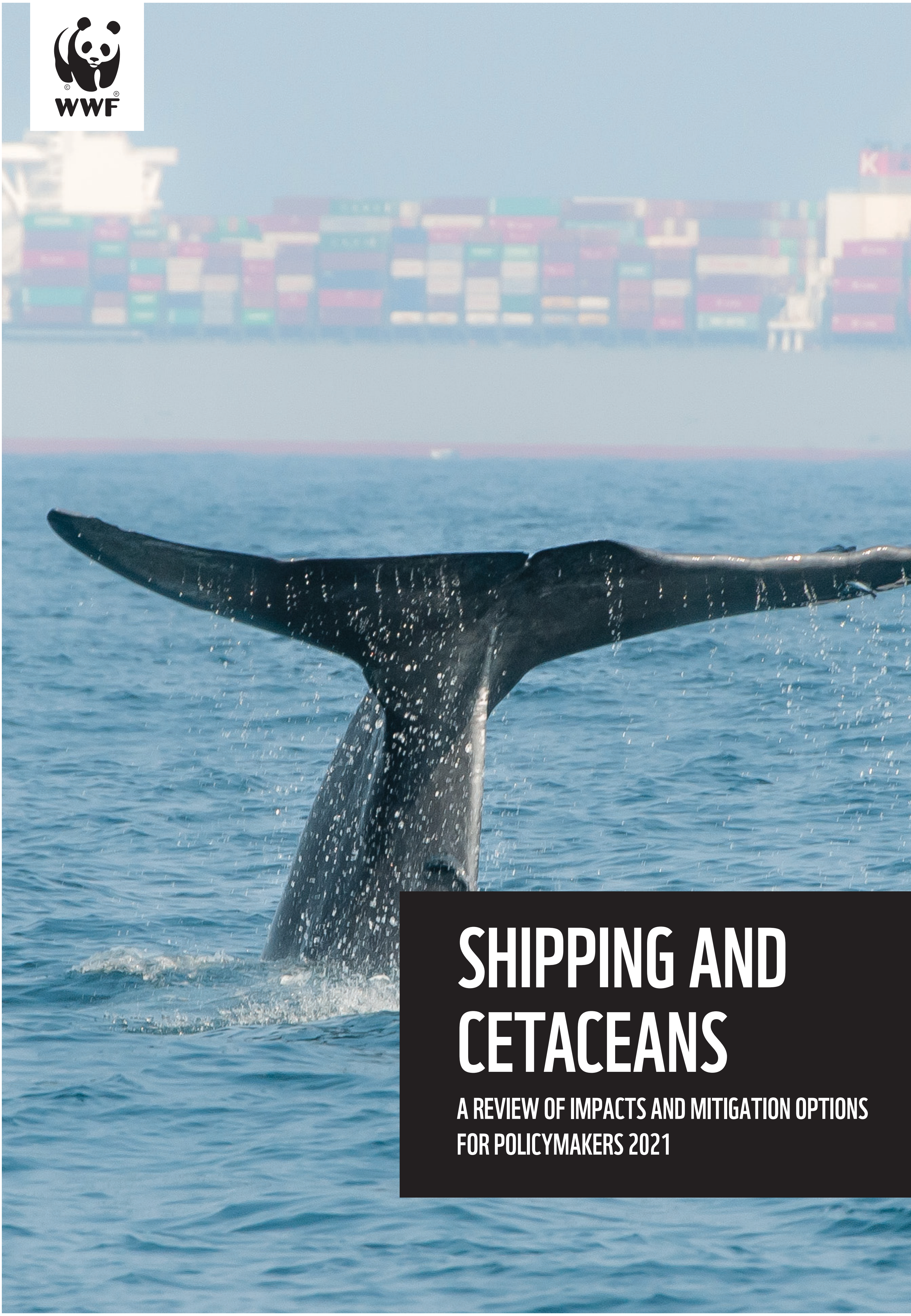

SHIPPING AND CETACEANS

A REVIEW OF IMPACTS AND MITIGATION OPTIONS FOR POLICYMAKERS 2021

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Peer review
This report was reviewed in draft form by the individuals listed below — a group of reviewers selected for their diverse perspectives, areas of expertise. The reviewers assessed the content and quality of the report. Their submissions — which will remain confidential — were considered in full by the authors and many of their suggestions were incorporated into the report. They were not asked to endorse the conclusions, nor did they see the final draft of the report before its release. Responsibility the final content of this report rests entirely with WWF.

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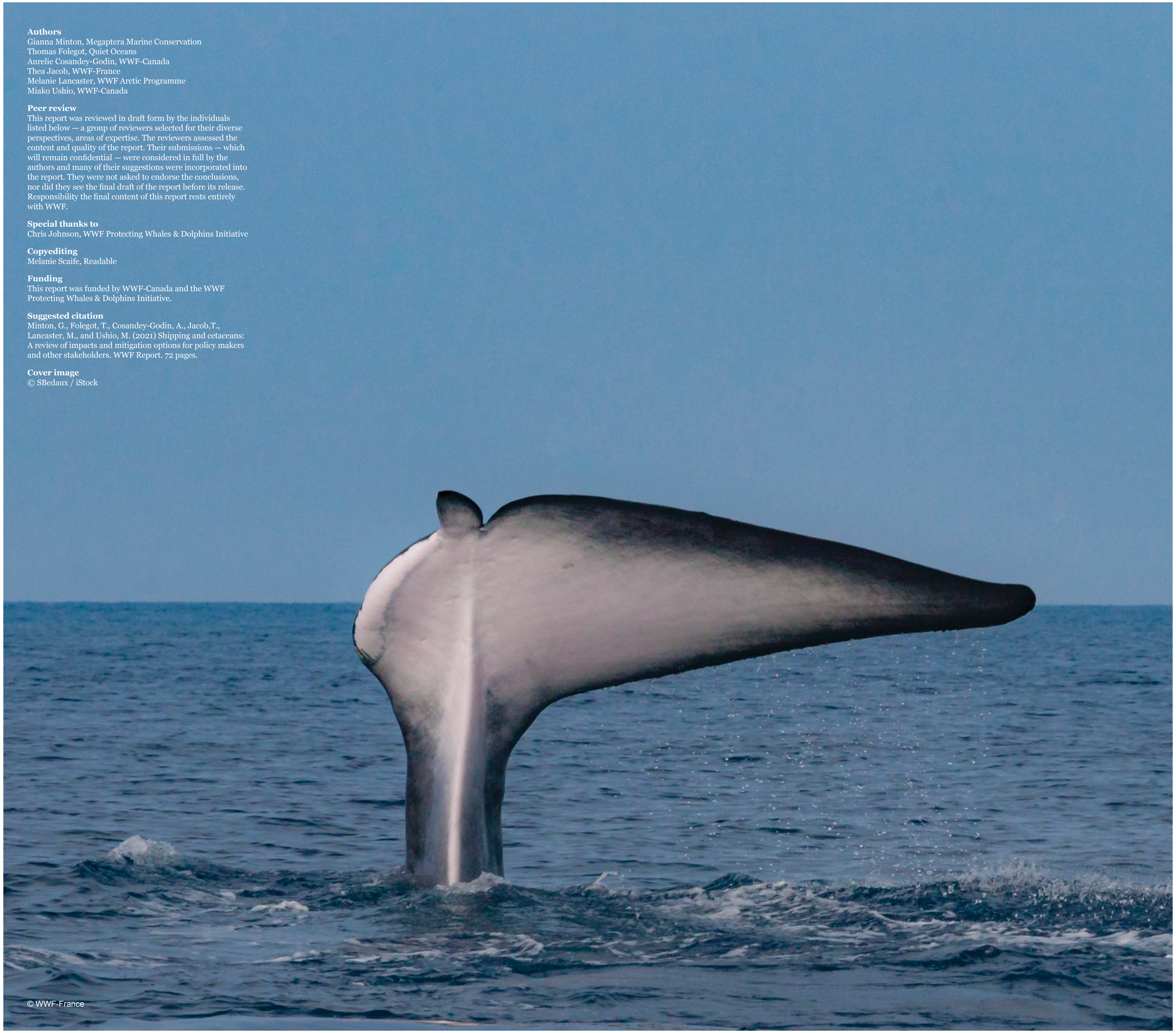

CONTENTS

GLOSSARY OF TERMS AND ABBREVIATIONS

ACCOBAMS Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area.

AIS Automatic Identification System. An automatic tracking system that uses transponders on ships and is used by Vessel Traffic Services. Vessels fitted with AIS transponders can be detected and monitored by onshore AIS base stations or, more commonly and when out of range of land-based receiving stations, through a satellite carrying AIS receivers that then transmit these signatures back to servers on earth.

ASCOBANS Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas.

Arctic Council An intergovernmental organization (IGO) with membership from Canada, Denmark, Finland, Iceland, Norway, the Russian Federation, Sweden and the United States. With working groups on Protection of the Arctic Marine Environment and the Sustainable Development Working Group, it has an important role to play in mitigating the impacts of shipping in the region.

ATBA Area to be avoided. These may be designated by the International Maritime Organization for reasons of danger or especially sensitive environmental factors.

CAFF Conservation of Arctic Flora and Fauna. A working group of the Arctic Council.

Cetacean A marine mammal belonging to the order Cetacea, which includes all whales, dolphins and porpoises.

CMS Convention on Migratory Species, also known as the Convention on the Conservation of Migratory Species of Wild Animals. This is an international agreement to conserve migratory species within their migratory ranges.

DMA Dynamic Management Area. These are areas that are not fixed in time and place but can be triggered by reports of whale sightings. Designations may be seasonal or more ephemeral based on real-time data on whales' movements. Management measures could include temporary designation as an area to be avoided, or mandatory speed restrictions.

ESA *The Endangered Species Act* of the United States, established in 1973.

HELCOM The Baltic Marine Environment Protection Commission, also known as the Helsinki Commission, is an IGO with 10 contracting parties: Denmark, Estonia, the European Union, Finland, Germany, Latvia, Lithuania, Poland, Russia and Sweden. It provides a platform for environmental policy-making at regional level.

IGO Intergovernmental Organization. A group created by a treaty or agreement between two or more nations, called 'member states' to work on issues of common interest. Examples relevant to this report include the International Whaling Commission (IWC), the United Nations in the form of its International Maritime Organization (IMO), and the Arctic Council.

IMMA Important Marine Mammal Areas

IMO International Maritime Organization. The United Nations specialized agency with responsibility for the safety and security of shipping and the prevention of marine and atmospheric pollution by ships. IMO's work supports the UN Sustainable Development Goals.

IWC International Whaling Commission. Established in 1946 under the International Convention for the Regulation of Whaling, it is the global body charged with conservation of whales and the management of whaling. Currently, there are 88 member governments from all over the world, and it works to address a wide range of conservation issues including bycatch and entanglement, ocean noise, pollution and debris, collision between whales and ships, and sustainable whale watching.

MARPOL The International Convention for the Prevention of Pollution from Ships (MARPOL) was adopted in 1973 for the "prevention of pollution of the marine environment by ships from operational or accidental causes."

MARPOL special Areas The IMO explains that MARPOL "defines certain sea areas as 'special areas' in which, for technical reasons relating to their oceanographical and ecological condition and to their sea traffic, the adoption of special mandatory methods for the prevention of sea pollution is required. Under the Convention, these special areas are provided with a higher level of protection than other areas of the sea."

MMPA *The Marine Mammal Protection Act* of the United States, established in 1972.

MSFD EU Marine Strategy Framework Directive

MPA Marine Protected Area. According to the IUCN, these are "A clearly defined geographical space, recognized, dedicated, and managed, through legal or other effective means, to achieve the long-term conservation with associated ecosystem services and cultural values." MPAs have defined conservation goals and restrict human activity, and range from nature reserves which have strict protections, to national monuments and protected seascapes with fewer protections. They can be protected by local, state, Indigenous, national, or international authorities. Protections vary substantially, and many do not meet IUCN MPA standards.

OSPAR Originally named for the Oslo and Paris Conventions, this convention now includes the governments of Belgium, Denmark, Finland, France, Germany, Iceland, Ireland, Luxembourg, The Netherlands, Norway, Portugal, Spain, Sweden, Switzerland and United Kingdom. The convention allows these countries to cooperate to protect the marine environment of the North-East Atlantic.

PAME Protection of the Arctic Marine Environment. A working group of the Arctic Council.

Polar Code Adopted in 2014, and in effect since 2017, the IMO's Polar Code stipulates the first mandatory rules for vessels sailing in the Arctic and Antarctic regions. It covers design, construction, equipment, operational, training, search and rescue, and environmental protection matters relevant to ships operating in the inhospitable waters surrounding the two poles, thus creating a new set of standards and certification that exceed the provisions of SOLAS and MARPOL.

PSSA Particularly Sensitive Sea Area. An "area that needs special protection through action by IMO because of its significance for recognized ecological, socio-economic, or scientific attributes where such attributes may be vulnerable to damage by international shipping activities." If a country would like to establish a PSSA within its territorial waters, the relevant government authorities must apply to IMO proposing an area for PSSA designation and adopt associated protective measures. Some areas that include transboundary areas and/or areas beyond national jurisdiction that are used by multiple countries may require multilateral coordination of proposals.

Precautionary Areas An area where vessels must navigate with caution due to navigational hazards or environmental sensitivities.

SDWG Sustainable Development Working Group. A working group of the Arctic Council.

SMA Seasonal Management Area. These are areas that are not fixed in time and place but can be triggered by reports of whale sightings. Designations in this instance are seasonal based on real-time data on whales' movements. Management measures could include temporary designation as an area to be avoided, or mandatory speed restrictions.

SOLAS The International Convention for the Safety of Life at Sea (SOLAS) was established in 1974 "to specify minimum standards for the construction, equipment and operation of ships, compatible with their safety. Flag States are responsible for ensuring that ships under their flag comply with its requirements."

STCC Sea Traffic Coordination Center. An organized traffic management entity that acts as a central hub maintaining a record of all vessels at sea using the AIS and/or radar, enabling the distribution of vessel routes between ship-to-ship and ship-to-shore.

STM Sea Traffic Management. A system originally developed by Sweden and intended to support real-time data exchange between ports, vessels and shipping companies to improve marine safety and environmental protection. It supports exchange of data about routing plans, navigation hazards and pilot assistance in difficult situations.

