was assumed to result in a reduction in fuel consumption and NO_X and SO_X emissions of around 13% and 24% respectively.

Considering black carbon emissions, there is little detailed information on the efficacy of speed reduction in reducing black carbon emissions. However, there is general agreement that at full engine load, black carbon emission is directly proportional to fuel consumption and a moderate reduction in speed will lead to reduction in black carbon emissions. When assessing the impact of reduction in vessel speed on black carbon emissions, similar route-level fuel consumption reductions to those identified above for CO_2, NO_X and SO_X were assumed; however, on account of the relationship between black carbon emission factors and engine load, an approximately linear reduction in black carbon with speed is conservatively estimated, although greater reductions may be achieved (Comer, 2019).

As regards the effect of reducing speed on the hydro-acoustic noise generated by merchant ships, for a ship fitted with a fixed pitch propeller, reducing speed is known to be an effective measure for reducing underwater noise, especially when it becomes lower than the cavitation inception speed. Although overall noise is reduced, it is not necessarily reduced across all frequency bands and a consistent relationship between speed and noise is not always apparent. For ships equipped with controllable pitch propellers, a relatively small proportion of the world fleet, there may be no reduction in noise with reduced speed.

Modelled data suggests significant reductions in underwater noise associated with reduced vessel speed. This is supported by measured data currently emerging from the Port of Vancouver-led ECHO (Enhancing Cetacean Habitat and Observation) Program, a voluntary commercial vessel slowdown and underwater sound measurement trial in shipping lanes overlapping critical habitat of the southern resident killer whale. The first slowdown trial in 2017 resulted in measured reductions in broadband noise exposure from all commercial vessel types, as well as noise reductions across most frequency bands. The biggest reductions in source levels were for container ships with more modest reductions associated with slower moving bulk/general cargo vessels.

Comparison of measured data from the ECHO Program with modelled data demonstrate that the well-established model of Ross (1976) which has been used for decades to estimate the relationship between sound energy and vessel speed aligns well with the results of the ECHO Program. This model indicates that a 10% reduction in speed would reduce underwater sound energy from shipping by around 40%; whilst a 20% reduction in ship speed would reduce underwater sound energy by around 67%

Ship collisions with whales and other marine wildlife occur where there is an overlap between marine mammals and vessel activities. Unlike many of the issues identified in this study, the problem tends to be local or regional, and is particularly focused around marine mammal migration routes and other areas where significant numbers of marine mammals are likely to be encountered. On the east coast of the United States, the vulnerability of North Atlantic right whales to ship strikes is well documented. Other areas/populations that have been identified as high risk include the fin whale population in the Mediterranean Sea, blue whales south of Sri Lanka, sperm whales in the Hellenic Trench off Greece, Bryde’s whales in the Hauraki Gulf and sperm whales around the Canary Islands.

A number of studies have confirmed an increased ship strike risk with increased speed; however, there is still limited data to quantify the relationship between strike rates and vessel speed (Leaper, 2019). Much of the available data relates to North Atlantic right whales and investigations of the impact of the speed restrictions in the Seasonal Management Areas introduced on the east coast of the United States on the risk of whales being struck by ships. Initial work by Vanderlaan and Taggart (2007) has been built on by other researchers. Most recently, modelling of mortality risk for the North Atlantic right whale by Leaper, estimates both the probability of a whale being struck by a ship and the probability that, if a strike occurs, it will be lethal. Both probabilities are affected by speed. The probability of lethal injury at the time of impact is estimated as 50% when vessel speeds are reduced by 10% and 22% when vessel speeds are reduced by 20% as compared to “business as usual”. The probability that a non-lethal strike will occur in relation to ship speed is harder to estimate and there is much more uncertainty.

Considering safety of navigation, there is little evidence to suggest that a general fleet wide reduction in speed would have an impact on safety of navigation. Most collisions are considered to happen through a combination of factors primarily related to watch keeping practices. Ship speed can be a contributory factor on occasion but it is understood to be only one factor in many to be considered. Local restrictions, however, can assist ship safety in particular situations, such as the requirement for oil tankers in congested sea areas such as the Straits of Singapore and Malacca (MPA, 2006) to slow down in order to reduce the risk of collisions. No data was able to be sourced to indicate the impact on navigational safety of fleet wide reductions in speed; however one P&I Association representative commented that “Whilst reduced vessel speeds may, and on balance probably would, help to reduce collisions and the impact, speed is only one factor in many to be considered in collisions" (Gillespie, 2013).