TSS Traffic Separation Scheme. Defined by the IMO as "a routing measure aimed at the separation of opposing streams of traffic by appropriate means and by the establishment of traffic lanes."

UNCLOS United Nations Convention on the Law of the Sea. Established in 1982, it addresses navigational rights; territorial sea limits; economic jurisdiction; legal status of resources on the seabed beyond the limits of national jurisdiction; passage of ships through narrow straits; conservation and management of living marine resources; protection of the marine environment; a marine research regime; and a procedure for settlement of disputes between states.

UNEP United Nations Environmental Programme.

URN Underwater radiated noise. A physical quantity that describes the amount of acoustic energy introduced in the marine environment by a source.

VTS Vessel Traffic Services. Defined by the IMO as "a service implemented by a Competent Authority, designed to improve the safety and efficiency of vessel traffic and to protect the environment." It is similar to air travel control for aircraft.

SHIPPING AND CETACEANS

Between 1992-2013, the volume of shipping traffic worldwide increased by 300%.

The world's busiest shipping lanes overlap with important whale habitats.

Increasing ship traffic is more than doubling underwater noise pollution every decade, including in the Arctic where noise pollution is increasing at a faster pace.

INCREASED SHIPPING IS A RISK FOR WHALES AND DOLPHINS

- Although affecting all cetaceans, large-bodied whales like blue, fin, humpback, sperm and North Atlantic right whales have been the most frequently struck by ships causing blunt force trauma and death.
- Underwater noise is causing hearing impairment and behavioural changes, masks communication, increases stress, and has effects on prey.

SOLUTIONS

This report highlights case studies and best practices where shipping impacts can be effectively reduced including:

- move ships away from whales;
- slowdown in major shipping lanes (10 knots or below);
- make ships quieter with noise reduction technologies and newbuild, and;
- encourage port-led incentives and eco-certification.

WWF

EXECUTIVE SUMMARY

Cetaceans – whales, dolphins and porpoises – share their habitats with an ever-expanding fleet of super-tankers, cargo vessels and high-speed ferries. The global volume of shipping traffic is increasing, along with the speed and size of the largest vessels. Meanwhile, some of the world's busiest shipping lanes overlap directly with important whale habitat.

Shipping poses multiple threats to cetaceans, from deaths directly caused by vessel strikes, to vessel noise interrupting communication and feeding behavior, which can lead to decreased health and reproduction. Ship strikes are one of the leading causes of human-induced mortality for several whale populations around the globe, including many that are already threatened or endangered after decades of whaling.

As shipping is almost by definition an international activity, addressing the threats requires an international response. This report details the most relevant frameworks providing mechanisms to mitigate the risks of ship strikes and shipping-generated underwater noise. It also gives an overview of the types of risks posed and potential impacts, and describes the tools available to measure, monitor and mitigate those impacts.

We provide four case studies where mitigation measures have been tested and applied to various species to manage impacts of shipping on cetaceans:

- A Traffic Separation Scheme to protect humpback whales;
- Re-routing shipping lanes, a Marine Protected Area and seasonal slowdowns for endangered North Atlantic right whales;
- Air pollution measures with co-benefits for reducing ship-strike risk and underwater noise for blue whales; and
- Port-led initiatives to reduce underwater noise and vessel disturbance for killer whales.

Each case describes the practical aspects of researching, proposing and implementing mitigation measures to reduce the risks of ship strikes and shipping-related underwater noise to cetaceans. Based on these case studies, we summarize learning and recommendations.

RECOMMENDATIONS

1. Where possible, separate ships from cetaceans by employing permanent or seasonal place-based management measures. Examples include International Maritime Organization routing measures, such as the official designation of Particularly Sensitive Sea Areas, Areas To Be Avoided, Traffic Separation Schemes, Separation Zones or the moving of traffic lanes away from important cetacean habitat (see Section 3.2.1) Designation of Marine Protected Areas is also an effective place-based management measure.
2. Where it is not possible to separate ships from cetaceans, employ permanent or seasonal speed restrictions in sensitive whale habitat: current knowledge suggests 10 knots or below.
3. Encourage ships to employ noise reduction technologies. Technical adaptations to vessel design, (e.g. propellers, engine and other machinery, hull movement through water) are described in section 3.3.
4. Continuously monitor and evaluate changes in spatial use by ships and cetaceans, and adapt policy measures accordingly.
5. Base management actions on the best available knowledge (scientific, local and Indigenous) of cetaceans' distribution and behavior, recognizing that habitats may be shifting due to climate change.
6. Improve knowledge about noise-sensitive species, including their use of sound and thresholds for behavioural changes and hearing damage from underwater noise from shipping.

1. INTRODUCTION: ASSESSING THE IMPACTS AND THE ACTORS

Cetaceans – whales, dolphins and porpoises – share their habitats with an ever-expanding fleet of super-tankers, cargo vessels and high-speed ferries. Maritime transport plays a role in roughly 90 per cent of all world trade, including 60 per cent of movement of the world's oil and gas products.[1]

The volume of shipping traffic worldwide increased 300 per cent between 1992 and 2013,[2] a trend that has continued in more recent years. Furthermore, the speed and size of the largest vessels have increased and marine vessel-based travel has also escalated, with fast passenger ferries increasingly used in coastal areas.[2,3] This increased vessel traffic carries with it a range of environmental hazards, including the release of increased water-borne and air-borne pollutants and greenhouse gases.[4,5] The contributions of shipping activity to climate change are estimated at 2.2 per cent of global greenhouse emissions in 2012, and could increase by as much as 250 per cent by 2050 if mitigation action is not taken.[6]

Some of the world's busiest shipping lanes overlap directly with important whale habitat, resulting in a high risk of injury and mortality to whales that are often unable to effectively avoid vessels' paths.[7,8] Ship strikes are one of the leading causes of human-induced mortality for a number of whale populations around the globe, including many that are already threatened or endangered after decades of whaling.[9,10]

Collectively, the global merchant fleet is the biggest contributor to the doubling every decade in background underwater noise levels over the last fifty years.[11] Underwater noise created by shipping has the potential to disrupt echolocation used by cetaceans for navigation and feeding, mask important communication between individuals in cetacean groups, cause short- or long-term displacement from areas, and in extreme cases cause physical damage and/or (temporary) hearing impairment.[12,13]

Shipping, whether for transportation of goods or people, is almost by definition an international activity involving a wide range of stakeholders from every corner of the world. Shipping is also expanding into corners of the globe that were previously inaccessible or unfrequented. For example, the expansion of shipping activities into the Arctic as ice cover retreats will introduce the threats of ship strikes and disturbance from underwater noise to the range of cetacean species that live in this region.[14,15] At the same time, fishing effort and tourism are expanding in Antarctic waters,[16,17] where several Southern Hemisphere whale populations converge to feed.[18,19]

The aim of this report is to provide advice on the impacts of shipping and the tools available to more accurately measure, monitor and mitigate those impacts for cetaceans. In addition, we provide four case studies illustrating how mitigation measures have been tested and applied to various species. Finally, the report examines lessons learned and provides recommendations and guidance for future work.

Addressing and reducing the threats of shipping activity to cetaceans will require a wide network of actors, ranging from local to international levels, and including representatives of science, industry, governmental, intergovernmental and non-governmental organizations, including Indigenous organizations and communities.

1.1 SHIP STRIKES: WHAT IS THE RISK TO CETACEANS?

As vessel traffic of almost every category is significantly increasing in the world over,[1,2] there is an increase in areas where whales and ships are likely to come into contact, with potentially negative outcomes. As air-breathing mammals, whales and dolphins must spend time at the water's surface between dives and during resting activity.[20] Some species also feed at the surface.[21] Most large cargo vessels or tankers travel at speeds that would not allow them to alter course if they detected a whale in their path, placing the responsibility on whales to take evasive action.[7,22] Whales that are resting or surfacing after a long dive may be particularly vulnerable if they are unable to detect ships or the danger that they present in time to manoeuvre out of harm's way.[7,8]

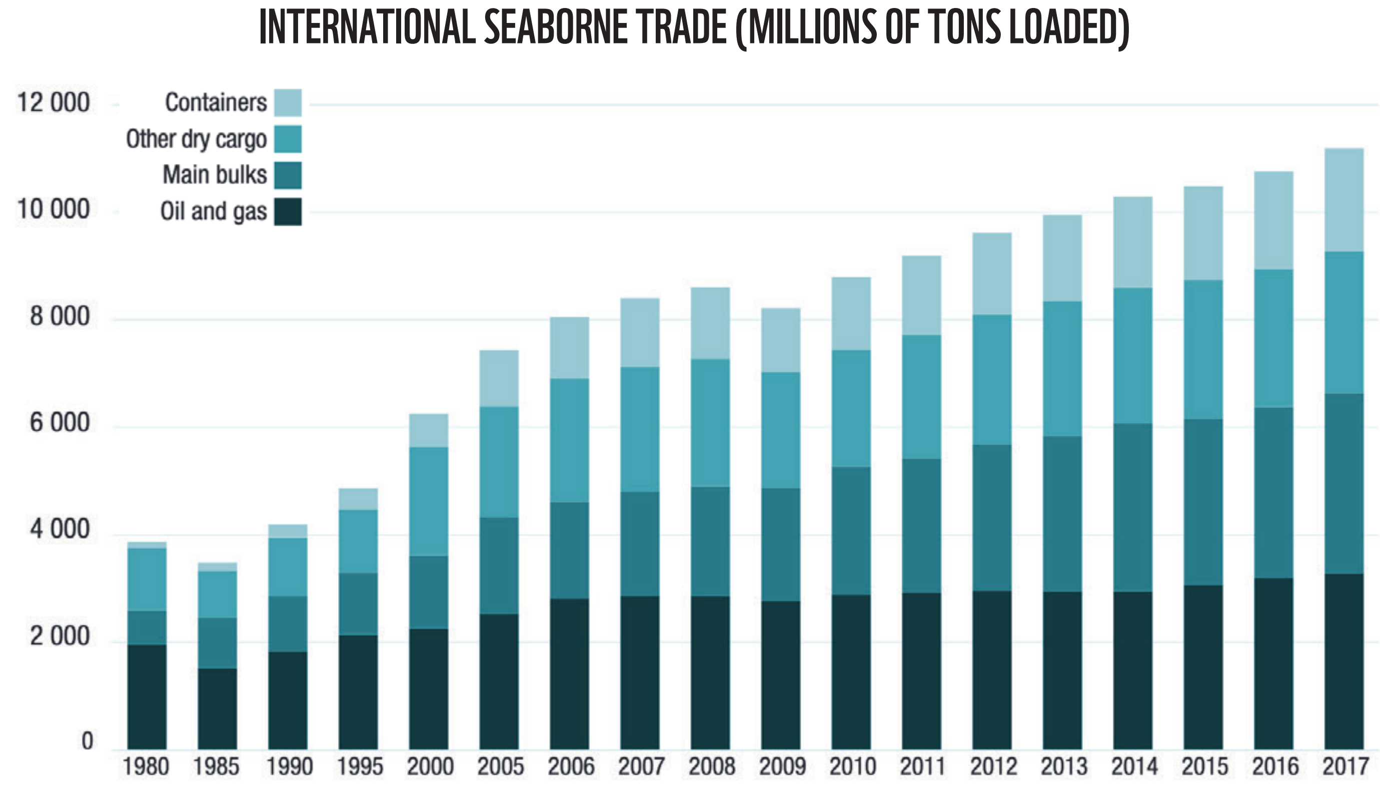

Figure 1: Trends in international sea-borne trade between 1980 and 2017. Source: UNCTAD. 2018. *Review of Maritime Transport 2018*. Report by the Secretariat of the United Nations Conference on Trade and Development, United Nations, Geneva, p. 116.

Injuries consistent with vessel strikes detected during post-mortem analysis of whales reveal that ship strikes are known to be a major cause of mortality for several whale populations, including some small and endangered populations, such as critically endangered North Atlantic right whales[10] and Mediterranean fin whales.[23-25] Injuries associated with ship strikes include major fractures to the skull, jaw or vertebrae, or propeller wounds.[26]

The International Whaling Commission (IWC) maintains a ship strikes database that has documented more than 900 ship strike incidents since 1820.[27] These records are collated through voluntary reports made to the IWC, as well as reviews of published scientific and popular literature/media.[27] Reports indicate that many ship strikes go unnoticed at the time of incidence, with some vessels only realizing they have struck a whale when they enter port with a carcass wrapped around the bow.[27,28] Strikes can cause sub-lethal injuries, such as cuts from propeller blades as well as severe blunt trauma from a direct impact.[28] Evidence of non-lethal ship strikes is sometimes detected during photo-identification studies of whale poulations,[29,30] but in these circumstances the injuries or scars that are documented cannot be tied to the specific events that caused them.

Given the challenges above, accurate statistics on the actual rate of occurrence of ship strikes are difficult to obtain.[28] A recent analysis of the records held in the IWC database indicates that of the 216 ship strike reports for which a definitive outcome for the whale could be determined, 57 per cent of incidents resulted in death, with an additional 6 per cent considered "possibly" or "probably" dead,[27] while an analysis of a large whale ship strikes database curated in the United States indicates that 68 per cent of documented ship strikes resulted in death.[31]

Evidence suggests that a variety of vessel types can be involved in whale collisions, ranging from non-motorized sailing vessels to fast passenger ferries and large container ships.[7,27,32,33] Large-bodied whales are most commonly impacted, with fin whales, humpback whales, sperm whales and North Atlantic right whales being the most frequently reported species in the IWC database.[23,27] However, smaller cetaceans (dolphins and porpoises) may also be at risk of vessel strikes, particularly those populations whose distributions overlap with high levels of vessel traffic.[34]

NUMBERS OF SHIP STRIKES PER VESSEL CATEGORY

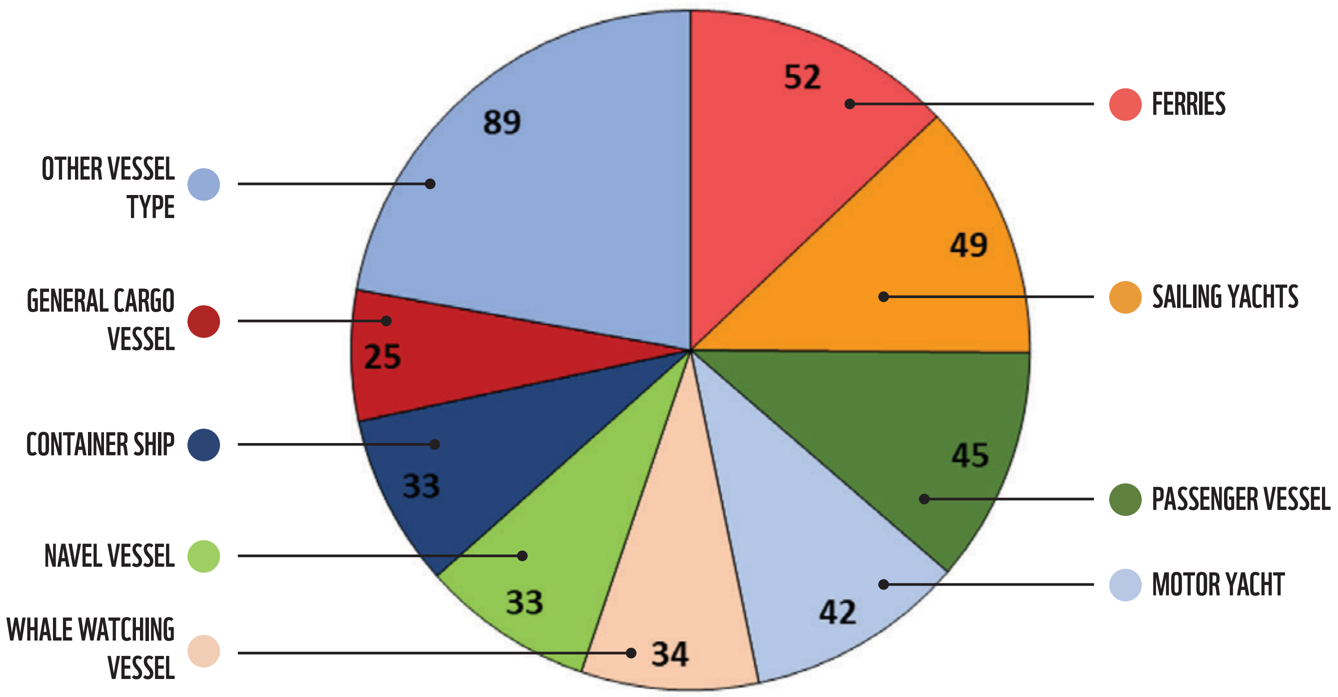

Figure 2: Numbers of ship strikes per vessel category, based on data held in the IWC Ship Strikes Database (1820–2019, n=402). Reproduced with permission from: Winkler, C., Panigada, S., Murphy, S. and F. Ritter. 2020. *Global Numbers of Ship Strikes: An Assessment of Collisions Between Vessels and Cetaceans Using Available Data in the IWC Ship Strike Database.* Report to the International Whaling Commission, IWC/68B/HIM/09.

FREQUENCY OF CASE CONCLUSIONS

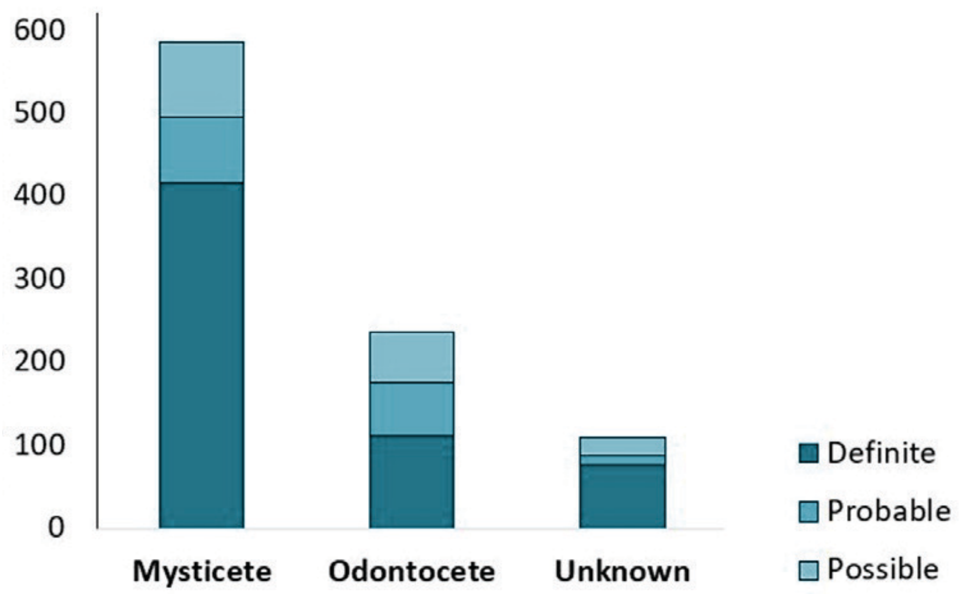

Figure 3: A depiction of the degree of certainty assigned to reports of ship strikes reported to the IWC Ship Strikes Database, broken down by cetacean suborder (baleen whales — mysticetes vs. toothed whales — odontocetes) (reports range from 1820–2019, n=933). Reproduced with permission from: Winkler, C., Panigada, S., Murphy, S. and F. Ritter. 2020. *Global Numbers of Ship Strikes: An Assessment of Collisions Between Vessels and Cetaceans Using Available Data in the IWC Ship Strike Database.* Report to the International Whaling Commission, IWC/68B/HIM/09.

NUMBERS OF RECORDS IDENTIFIED TO SPECIES LEVEL

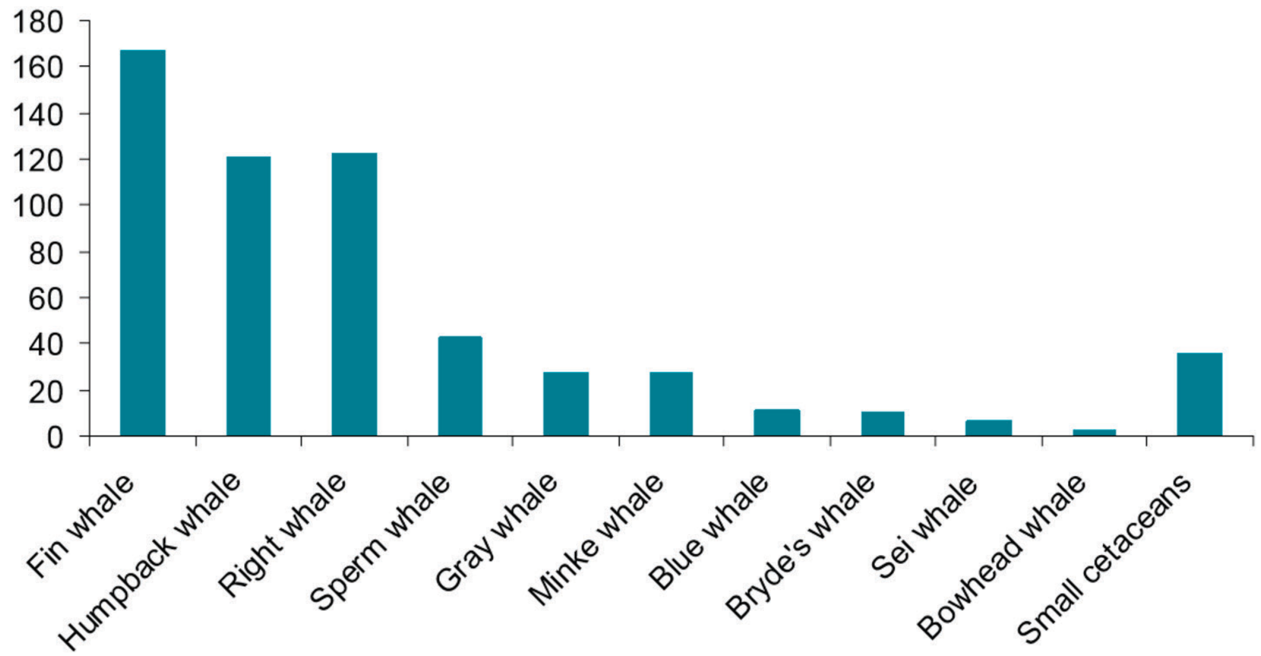

Figure 4: Species involved in vessel strikes documented in the IWC Ship Strikes Database (data analyzed through 2007). Reproduced with permission from: Van Waerebeek, K. and Leaper, R. 2008. *Second Report of the IWC Vessel Strike Data Standardisation Working Group,* Document number SC/60/BC 5 International Whaling Commission, Santiago, Chile, p. 8.

Factors that may affect a species' or individual whale or dolphin's vulnerability to ship strike in a particular location or point of time can include: [35]

- **Age:** Where age classes of ship-struck whales are reported, a disproportionate number of incidents involve immature individuals,[27] indicating that their lack of experience around vessels may render them more vulnerable than adults;[36]
- **Behavior:** Resting individuals may be less alert and more susceptible to ship strikes,[20] as are whales that feed at or near the surface – such as North Atlantic right whales that typically skim feed on copepod prey at the surface of the water;[21]
- **Ambient noise:** High levels of background noise, whether natural or from man-made sources, may mask the sound of an approaching vessel.[37,38]

Assessing mortality rates from shipping is difficult. However, necropsies of stranded whales in most areas of high-density shipping indicate that ship strikes account for 10 to 20 per cent of large whale mortality.[26,39,40] To help quantify the risk of ship strikes in areas where stranding data is unavailable or events are unreported, scientists conduct risk assessments by mapping vessel traffic against cetacean distribution. These mapping exercises allow them to analyze the ships' and the whales' locations and/or movements to develop mathematical and geospatial models of risk.[8,41-43] Vessel traffic data is usually mapped through Automatic Information System (AIS) transmissions (see glossary and more details in Section 1.3) or through shore-based monitoring systems.[44]

Cetacean distribution data to inform the models can be derived from traditional vessel-based or aerial surveys,[45,46] satellite tracked whales,[47] or data that has already been compiled to identify and delineate important habitat for cetacean species vulnerable to ship strike.[41] Risk can be calculated and quantified in a variety of ways. Some studies focus on mapping overlaps in whale and vessel densities while others calculate probabilities of "near-miss events" occurring where whale density modeling or satellite tagging data indicates that whales traversed shipping lanes or came into close proximity with ships.[48,49]

1.2 UNDERWATER NOISE: SHORT-TERM DISRUPTIONS WITH LONG-TERM IMPACTS FOR CETACEANS

Sound travels further through seawater than does light.[50] As a consequence, a wide range of marine species from molluscs to fish to marine mammals rely heavily on sound for communication, navigation, location of prey and avoidance of predators.[51-53] Cetaceans have highly adapted hearing and are particularly dependent on sound for survival.[53] Toothed cetaceans include all species of dolphins and porpoises as well as sperm, pilot and killer whales. They use echolocation to find prey and navigate underwater. Cetaceans using echolocation emit clicks or pulses of sound that are then reflected back to them when they make contact with prey items or other features underwater, allowing them to process the reflected sound and form a 3D image of the object in their path.[54,55] This sensory capability is essential for survival in marine environments that are often too dark and/or too turbid to use visual cues to find food or avoid danger. Toothed cetaceans and baleen whales all rely on underwater sound for communication. Cetaceans can communicate over short distances, for example, as dolphins feed or socialize in tightly formed groups,[56] or over long distances, for example, when baleen whales use low-frequency sound to communicate.[57,58] Cetacean vocalizations can also play an important role in social interactions and reproduction, for example, male humpback whales producing long and complex structured song during their mating season, which is believed to play an important role either in attracting mates or establishing social hierarchies.[59-61]

Because ship noise peaks in the low frequencies used by baleen whales for long-distance communication, initially it was believed that baleen whales would be most sensitive and potentially affected.[53] However, ships also emit energy at higher frequencies in the hearing range of toothed whales, dolphins and porpoises as illustrated in Figure 6. Anthropogenic underwater noise related to shipping can pose a threat to cetaceans in the following ways, illustrated in Figure 7:

1. HEARING IMPAIRMENT

Animals in close range to the source of underwater noise may experience either temporary or permanent damage to their hearing. While underwater noise from shipping has not *yet* been linked to such impairment in whales or dolphins, it has led to documented temporary hearing impairment in seals.[68] Furthermore, some activities associated with shipping (e.g. seismic surveys, pile driving or construction) can cause either temporary threshold shifts (TTS), which are similar to the temporary "deafness" humans experience after a loud concert, or permanent threshold shifts (PTS) when received sound waves are so strong that they cause irreparable physical damage to the auditory organs. As with behavioral responses, TTS and PTS can lead to reduced health and long-term survival both for individual cetaceans and for populations if exposure is repeated over a long term, which is likely to be the case in areas where high densities of vessel traffic and preferred habitats of cetaceans overlap.[62]