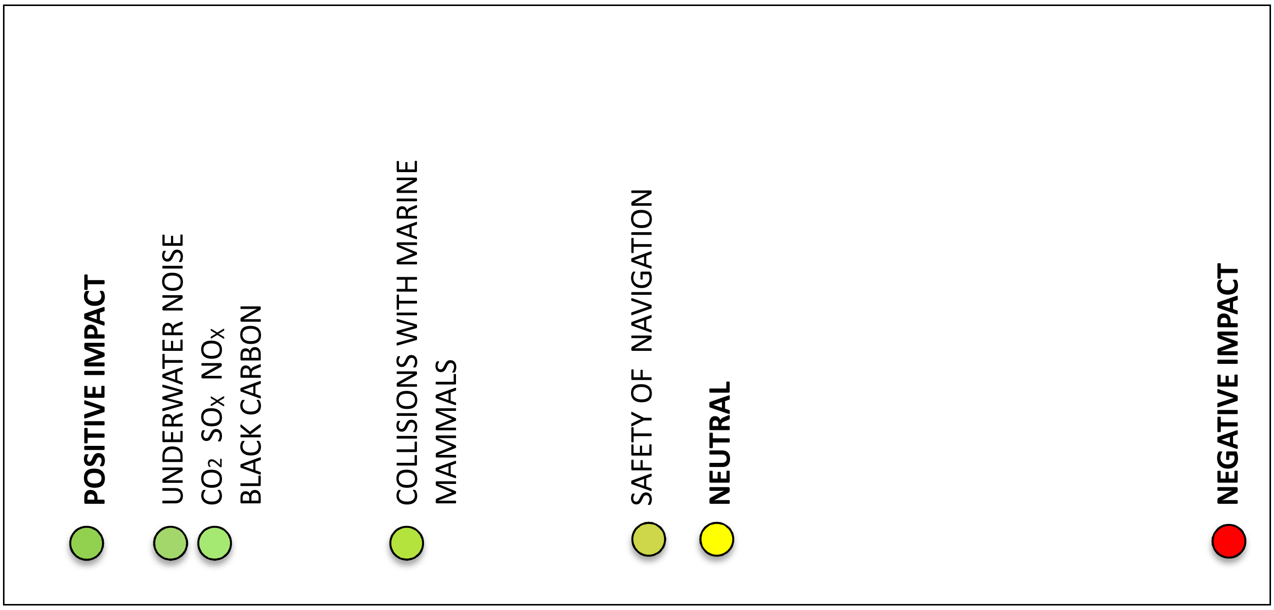


Figure 13 Preliminary view of the mitigation potential of a 10-20% reduction in vessel speed for the range of safety and environmental issues reviewed

Given the preliminary nature of the review, the variability in data availability and the difficulty in comparing vastly differing environmental impacts such as NO_X emissions and the impact of underwater noise on marine mammals, it is difficult to quantify the *aggregate* safety and environmental benefits associated with a modest reduction in vessel speed of between 10-20% globally or regionally. However, differences in the mitigation potential of vessel speed reduction for the individual issues examined were apparent. These ranged from a highly positive potential impact on underwater noise, CO_2 emissions and the air pollutants, NO_X, SO_X to what appeared to be a small positive impact on safety of navigation in most circumstances. Whilst significant benefits in terms of reduced collisions with marine mammals are present, these are less apparent since marine mammal collisions are generally a more local or regional issue and tend to require greater reductions in speed to give positive benefits (Figure 13).

The suggested absolute and relative mitigation potential of vessel speed reduction for the different environment and safety issues examined are tentative and based on review of the data that was available to the author at the time the review was conducted. More detailed investigation would be required to establish more accurately the absolute and relative mitigation potential of a modest reduction in vessel speed of between 10-20% globally or regionally.

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