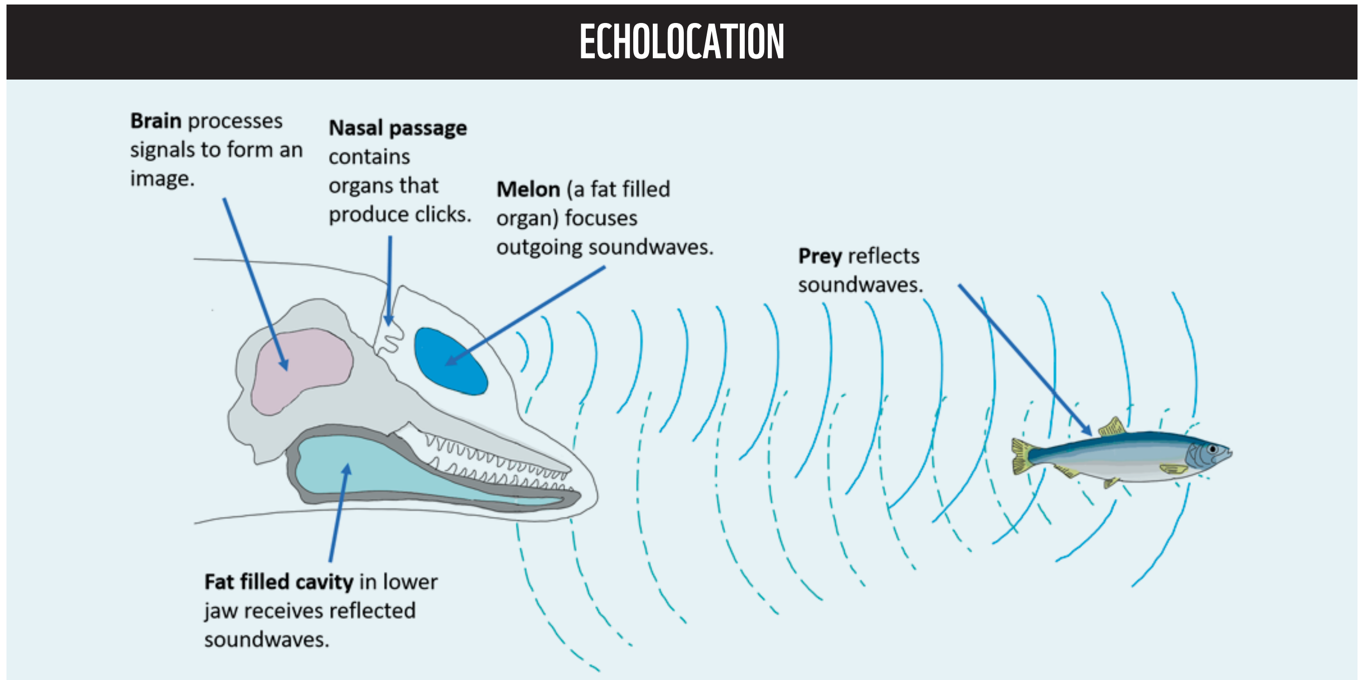

Figure 5: Toothed whales and dolphins use echolocation to navigate and find prey. Underwater noise can interfere with this process. Reproduced with permission from the International Whaling Commission (see https://wwhandbook.iwc.int/en/downloadable-resources/resources-for-guides-and-educators)

2. MASKING

Underwater radiated noise (URN) generated by ships' engines and propeller cavitation can mask and thus interfere with echolocation or communication between cetaceans.[38,62]

3. BEHAVIOR CHANGE AND STRESS

Underwater noise can induce stress and/or behavioral reactions that may include interruption of critical life functions like feeding, resting or socializing in order to move away from the sound source.[62-64] These behavior changes, especially if repeated over time, are likely to have a negative impact on the individual's energy expenditure and long-term health.[65] If a significant proportion of individuals in a population is exposed to the disturbance over a prolonged period, increased stress hormones and the extra energy required to avoid noise could result in lower reproductive rates and eventually population declines.[66] This may be especially true for small populations that have already experienced declines from other pressures.[67]

4. EFFECTS ON PREY

Underwater noise can also affect the fish and other species that form the basis of cetaceans' diets.[69] If these populations are compromised or driven away, cetaceans will also suffer or be forced to move from their preferred feeding grounds.

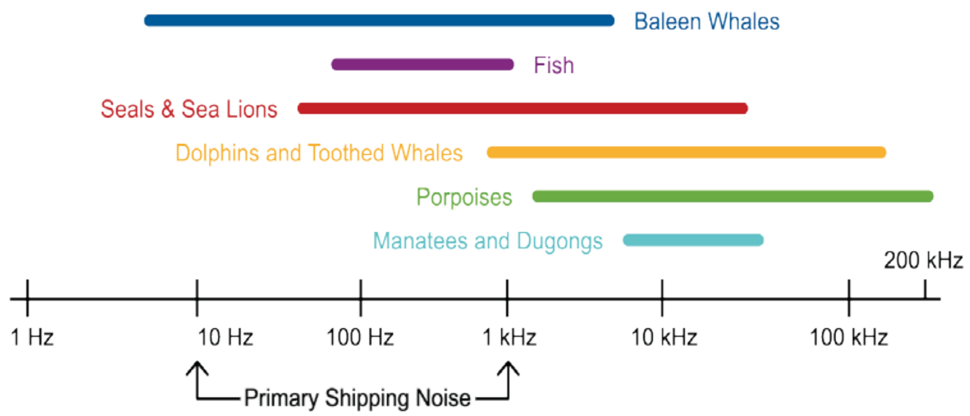

Figure 6: How marine animal sounds, primary shipping noise and surface waves fit into the soundscape. Modified from figure reproduced with permission of B. Southall, NMFS/NOAA.

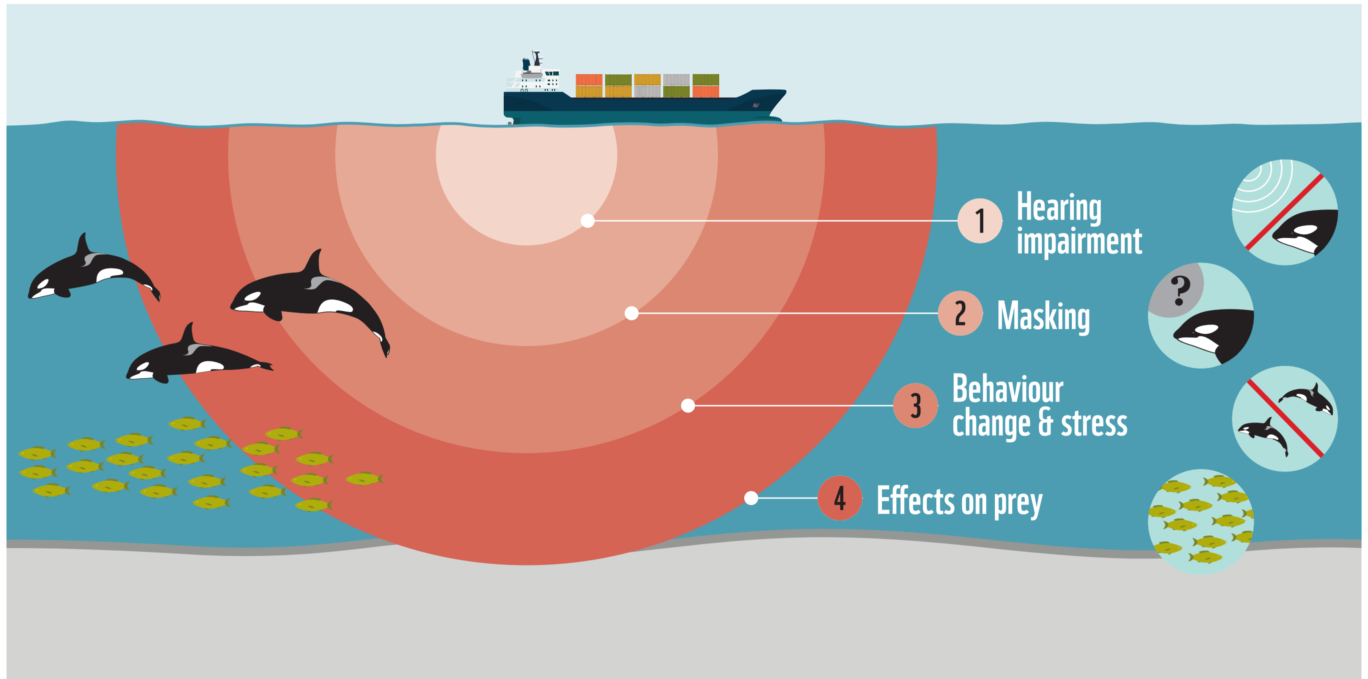

Figure 7: Impacts of underwater noise on cetaceans

With the steady global increase in marine traffic,[2] shipping has been linked to an increase of ambient low frequency (10–100Hz) noise in many regions, with some increases as high as three decibels per decade.[62,70] A 2016 study predicts that increased numbers of vessels traveling further could increase the underwater source-level sound generated by global shipping (particularly from container and bulk carrier ships) by as much as a factor of 1.9 by 2030.[71] This would mean that background noise in the range of baleen whale vocalizations would almost double. Studies have used modeling of received underwater noise against known frequencies of cetacean echolocation and vocalizations to demonstrate masking effects on a number of whale species.[38,62,72] Multiple studies have also documented behavioral changes in several cetacean species in response to vessel noise.[64,65,73-77] In a 2019 review of 154 studies related to the impacts of shipping noise on marine mammals, Erbe et al.[62] note that the (potential) impacts on 47 different species have been studied, with bottlenose dolphins, humpback whales and beluga whales featuring most frequently.

These studies show that responses of cetaceans to vessel noise can vary depending on the species and their behavioral state, location and categories of vessels. Examples of well-documented responses in different species and regions include:

- Humpback whales responded to vessel noise with changes in their vocalizations (increasing volume or ceasing their song),[74,78] cessation of feeding[79] or changes in dive duration, surface behavior, swimming speed or breathing patterns.[75,80]
- Endangered North Atlantic right whales, appeared not to show behavioral responses to either actual or simulated ship noise,[81] potentially putting them at greater risk of ship strikes.
- The Southern and Northern resident killer whale populations on the west coast of Canada and the United States have been the focus of multiple studies documenting decreased foraging, more surface active behavior, and changed breathing and swimming speeds in relation to vessel traffic.[82-86]
- Bottlenose dolphins have been the focus of dozens of studies around the world, although most of these have focused on the impacts of underwater noise generated by smaller watercraft such as whale-watching vessels (summarized in Parsons 2012).[87] In extreme cases, dolphins have been known to abandon an area that was heavily used by whale-watching vessels and other craft.[88]
- Chronic exposure to underwater nose from shipping is linked to increased levels of stress hormones,[89] and stress is likely to increase with the loss of feeding, resting or socializing opportunities associated with noise avoidance.[62] Increased stress is known to make mammals more vulnerable to disease and other impacts,[90,91] and scientists are only beginning to understand how to measure this in free-ranging cetaceans, using biopsy samples or blow samples collected with unmanned aerial vehicles or drones.[92-94]

In summary, the wealth of studies conducted to date unequivocally demonstrate that underwater noise generated by shipping has the potential to cause short-term behavior changes in cetaceans, which in turn are likely to have long-term impacts on individual and population-level well-being and survival. As summarized by Erbe 2019,[62] the detail of how severe these impacts can be, requires an understanding of:

- The species that may be impacted;
- Their auditory and behavioral response to different frequencies of underwater noise;
- How they use the habitat where the shipping noise is generated (e.g. impact will be potentially more significant if it disrupts feeding, resting, nursing or important social interactions);
- The types of vessels that are present and the characteristics of the noise they produce;
- Other physical or oceanographic features that may affect the way the ship noise is propagated and received underwater.

More details on these parameters are provided in Section 3.3. However, to begin with, it is useful to identify the areas where cetacean populations and high densities of vessel traffic are likely to co-occur.

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1.3 GLOBAL RISK: PLACES AND POPULATIONS

The IWC's Strategic Plan to Mitigate Ship Strikes[23] identifies a number of priority whale populations that are thought to be particularly at risk. This strategy uses the following definitions:

High Risk Areas: A High Risk Area is defined as the convergence of either areas of high volume of shipping and whales, or high numbers of whales and shipping. Areas of high volumes of shipping include designated shipping lanes, historic shipping routes and port approaches. Areas of high numbers of whales include areas where whales aggregate, whales are known to return in numbers on a regular basis, or critical population areas or habitats (Russell, 2001).[95] As used herein, the term "High Risk Area" is a relative term with no specific threshold assigned to its use.

At risk populations: An at-risk population is one in which the population viability is at risk due to ship strikes. Viability may be influenced by a number of single or interacting factors including the proportion of a population in high risk areas, populations that are prone to ship strikes, for species that swim slowly or remain at surface for long periods of time (sperm whales, humpback whales, bowhead whales and right whales) or for populations that have a small number of reproductively mature females (e.g. western gray whales, eastern North Pacific right whales, Arabian Sea humpback whales and Chile-Peru right whales).

(Definitions used by the International Whaling Commission in its Strategic Plan to Mitigate Ship Strikes (Cates et al., 2017).)

The IWC has undertaken an analysis of published and unpublished literature to identify specific geographical areas and whale populations where an overlap of heavy shipping traffic and high densities of whales leads to a particularly high risk of ship strikes:[96]

AT-RISK POPULATIONS

1. Blue whales in Sri Lanka[97-100]
2. Bryde's whales in the Hauraki Gulf, New Zealand[33]
3. Sperm whales in the Canary Islands[101,102]
4. North Atlantic right whales[9,103-107]
5. Humpback whales in Panama[49]
6. Blue whales in the Eastern North Pacific[8,108,109]
7. Mediterranean High Risk Areas
   - Sperm whales and fin whales in the Strait of Gibraltar[25]
   - Fin and sperm whales in the Eastern Alboran Sea[110]
   - Fin and sperm whales around the Balearic Islands[110]
   - Fin and sperm whales in the northwest Mediterranean[24,48,181]
   - Fin and sperm whales in the Hellenic Trench, Greece[111,112]
8. Right whales in the southeast Pacific (Chile-Peru)[96,113]
9. Arabian Sea humpback whales[98]
10. Western gray whales feeding around Sakhalin Island[9,114]
11. Right whales in the Eastern Bering Sea[115,116]
12. Bowhead whales and other cetaceans in the Arctic[14,117]
13. Omura's whales in Northwest Madagascar[118,119]
14. Bryde's whales in the Gulf of Mexico[120]

These analyses on co-occurrence of whales and high densities of shipping were undertaken primarily with a focus on the risk of ships strikes. While no specific global analysis has been undertaken in the same manner to focus on shipping-related underwater noise hotspots, it is highly likely that these areas of whale and ship co-occurrence also present high-risk areas for disturbance to cetaceans from underwater noise.

A recent analysis of vessel traffic density that overlaid AIS data from one year with the boundaries of Important Marine Mammal Areas helped to highlight potential risks of ship strikes.[121] This analysis identified some potential high-risk areas in the Indian Ocean and Asia that had not previously been highlighted in global ship-strike risk assessments.

HIGH RISK AREAS FOR SHIP STRIKES

The International Whaling Commission (IWC) has undertaken an analysis of published and unpublished literature to identify specific geographical areas where an overlap of heavy shipping traffic and high densities of whales leads to a particularly high risk of ship strikes. These areas should be targeted for mitigation efforts:

MEDITERRANEAN

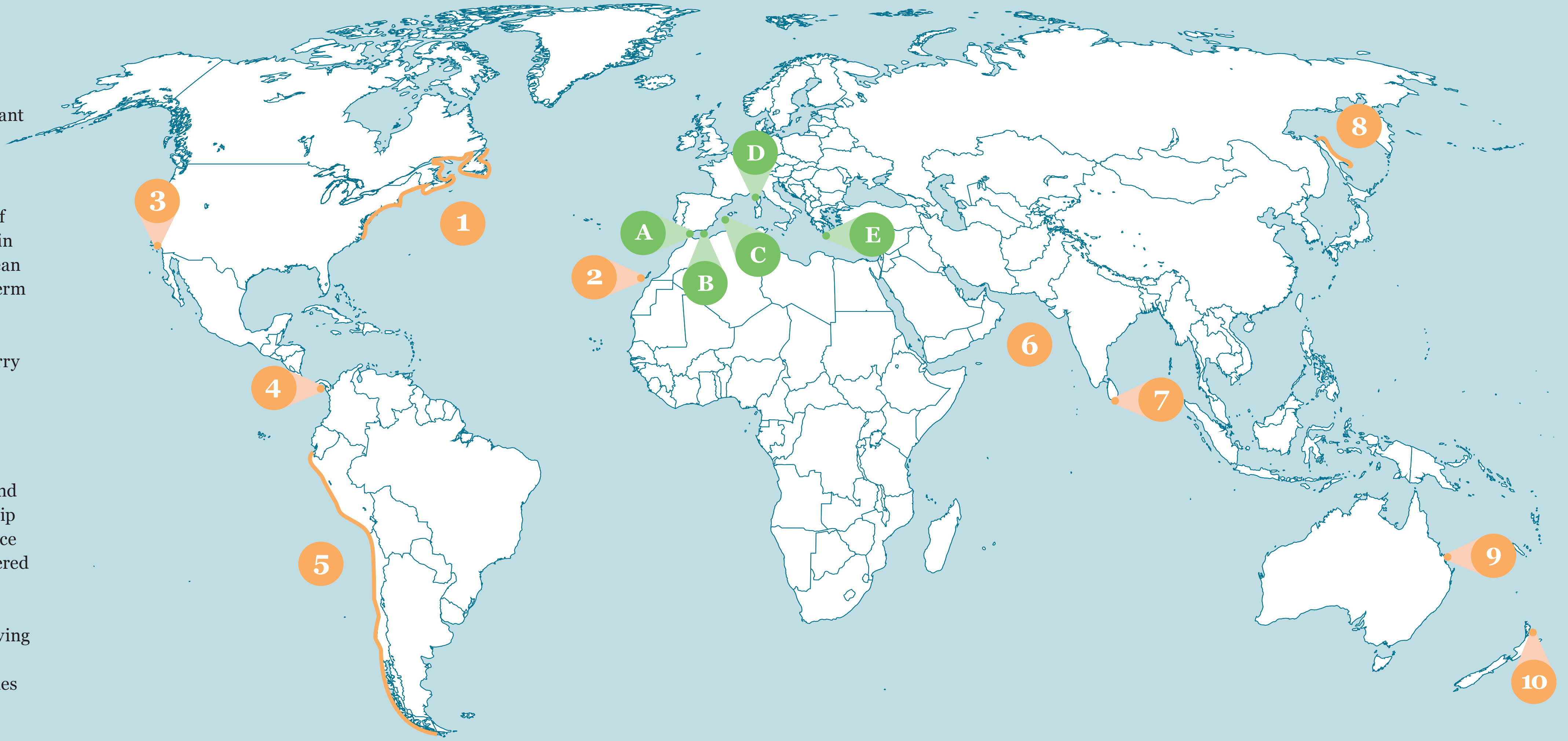
A Sperm whales in the Strait of Gibraltar: More than 90.000 ships cross the Strait annually in an important feeding ground.

B Cetaceans in the Alboran Sea: This is one of the main cetacean hotspots in Europe and the Mediterranean – particularly for fin and sperm whales and vessel traffic is exponentially increasing – particularly ferry and fastferry lines.

C Fin and sperm whales around the Balearic Islands: Both occur around these islands together with high levels of shipping and fast ferry traffic.

D Fin and sperm whales in the North West Mediterranean Sea, Slope and Canyon System IMMA and the Pelagos Sanctuary: Both of these isolated and endangered populations are at risk of collision with cargo vessels, tankers and particularly high speed passenger ferries throughout the area.

E Endangered sperm whales in the Hellenic Trench, Greece: These deep waters of Greece are an important feeding ground, but also host some of the Mediterranean's busiest shipping routes.



1 North Atlantic right whales: With a population thought to be hovering around or under 500 individuals, ship strikes are a significant source of mortality for this endangered population. A number of mitigation measures are already in place and are proving effective for this population, offering examples of strategies for other high-risk areas.

2 Sperm whales in the Canary Islands: Mortality from ship strikes caused predominantly by high-speed ferries is thought to be unsustainable in this area with an abundance estimate of just over 200 whales.

3 Eastern North Pacific blue whales: Fatal collisions with vessels is a known source of mortality for this population.

4 Humpback whales in the Gulf of Panama: Analysis of AIS data (shipping tracks) and movements of 15 satellite tagged whales indicated that 8 individuals had 98 encounters within 200m of 81 different vessels in just 11 days. This study was able to help convince authorities to move the shipping lane to an area with lower whale densities.

5 Southern Pacific right whales: Collisions with vessels and entanglements in fishing gear are the leading causes of human-induced mortality of this critically endangered population of around 50 individuals.

6 Arabian Sea humpback whales: Fewer than 100 whales remain off the coast of Oman after illegal Soviet whaling in the 60's and the construction of new ports causes concern in this region which hosts some of highest densities of oil tankers and other types of cargo transport in the world.

7 Blue whales in the Northern Indian Ocean: Distinct from those in the Southern Hemisphere, their core habitat overlaps directly with busy shipping lanes. Routing measures have been proposed but not yet adopted.

8 Western gray whales: This small remnant population may be showing slow signs of recovery, but its low numbers (latest estimate is 174) mean that it cannot sustain any additional mortality from ship strikes - a risk in this region where oil and gas extraction occurs in the population's only known feeding ground.

9 Humpback whales around the Great Barrier Reef: While humpback whales off both coasts of Australia are showing strong recovery after whaling, conservative estimates predict a doubling of shipping traffic in the region by 2025, posing a mounting threat to these whales in their breeding grounds.

10 Bryde's whales in the Haruaki Gulf: 85% of deaths for which a cause of mortality could be determined, were caused by vessel-strike; unsustainable for this endangered year-round population.

Figure 8: Map depicting known risk areas for ship strikes based on the IWC's Strategic Plan to Mitigate Ship Strikes[23] and formatted by WWF in 2018. While the map refers specifically to ship-strike risk, it is likely that these same areas represent areas where ship-generated underwater noise has negative impacts on whale populations.

2. FRAMEWORKS FOR ACTION

Understanding the threats that shipping poses to cetaceans, together with the potential hotspots where these risks are concentrated, is an important first step to reducing threats. However, as shipping is almost by definition an international activity, addressing the threats requires an international response. Here we provide a brief overview of the most relevant frameworks that provide mechanisms to mitigate the risks of ship strikes and shipping-generated underwater noise.

2.1 INTERNATIONAL FRAMEWORKS

Three main international intergovernmental bodies are concerned with assessing and recommending action to mitigate the threats posed by shipping to cetaceans on a global scale: the International Maritime Organization (IMO), the International Whaling Commission, (IWC) and the Convention on Migratory Species (CMS).

The International Maritime Organization (IMO)

The IMO is the United Nations' specialized agency with responsibility for the safety and security of international shipping and the prevention of marine and atmospheric pollution by ships. Its main role is to create a regulatory framework for the shipping industry that is universally adopted and implemented. The IMO's Marine Environment Protection Committee considers ship strikes to cetaceans and underwater noise. The IMO has determined several formal measures that can be put in place to reduce the risk of ship strikes to cetaceans, which have been formalized in a 2009 guidance document.[122] Generally recommended measures fall into two broad categories, routing measures and speed restrictions, which can be either mandatory or voluntary. The formal categories of routing measures defined by the IMO are summarized in Section 3.2.1.

In 2014, the IMO issued *Guidelines for the reduction of underwater noise from commercial shipping to address adverse impacts on marine life*.[123] These guidelines are voluntary and research shows that they are not being followed in many instances, largely because they are not mandatory and lack measurements or limits to be followed. In December 2019, Australia, Canada and the United States submitted a proposal to review and update these guidelines so that they better reflect new available technologies, address the urgent need to respond to climate change, and improve implementation and regulatory effectiveness.[124]

The IMO has also set a target to reduce the total annual greenhouse gas emissions from international shipping by at least 50 per cent by 2050 compared to 2008 values, while at the same time pursuing efforts to phase them out entirely. This target may help to drive the industry to adopt measures that will also reduce ship-strike risk and underwater noise associated with shipping.[125]

The International Whaling Commission (IWC)

With more than 80 members, the IWC is an intergovernmental organization (IGO) established in 1946 under the International Convention for the Regulation of Whaling. While its initial aim was to foster scientific understanding of whale populations and collaboration to support sustainable whaling, the body now also has a mandate for a range of conservation initiatives,[126] including a Bycatch Mitigation Initiative; ship strikes working group; strategic plan to mitigate ship strikes;[23] resolution on underwater noise (Resolution 2018-4); and a commitment to work with the IMO on issues related to ship strikes and underwater noise. The IWC has a Ship Strikes Working Group that was convened in 2005. This group maintains a Ship Strikes Database, which was launched in 2007.[28] It also has a Strategic Plan to Mitigate the Impacts of Ship Strikes on Cetacean Populations, which identifies a number of priority at-risk regions and populations, and formally establishes intentions to collaborate with other IGOs to mitigate threats, including CMS; the Agreement on the Conservation of Cetaceans of the Black Sea, Mediterranean Sea and Contiguous Atlantic Area (ACCOBAMS); Agreement on the Conservation of Small Cetaceans of the Baltic, North East Atlantic, Irish and North Seas (ASCOBANS); and the International Union for Conservation of Nature (IUCN) Marine Mammal Protected Areas Task Force.[23] Key elements of the strategic plan include to:

- initiate efforts to get more comprehensive and accurate reporting of ship-strike incidents into the Ship Strikes Database;
- review records of ship strikes and add new records to the database in a reasonable time frame;
- improve the reliability of species identification of ship-struck whales;
- maintain an easily assessable compendium of relevant papers and reports of ship-strike issues;
- produce an updated bibliography related to ship-strike issues on a two-year schedule;
- implement a standard protocol for reviewing and recording data into the Ship Strikes Database; and
- publish summary statistics from the Ship Strikes Database on a routine basis, and couple this with outreach efforts.

The Convention on the Conservation of Migratory Species of Wild Animals

Also known as the Convention on Migratory Species (CMS) or the Bonn Convention, this is an international agreement to conserve migratory species within their migratory ranges. The Agreement was signed under the auspices of the United Nations Environment Programme (UNEP) and is focused on the conservation of wildlife and habitats on a global scale. It has two regional agreements that focus specifically on cetacean conservation: the ACCOBAMS and ASCOBANS. The CMS addresses the risk of ship strikes in its Global Programme of Work for Cetaceans, and ASCOBANS and ACCOBAMS are both actively engaged in monitoring and mitigating ship strikes in the ranges covered by their agreements.

The CMS has taken active measures to address the issue of underwater noise, most recently through Resolution 12.4 on the Adverse Impacts of Anthropogenic Noise on Cetaceans and other Migratory Species.[127] This resolution informs the CMS global programme of work on cetaceans, as well as the work of a joint CMS, ASCOBANS, ACCOBAMS underwater noise working group.[128] The CMS has also provided useful guidelines on mitigating underwater noise through its *CMS Family Guidelines on Environmental Impact Assessment for Marine Noise-generating Activities,*[129] which are further underpinned by a follow-up document: *Technical Support Information to the CMS Family Guidelines on Environmental Impact Assessments for Marine Noise-generating Activities.*[130]

2.2 REGIONAL FRAMEWORKS

The European Union (EU)

The EU has been promoting research into the mitigation of underwater noise, including from shipping. The EU Marine Strategy Framework Directive (MSFD) provides a definition of Good Environmental Status in relation to biological diversity,[131] which includes several standards and measures related to underwater noise. Descriptor 11 of the MSFD pertains to underwater noise and requires member states to establish threshold values to ensure that the spatial distribution, temporal extent and levels of anthropogenic continuous low-frequency sound do not exceed levels that adversely affect populations of marine animals.[132] European regional seas organizations such as the OSPAR Convention and the Helsinki Commission (HELCOM) have embraced the issue of underwater noise under the impetus of the MSFD and promote regional coordinated implementation of the directive objectives.

The Arctic Council

The eight Arctic states (countries) are members of the Arctic Council: Canada, the Kingdom of Denmark (including Greenland and the Faroe Islands), Finland, Iceland, Norway, the Russian Federation, Sweden and the United States. With working groups on Protection of the Arctic Marine Environment (PAME), Conservation of Arctic Flora and Fauna (CAFF) and Sustainable Development (SDWG), the Council has an important role to play in regulating shipping in the region. Since 2017, underwater noise has been on the agenda of the PAME working group. The IMO's Polar Code[133] applies both in the Arctic and the Antarctic and requires marine mammal distribution to be considered when voyage planning. Concerns about increased shipping in the Arctic due to climate change and retreating sea ice increase the urgency and importance of the Arctic Council's work.[14,117]

A pod of endangered Humpback Dolphins *(Sousa)* taken from the air in shallow waters.

2.3 NATIONAL FRAMEWORKS

Article 17 of the United Nations Convention on the Law of the Sea (UNCLOS) requires all countries to grant the right of "innocent passage" through their territorial waters. Article 22 also indicates that countries may require ships exercising that right of passage to use designated sea lanes or Traffic Separation Schemes (TSS) for the safety of navigation. However, the article directs countries to "take into account the recommendations of the competent international organization" when doing so. This means that in many cases only the IMO has the authority to designate routing measures, speed reductions or other noise reduction measures to reduce the impacts of shipping on whales in marine habitats. Nations may, however, employ port State control under international law to enforce certain laws within their waters. Countries interpret this differently. Several countries, including the US (which is not a signatory of UNCLOS) and Canada, interpret port State authority to include laws to protect the environment and thereby, cetaceans.[134-136]

There are several legal and regulatory frameworks, including environmental standards, endangered species and marine mammal protection laws that individual countries can use at the national level. They can also ensure that species potentially impacted by shipping are designated as conservation priorities, and are well-studied and monitored, so that the data required to propose measures to the IMO is available when it is needed. These frameworks vary greatly between countries and are not summarized in this report.

2.4 INDUSTRY-BASED FRAMEWORKS

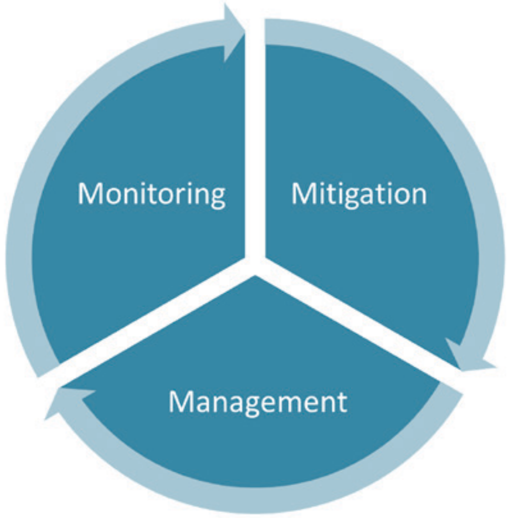
Where international, regional or national measures fall short, industry-led standards can promote best practice for reducing ship-strike risk and underwater noise related to shipping. Industry-led initiatives can include:

- **Certification programs:** Several certification programs offer ship owners and port authorities incentives to adhere to environmental standards.
- **Ports modeling best practice:** Even without the incentive of certification schemes, some ports around the world have modeled best practice with respect to reducing the risk of ship strikes and the impacts of underwater noise in their spheres of operation.
- **Classification Societies**: Shipping Classification Societies are licensed by flag states to classify and certify marine vessels based on their structure, design and safety standards. A limited number of certifications are available for underwater noise standards.
- **Fleet and Company Protocols:** Individual fleets and companies may have protocols to deal with encounters of marine mammals in their operations. These efforts as part of broader Corporate Social Responsibility can include voyage planning, use of mariner guides, reporting of encounters and protocols to modify operations. Several companies also train their mariners to be more aware of marine mammals.

These industry-led incentives are discussed in more detail in Section 3.5.

3. MONITORING, MITIGATION AND MANAGEMENT MEASURES

Whether addressing ship strikes or underwater noise, effective management should be based on a three-phase cycle with the following components:



- **Monitoring** or collection of baseline data on the distribution and density of vessel traffic as well as the monitoring of the cetacean species potentially impacted by those vessels.
- Selection and implementation of **mitigation** measures appropriate to reduce threats and suitable for the biological, geographical and political context.
- Establishment of a **management** regime supported by the legal tools and strategies that enable and encourage the monitoring tools and mitigation measures to be effectively applied.

The following sections focus on the available options for each of these components of the cycle in relation to ship strikes and shipping-generated underwater noise.

3.1 MONITORING TECHNOLOGIES

3.1.1 MONITORING VESSEL MOVEMENTS

Technologies for monitoring vessels are constantly evolving and adapting. The most commonly used tool for monitoring and assessing vessel traffic patterns around the globe is the Automatic Identification System (AIS). Originally established to ensure maritime safety and traffic management, it is now used for a wide range of analyses that inform conservation as well as industry.[137]

Vessels of 300 gross tonnage or more sailing on international voyages, as well as cargo ships of 500 gross tonnage or more sailing in local waters, and all passenger ships irrespective of size, are required by the IMO to carry AIS equipment. Although vessels transmit information through VHF (Very High Frequency) Radio, AIS transceiver data collected from satellite and internet-connected shore-based stations is aggregated and made available on the internet to authorized users through several service providers. Information transmitted by vessels over AIS includes dynamic data (e.g. vessel position [GPS], ground speed, course, true heading, angular rate of turn), static data (e.g. the Maritime Mobile Service Identity Number [MMSI], the IMO registration number, its radio call sign, the name of the ship, the vessel and its dimensions) and data manually entered by the operator (e.g. navigation status, destination, expected time of arrival at destination and draft).

A separate Vessel Monitoring System (VMS) has been set up for fisheries. This system is also used for smaller vessels. However, requirements for VMS use by fishing vessels vary from one country to another and VMS is not used by the container ships and tankers most commonly implicated in ship strikes.[23] As such, it is not often used in ship-strike or underwater noise risk assessments.

Data can be viewed on a broad scale to assess global marine traffic patterns or on a finer scale to assess the signatures, speed of travel and movements near known concentrations of vulnerable cetaceans of individual vessels. However, it should be noted that smaller vessels, not required to carry AIS can also be involved in ship strikes and generate potentially disturbing underwater noise. Additional tools are required to monitor the potential impact of these vessels and can include shore-based vessel monitoring using marine-radar sensors linked to a high-definition camera, as has been the case in the San Francisco Bay,[44] the use of satellite imagery to assess vessel distribution,[47,138] or more basic technology including human observers, as currently underway in Alaska, where Indigenous groups help to monitor marine traffic.[139]

3.1.2 COLLECTING AND ASSESSING DATA ON WHALE POPULATIONS FOR USE IN RISK ASSESSMENT AND MODELING

Data on cetacean distribution for use in models to assess shipping risk to cetaceans can be derived from a wide range of sources. In areas where dedicated cetacean research has been prioritized, data can be quite precise and includes abundance estimates as well as insight into seasonal shifts in distribution and population trends. This is the case in most of the marine areas around North America and Europe, where government policy and regulations require the regular monitoring of marine mammal populations. In these data-rich areas, understanding of cetacean distribution can be based on the results of ship-board or aerial line-transect surveys,[140] long-term photo identification studies,[141] satellite tagging and monitoring of individual whale's movements,[8,47] or analysis of stranding patterns and causes of mortality of stranded whales.[39,142] Data can also be collected from platforms of opportunity, such as seismic survey vessels staffed by marine mammal observers[143,144] or whale-watching vessels.[145] New technology is also emerging to allow whale detection through Infrared or thermal imaging on these platforms of opportunity, potentially increasing the amount of data that can be collected even during poor sightings conditions.[146-149]

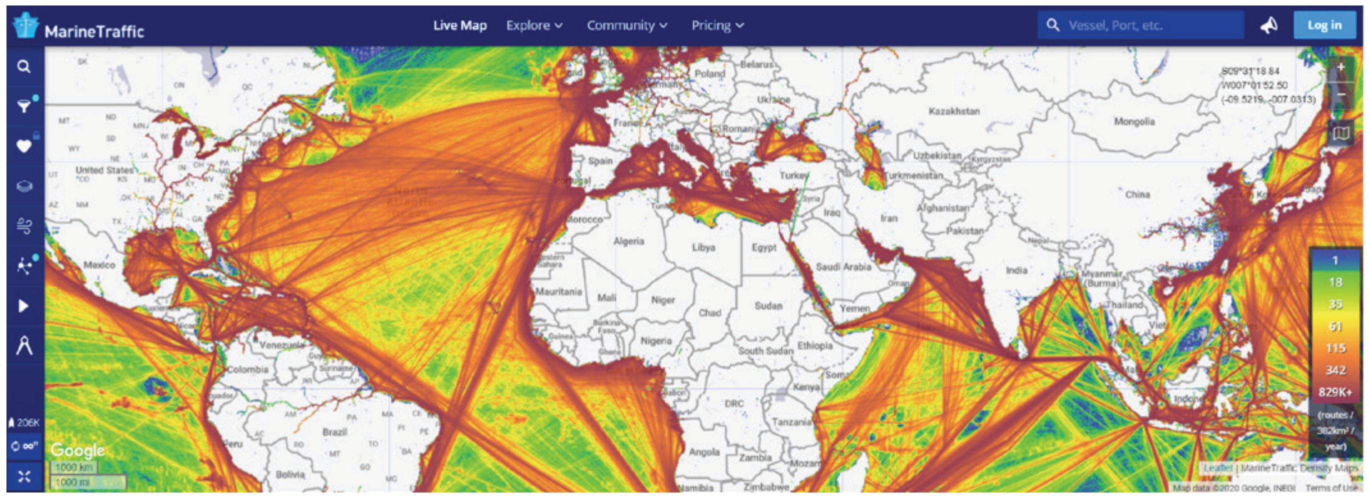


Figure 9: Example of publicly available AIS data from Marinetraffic.com showing densities of vessel traffic from 2017, viewed 3 April 2020.

Data on cetacean distribution can also be derived from (passive) acoustic monitoring to detect whale vocalizations,[150] a methodology that can be operable for longer time periods with almost no restrictions from weather conditions or visibility. A passive acoustic recording device, illustrated in Figure 10, can be left unattended.

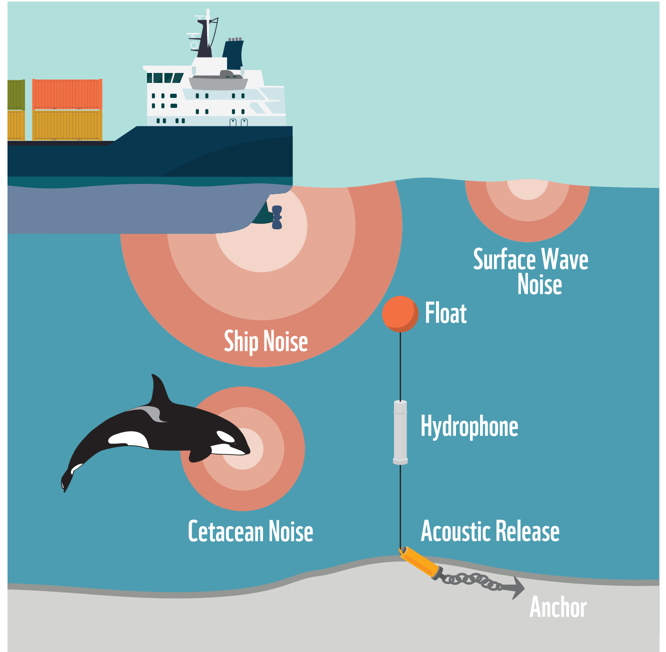


Figure 10: Passive acoustic recording devices can be used for long term monitoring of noise from cetaceans and from ships

In areas where little or no dedicated cetacean research has been conducted, historical whaling data or publicly available global sightings databases can be consulted, such as OBIS Seamap.[151] However, older datasets may not accurately capture current distributions or densities, which change as populations grow or decline and/or shift in relation to climate change and/or other external parameters. Alternatively, habitat models can be used to predict the presence of vulnerable whale species in surveyed areas based on their known presence in other similar habitats.[100]

Finally, the presence of Important Marine Mammal Areas, Ecologically or Biologically Significant Marine Areas or Key Biodiversity Areas that specify cetaceans (specifically large whales) as one of the qualifying species, can also be used as proxy indicators of cetacean distribution[152] and used as a basis to identify potential risk areas.[121]

3.1.3 MONITORING UNDERWATER NOISE

Several different methods exist to monitor underwater noise related to shipping. Noise measurements can be taken from individual vessels to understand the levels of URN emitted by different classes of vessels.[153,154] Passive acoustic recorders can also be placed in strategic locations to record and monitor vessel noise – either in areas of high vessel density locations around ports,[155-157] or areas of known or suspected importance for vulnerable whale species.[158,159]

It is important to note that noise propagation from anthropogenic sources is strongly influenced by static and dynamic factors such as local bathymetry, noise from other marine organisms and oceanographic conditions (such as temperature, salinity, currents, ice, tide and wind/wave action). Combined with the knowledge that underwater noise can propagate over large distances, measured noise at any place or point in time may not be representative of the conditions permanently present in a cetacean's habitat over time. For this reason, modeling that uses measured sound levels to map an underwater soundscape which incorporates the various static and dynamic influences in a statistically robust manner generates a more comprehensive understanding of a cetacean's likely received noise levels than single point measurements.

Furthermore, in locations where underwater shipping noise has not been measured empirically through passive acoustic recording, researchers can combine published data on levels of URN with AIS density data from different categories of vessels to model the soundscape and potential impact in areas of importance for cetacean populations.[160-162] One example is the Quonops Online Services© that provides publicly accessible underwater noise maps at local or regional scales (see https://qos.quiet-oceans.com).

3.2 SHIP-STRIKE MITIGATION MEASURES

Generally, mitigation falls into three broad categories: 1) Measures that keep vessels away from whales; 2) Measures to slow vessels down in the (possible) presence of whales; and 3) Avoidance manoeuvres in response to the (reported) presence of whales.

The IWC's Strategic Plan to Mitigate the Impacts of Ship Strikes on Cetacean Populations[23] outlines seven key stages in identifying high-risk areas for ship strikes and mitigating the threats within those areas, which provides a useful framework for determining the tools required to reduce the threat of ship strikes and underwater noise from shipping to cetaceans.

In concert with this effort, the IWC has produced a useful table summarizing the different measures that can be implemented to reduce the risk of ship strikes to cetaceans (see Appendix 2).

Stage 1	High-risk area of potential concern identified based on overlap of shipping and whale distribution or a high number of reported incidents.
Stage 2	Survey data for whales, AIS data for shipping used to inform risk analysis and local vs international jurisdiction.
Stage 3	Consideration of possible practical options based on risk analysis. Recommendations from IWC Scientific Committee, IWC approaches relevant states to offer information and advice.
Stage 4	Stakeholder workshops to discuss possible mitigation measures and optimize risk reduction with stakeholder interests.
Stage 5	Relevant states consider proposals to IMO assisted by supporting information from IWC.
Stage 6	Measures implemented through IMO.
Stage 7	Continued monitoring to evaluate ongoing effectiveness of measures.

Table 1: Stages in identifying high-risk areas and developing appropriate mitigation strategies. Source: Cates, K., DeMaster, D.P., Brownell Jr, R.L., Silber, G.K., Gende, S., Leaper, R., Ritter F. and S. Panigada. 2017. Strategic Plan to Mitigate the Impacts of Ship Strikes on Cetacean Populations: 2017-2020, International Whaling Commission, Cambridge, United Kingdom.

3.2.1 MEASURES TO KEEP SHIPS AWAY FROM WHALES

The most effective way to reduce the risk of ship strike is to ensure that ships cannot encounter whales by separating them in time and space. Measures to keep ships away from whales can fall into different categories depending on whether they are permanent, seasonal or dynamic, and whether they are voluntary or mandatory. Voluntary measures can be encouraged and adopted by the shipping industry through certification schemes or port authorities wishing to encourage best practice in their spheres of influence (see Section 3.5). They can also be promoted by national governments or IGOs like the IMO.[122]

Article 17 of the United Nations Convention on the Law of the Sea (UNCLOS) requires coastal nations to grant the right of innocent passage through their territorial waters, with limited capacity to designate mandatory shipping lanes or areas to be avoided for safety reasons without formal approval from the IMO. As such, nations wishing to implement measures to keep ships away from whales must present their case to the IMO, which has a range of legally binding and voluntary measures to reduce ship strikes.[122]

The IMO has defined the following categories of routing measures to reduce risks to vessels, habitats or wildlife (see the IMO website: http://www.imo.org/en/OurWork/Safety/Navigation/Pages/ShipsRouteing.aspx and/or MSC/Circ.1060, as amended Guidance note on the preparation of proposals on ships' routeing systems and ship reporting systems):

- **Traffic Separation Scheme (TSS):** a routing measure aimed at the separation of opposing streams of traffic by appropriate means and by the establishment of traffic lanes.
- **Traffic lane:** an area within defined limits in which one-way traffic is established. Natural obstacles, including those forming separation zones, may constitute a boundary.
- **Separation zone or line:** a zone or line separating traffic lanes in which ships are proceeding in opposite or nearly opposite directions; or separating a traffic lane from the adjacent sea area; or separating traffic lanes designated for particular ship classes proceeding in the same direction.
- **Recommended route:** a route of undefined width, for the convenience of ships in transit, which is often marked by centreline buoys.
- **Precautionary Area:** an area within defined limits where ships must navigate with particular caution and within which the direction of flow of traffic may be recommended.
- **Area to be avoided (ATBA):** an area within defined limits in which either navigation is particularly hazardous, or it is exceptionally important to avoid casualties, and which should be avoided by all ships, or by certain classes of ships.

The IMO also has a formal designation for an area of high or vulnerable biodiversity where shipping measures could or should be considered: **Particularly Sensitive Sea Area (PSSA).**[163] This is identified by the IMO as "an area that needs special protection through action by IMO because of its significance for recognized ecological or socio-economic or scientific reasons and which may be vulnerable to damage by international maritime activities." PSSAs are proposed by the government(s) of the area in question. The IMO has designated 17 PSSAs to date, which are depicted in Figure 11.

The processes for formal IMO designation of TSSs, PSSAs or ATBA require a great deal of collaboration between researchers who can provide evidence of a credible risk/reason for concern, regional stakeholders, national governments who need to make the formal application for the desired status, and the IMO, which has to evaluate the application and decide on the appropriate measure.

Seasonal routing measures are alternatives to permanent TSSs, ATBA that are usually defined by fixed calendar dates known to coincide with migration patterns of whale populations. These rely on good quality long-term datasets proving predictable migration patterns and site fidelity to areas used for feeding, breeding or migration.

Dynamic routing measures can be even more flexible and can be brought into play as and when whales are observed in an area. These have the advantage of being able to adapt to recent observed changes in the timing and exact location of whales' migration and feeding grounds related to climate change.[164] However, they are difficult to encode in IMO or national regulations and as such are usually voluntary. They require reliable and rapidly communicated detection and reporting schemes, so may not be realistic to employ in all parts of the world.

Where routing measures are not embedded in national or IMO regulation, they can also be applied on a voluntary basis with incentive schemes to encourage compliance (see Section 3.5).

With all routing measures, it is of great importance when proposing a shift in vessel traffic, that assessments are robust[165] and that good data is available for **all** species that might be affected by ship strike or impacted by shipping noise. Without a full understanding of the (seasonal) distribution of all the species in the region, removing the risk for one species (e.g. humpback whales with a nearshore distribution) might displace that risk to another species (e.g. sperm whales with an offshore distribution). The IWC Scientific Committee has established a ship routing group that can provide advice on any proposed changes to routing systems with respect to possible risks to cetaceans.

Figure: IMO designated Particularly Sensitive Sea Areas as of April 2020. Note that the extension of Torres Strait to the Great Barrier Reef PSSA (2005) is not included on this map.

3.2.2 SPEED RESTRICTIONS

If ships cannot be kept away from whales, reducing their speed can reduce the risk of ship strikes. Studies have demonstrated that reducing speed to 10 knots or slower can reduce the risk of a lethal ship strike.[22,166,167]

Speed restrictions fall into three categories:

- **Permanent speed restrictions** in zones where a high risk of collision has been identified, and risk is present year-round. These are appropriate in areas where patterns of whale distribution are predictable and well-understood. Nations can enforce speed restrictions in their own territorial waters (usually up to 12 nautical miles from shore). This approach can be effective in many settings, as approaches to ports, where vessel traffic is often concentrated, are most often located in territorial waters, and many vulnerable whale species are also concentrated in nearshore areas during their breeding and feeding activities. However, all nations have a duty provide "innocent passage" to vessels traveling through their Exclusive Economic Zone and as such, only the IMO has authority to enforce speed restrictions beyond any nation's territorial waters (through the implementation of a PSSA, for example).
- **Seasonal speed restrictions** can be implemented during the seasonal presence of migratory whales on their breeding or feeding grounds, or during peak densities in migration corridors.
- **Dynamic speed restrictions** can be implemented in response to real-time observations of (aggregations) of whales, and as with the dynamic routing measures (see 3.2.1), are generally voluntary. These depend on a reliable reporting network or technology and good communication with ports and vessels.

In addition to reducing the risk of (lethal) ship strikes, speed restrictions generally reduce underwater noise as well as carbon emissions.[125] These synergistic benefits are discussed in more detail in Section 3.4.

3.2.3 REAL-TIME DETECTION AND ALERTING MEASURES

There has been much interest in developing real-time whale detection technologies so that vessels can avoid areas where whale sightings have been made or engage in avoidance manoeuvres. These measures are based on the assumption that vessels could alter their course or speed in time to avoid interaction with the whales, an assumption that may be flawed in the case of vessels of several thousand gross tonnage, and whales that may continue moving in unpredictable directions after they are first detected. Nonetheless, real-time methods for whale detection can be:

- **Observer based:** requiring an observer on board to keep watch and sound the alert when whales are detected. Infrared technology also allows real-time detection of whales in low-visibility situations. However, ship-based real-time detection may not provide sufficient time for vessels to take appropriate evasive action. As such, these systems are limited in their practical application to small maneuverable vessels.
- **Technology based:** using acoustic buoys or other passive acoustic devices to detect whales acoustically and send out an alert to all vessels/mariners in the region so that they can take measures to avoid the areas where whales have been observed. While this technology has proved accurate in detecting whales,[168] its effectiveness to alter vessels' speeds and movement and thus reduce ship-strike risk relies on the effectiveness of communication channels that are chosen and the receptiveness of vessel captains/crew to adapt their behavior.[169]
- **A combination of observer- and technology-based alerts:** in which the first vessel to detect a whale through on-board observers uses specialized equipment and software to transmit messages to surrounding vessels that can then slow down or engage in avoidance measures. However, more information is required in such a system to ensure that the alternative route chosen by a vessel does indeed reduce the risk of encountering a whale.

Two real-time detection and alert systems that have been tested in the United States and the Mediterranean are Whale Alert and Repcet. Whale Alert is featured in the case study on North Atlantic right whales in Section 4.2. Repcet is a system developed to mitigate the risk of ship strikes in the Pelagos Sanctuary in the Northwest Mediterranean. While Repcet's use is mandatory for certain categories of vessels in the Pelagos Sanctuary in the Mediterranean and the AGOA Sanctuary in the Caribbean, its effectiveness has not been proven to date.[48,170]

3.3 UNDERWATER NOISE REDUCTION MEASURES

Measures to move ships away from whales will also result in reduced exposure to noise and are effective tools for reducing the impact of shipping-generated underwater noise on cetaceans. An additional approach is to reduce the noise of the ship itself.

3.3.1 MEASURES TO KEEP SHIP NOISE AWAY FROM WHALES

Area-based measures are generally accepted as one of the most effective ways to reduce the impact of noise on cetaceans.[13,171,172] As such, the measures described in Section 3.2.1 should also be considered effective noise-reduction measures. The official designation of PSSAs, ATBA, TSSs, Separation Zones or the moving of traffic lanes away from important cetacean habitat can all help to reduce exposure to underwater noise as well as the risk of ship strikes.[173]

3.3.2 VESSEL DESIGN AND MAINTENANCE FEATURES TO REDUCE UNDERWATER NOISE

Where ships cannot be kept away from whales, measures to reduce underwater noise from vessels usually focus on technical adaptions to vessel design that will allow them to operate more quietly. Vessels propagate underwater noise through three main categories of their operation:[174]

- Noise generated by the propeller;
- Noise generated by the engine and other machinery;
- Noise generated by the movement of the hull through water.

Of these three categories, the noise generated by a cavitating propeller is usually the most significant and is the most frequent focus of mitigation efforts, followed by hull design and changes to the engine/machinery of the ship.[174,175] Propeller-induced cavitation occurs when bubbles rapidly form and collapse as the propeller turns to move the vessel forward. The diameter, blade number and pitch/angle of the propeller can all affect the intensity of this cavitation, as can the shape of the vessel's hull, which determines how water flows around the vessel and toward the propellers at the back of the vessel.

Research vessels and war ships use a range of methods to navigate as quietly as possible, but many of the adaptations they use reduce efficiency and require more fuel, thus incurring cost and increasing CO_2 emissions. As such, the IMO and others investigating practical measures for noise reduction tend to focus on other measures that can reduce underwater noise when designing and building new ships or maintaining and retro-fitting existing vessels. These are summarized in in the 2014 IMO Guidelines for the reduction of underwater noise from commercial shipping.[123] More detail is also available in a number of reviews[130,174,176-178] including Hemmera 2016 (replicated here in Appendix 2).[179] Recommended measures include the following:

Measures to reduce propeller-induced cavitation:

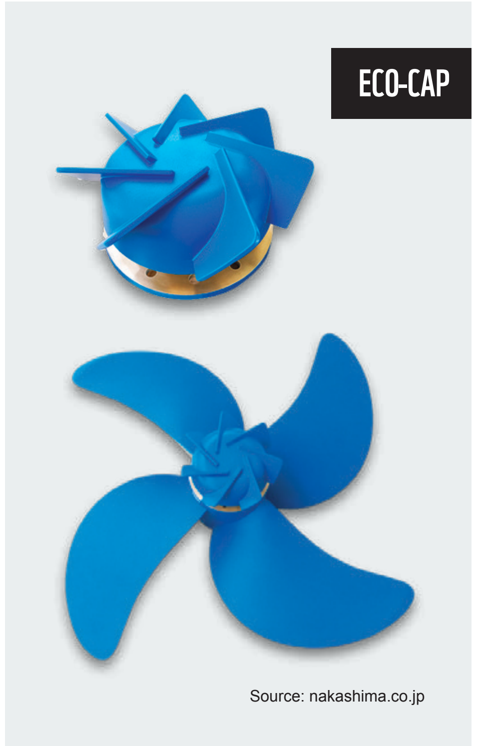
- **Good maintenance of the propeller blade surface:** This includes regular repairs and use of (non-toxic) anti-fouling treatments, as even small amounts of damage/imperfections on the propeller edges can lead to increased cavitation and noise.
- **Optimizing propeller design for the most frequent/likely operating conditions:** Propellers are often designed to run optimally under the ship's full load in calm seas, but vessels are more likely to be operating with less than full loads and in a range of different sea conditions, which can lead to increased cavitation.
- **Use of propeller designs that claim to increase efficiency and reduce cavitation:** Some examples are High Skew Propellers, Contracted and Loaded Tip (CLT) propellers, Kappel propellers and New Blade Section (NBS) propellers (summarized in Leaper et al. 2012, and depicted in Figure 12).[174]
- **Use of propeller hub caps:** This can reduce "hub vortex cavitation".
- **Use of wake inflow devices:** These can improve the flow of water into the propeller and increase efficiency.
- **Increasing the efficiency of the interaction between the propeller and the rudder:** Various patented adaptations have been designed to improve the interaction between the rudder and the propeller, including a twisted rudder and the Costa Propulsion Bulb.
- **Changes to the hull design:** These can help regulate the flow of water into the propeller and reduce vibration and noise form an uneven wake. An asymmetrical afterbody can also improve flow to the propeller and thus improve efficiency.
- **Regular hull cleaning and/or coating to reduce fouling:** This will improve water flow around the hull and into the propellers.

Measures to reduce the reverberation of engine/ machinery noise through the hull:

- Use of machinery/equipment with low noise and vibration levels;
- Use of vibration isolators that use soft/ elastic materials to mount or surround machinery to dampen vibration and sound;
- Use of four-stroke diesel engines rather than two-stroke diesel engines;
- Use of alternative propulsion mechanisms like diesel-electric propulsion and high-quality electric motors that reduce vibration in the hull, or LNG, gas or steam turbine (COGAS) power.

While some of these design features can only be implemented for new ships as they are built, many can be retrofitted to existing ships. A recent successful example comes from the container shipping company Maersk and the Marine Physical Laboratory at the Scripps Institution of Oceanography. In 2015 and 2016, Maersk retrofitted 11 Panamax-size container vessels to improve fuel economy, focusing on propellers and hulls, specifically a modification of the bulbous bow to reduce drag, a new propeller with four fins, and propeller boss cap fins to reduce cavitation. These retrofits resulted in a 10 per cent improvement in fuel efficiency. In addition, a Scripps-monitored hydrophone in the Santa Barbara Channel shipping lane off the coast of California was able to capture sufficient pre- and post-retrofit data for five of the Maersk container ships. It found a six-decibel reduction in the 8–100Hz frequency band and an eight-decibel noise reduction in the 100–1,000Hz frequency band as a result of the retrofits[180] when allowance was made for differences in the draught of the vessels and the way that would affect sound propagation.

A table of design features, adapted from ACCOBAMS 2013[176] for a study commissioned by the Port of Vancouver, can be found in Appendix 1.



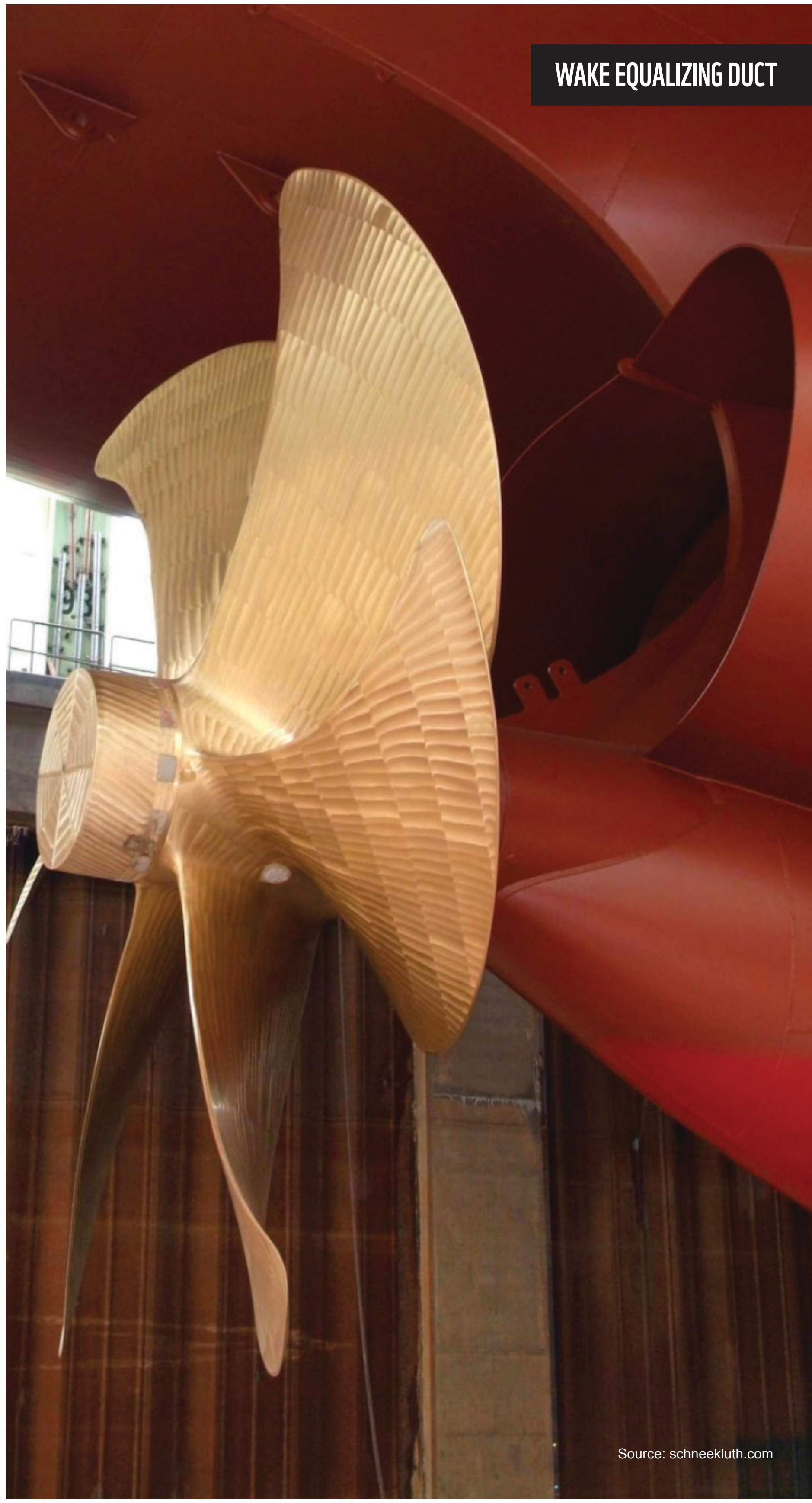


Figure 12: Illustrations of propeller designs and modifications that can reduce underwater noise from cavitation. Source: AQUO, Comprehensive listing of possible improvement solutions and mitigation measures, Deliverable D5.1, European Commission, 2014.

3.3.3 VESSEL OPERATION MEASURES TO REDUCE UNDERWATER NOISE

In general, slower vessel speeds are associated with significant reductions in underwater noise.[123,178] However, different vessels have different speeds at which their propellers begin to cavitate (known as the Cavitation Initiation Speed or CIS), and certain unique builds of double propellers do go against this rule of thumb. One empirical study of vessel noise in the Santa Barbara Channel found that the lowest cumulative URN at source level was associated with vessels traveling at 8kn,[159] and another modeling study estimated that a 10 per cent reduction in speed across the global shipping fleet would result in a 40 per cent reduction in underwater noise associated with shipping.[125]

3.4 SLOW STEAMING: REDUCING SHIP-STRIKE RISK, UNDERWATER NOISE AND GREENHOUSE GAS EMISSIONS

Many conservation and environmental organizations as well as ship owners and policymakers are beginning to view speed reductions, or slow steaming, as one of the most effective measures that the shipping industry can undertake to mitigate the risks of both ship strikes and underwater noise.[125,181] Slow steaming has the following advantages in comparison to other measures:

- In the case of ship strikes, the large amount of data indicating predictable spatial or temporal distribution of cetaceans that is required to justify moving a shipping lane or creating an ATBA or a new TSS is often a stumbling block. In addition to providing convincing justifications to ship owners and transport companies that might incur additional costs by navigating longer distances to avoid whale areas, it is important to collect reliable data on all whale species that might be impacted in order not to displace risk from one species to another. This process can take years. Slow steaming is a measure that will benefit all whale and dolphin species as well as other marine life that will benefit from lower noise levels, and it is a measure that can be implemented with immediate effect under the precautionary principle in any location around the world.

- While design adaptations for new vessels under construction should always use the best available technology to reduce URN, slow steaming does not require any technical adaptations for existing vessels.

- In addition to reducing the risk of ship strikes and shipping-generated underwater noise, navigating at lower speeds uses less fuel, with the fuel savings, for the propulsion for the voyage, roughly proportional to the square of the speed. While this incurs savings for the ship owners/transport companies, it must be balanced against other potential costs incurred, because the voyage will take longer.[178] However, it is worth noting that on the whole, slow steaming is a cost-saving measure that many transport companies undertook when fuel prices were at a peak in 2008 to 2010.

- Reducing speeds across shipping fleets may be one of the most effective short-term measures to help the IMO reach its target to reduce greenhouse gas emissions from international shipping by at least 50 per cent from 2008 levels by 2050.[125,182] Studies demonstrate that a 10 per cent speed reduction from ships globally could result in a 13 per cent reduction in greenhouse gas emissions.[183] Another study found that reducing speeds by 10 to 20 per cent could produce 13 per cent to 24 per cent less CO_2, SO_x and NO_x emissions, respectively (see also Section 4.3).[184] This average reduction could be achieved in large part by compliance from a portion of the fleet; studies indicate that as much as half of the total underwater radiated noise from the world's shipping fleet is generated by the 15 per cent of ships with source levels above 179dB re 1μPa @ 1m.[185]

In April 2019, several ship owners partnered with non-governmental organizations (NGOs) to draft an Open letter to IMO member states supporting a mandatory speed measure to reduce shipping emissions. This issue was discussed at the November 2019 meeting of the IMO Marine Environmental Protection Committee. However, as of the time of writing this report, no definitive action has been taken on this proposal.

3.5 INCENTIVE MEASURES AND CERTIFICATION OF GOOD PRACTICE

Several voluntary measures, encouraged through incentives and/or certification schemes, are being developed in the absence of legally enforceable regulations, to promote practices that reduce risk of ship strikes or reduce underwater noise from ships.

Certification programs: Several certification programs offer ship owners and port authorities incentives to adhere to environmental standards. Of the various programs that exist, two (Green Marine and Green Award) specifically include standards to reduce underwater noise. Here, we provide more detail about the the Green Marine program, a North American voluntary environmental certification program. Since 2020, European ship owners have now access to the certification program through the Green Marine Europe label. The certification scheme addresses key environmental issues through 12 performance indicators. Vessels and ports can qualify for certification if they adhere to the following measures known to reduce underwater noise and risk to cetaceans (see https://green-marine.org/certification for more detail):

GREEN MARINE

For vessels:

- Periodic cleaning of the hull and maintenance of the propeller blades;
- Familiarity with sensitive areas in North America where ships are likely to navigate, and adherence to voluntary traffic measures to reduce risk to wildlife;
- Collection of whale-sightings data and contribution of data to a recognized central database;
- Adoption and implementation of a management plan for marine mammals with the aim of reducing the potential impacts of vessels, particularly in recognized sensitive areas;
- Integration of ship noise reduction technologies;
- Accurate assessment of the sound level of ships.

For ports: (see https://green-marine.org/wp-content/uploads/2020/03/2020_Summary_PortsSeaway.pdf)

- Ensure awareness of underwater noise and ship-strike regulations among community of mariners using the port;
- Promote the collection of cetacean sighting details if appropriate by using a recognized application like Whale Alert or Whale Report (see more details in Section 4.2.4);
- The determination of local issues in terms of acoustic impact, species and areas concerned;
- The implementation of visual observation (Marine Mammal Observer) during maritime coastal work;
- The adoption and implementation of an underwater noise management and mitigation plan, including monitoring of ambient noise as well as monitoring of individual ships approaching and departing the port;
- Collaboration in research that includes measurement of URN;
- Offering a recognition program for ship owners who demonstrate noise reduction.

Ports modeling best practice: Even without the incentive of certification schemes, several ports around the world have modeled best practice in reducing the risk of ship strikes and the impacts of underwater noise in their spheres of operation. This approach is extremely valuable, as the areas around ports are known to concentrate vessel traffic and host high levels of underwater noise.[155,156,186] Several ports grant a reduction in port dues in the order of 5 to 20 per cent to vessels meeting certain environmental standards and certified by an environmental certification program.[179] Other ports collaborate extensively with local researchers to implement measures to reduce risks to cetaceans.[187] One example is the EcoAction criteria developed by the Port of Vancouver in 2016, by which vessels using the port can strive toward different award levels (Bronze through Gold) by demonstrating adoption of a combination of the measures summarized in Appendix 1.

Classification Societies: Shipping Classification Societies are licensed by flag states to classify and certify marine vessels based on their structure, design and safety standards. Only a limited number of these state-recognized certifications focus specifically on underwater noise. These include:

- American Bureau of Shipping (ABS): Underwater Noise. Certification on the maximum sound level of vessels and measurement;
- Bureau Veritas (BV): NR614 - Underwater Radiated Noise (URN). Certification of sound level measurement of ships;
- Det Norske Veritas - Germanischer Lloyd (DNV-GL): SILENT. Certification on the maximum sound level of vessels and measurement (the first certification to be created on underwater noise);
- Lloyd's Register (LR): UWN-L. Certification on the maximum sound level of vessels and measurement;
- Registro Italiano Navale (RINA): DOLPHIN. RINA DOLPHIN notation sets two limits for commercial vessels: DOLPHIN Transit, for normal seagoing conditions, and DOLPHIN Quiet, for ships traveling at 10kn. This applies to areas of high environmental importance, for example areas with a high concentration of marine mammals.

3.6 ECONOMIC AND OTHER IMPACTS OF MITIGATION

Proposals to introduce mitigation measures are more likely to be considered by government and industry stakeholders if they are accompanied by a realistic assessment of their potential economic and logistic impacts. Those seeking change to "business as usual" should be realistic about the costs and/or possible delays associated with the proposed change, and demonstrate how they can be balanced against environmental gains, the industry's "green credentials" and other positive gains.

For example, a study conducted by WWF France in the Pelagos Sanctuary determined that of all the vessels operating in the region, 100 of them accounted for 50 per cent of the risk of ship strikes in the Sanctuary.[48] A voluntary speed reduction to 10kn would result in a maximum cumulative delay of only 105 minutes per month for the busiest ferry in its peak season, a delay deemed reasonable when viewed against an average journey time of 8 hours per vessel and the potential conservation gains. Planning for slower transit on a scheduled basis was perceived to be more practical than unplanned delays that might result from the Repcet real-time alerts that would cause vessels to change course or slow down, potentially throwing schedules off and causing customer dissatisfaction.

Another study estimates that the cost of fitting low-cavitation propellers to ships would amount to less than 1 per cent of the ship's overall building cost, and that retrofitting existing vessels with low-cavitation propellers would result in overall savings due to the increased efficiency and fuel savings for container ships, tankers and passenger ferries alike.[178]

4. CASE STUDIES:

MITIGATION IN ACTION AND LESSONS LEARNED

4.1.1 CONTEXT

The Pacific coast of Panama serves as a mating and calving ground for humpback whales from the Southern and Northern Hemispheres. Humpback whales that feed in the North Pacific are present in limited numbers during the Northern Hemisphere winter.[188] However, many more Southern Hemisphere humpback whales arrive in the Gulf of Panama between June and November, following a long journey from Antarctic and Chilean feeding grounds.[189-192] A study conducted between 2003 and 2009 in Las Perlas Archipelago within the Gulf identified 295 individual humpback whales, including many mother–calf pairs, and individual whales that were also observed on the Antarctic Peninsula, Chile and Colombia.[191,193] Research clearly shows that the Gulf of Panama serves as important habitat for Southeast Pacific humpback whales.

The Gulf of Panama also hosts a huge volume of vessel traffic transiting through the Panama Canal and ports, which serves as a major crossroads for global shipping traffic. The Panama Canal connects sea routes from the east coast of the United States to the west coasts of North, Central and South America, as well as Asia (Figure 13).[194] Roughly 17,000 transits are made through the canal and Pacific ports each year.[194]

This section features four case studies that illustrate some of the practical aspects of researching, proposing and implementing mitigation measures to reduce the risks of ship strikes and shipping-related underwater noise to cetaceans. Tables featuring a more complete listing of places where different mitigation measures have been implemented can be found in Appendix 2.

4.1 A TRAFFIC SEPARATION SCHEME TO PROTECT HUMPBACK WHALES

CASE STUDY AT A GLANCE	
Target species for protection	Humpback whales and other large cetaceans
Location	Pacific approaches to the Panama Canal and ports
Primary mitigation measures applied	Introduction of a Traffic Separation Scheme, seasonal speed restrictions
Main stakeholders (catalyzing process)	Scientists, shipping industry
Key stakeholders (implementing measures)	Scientists, government agencies, shipping industry, enforcement agencies
Year first measures implemented	2014

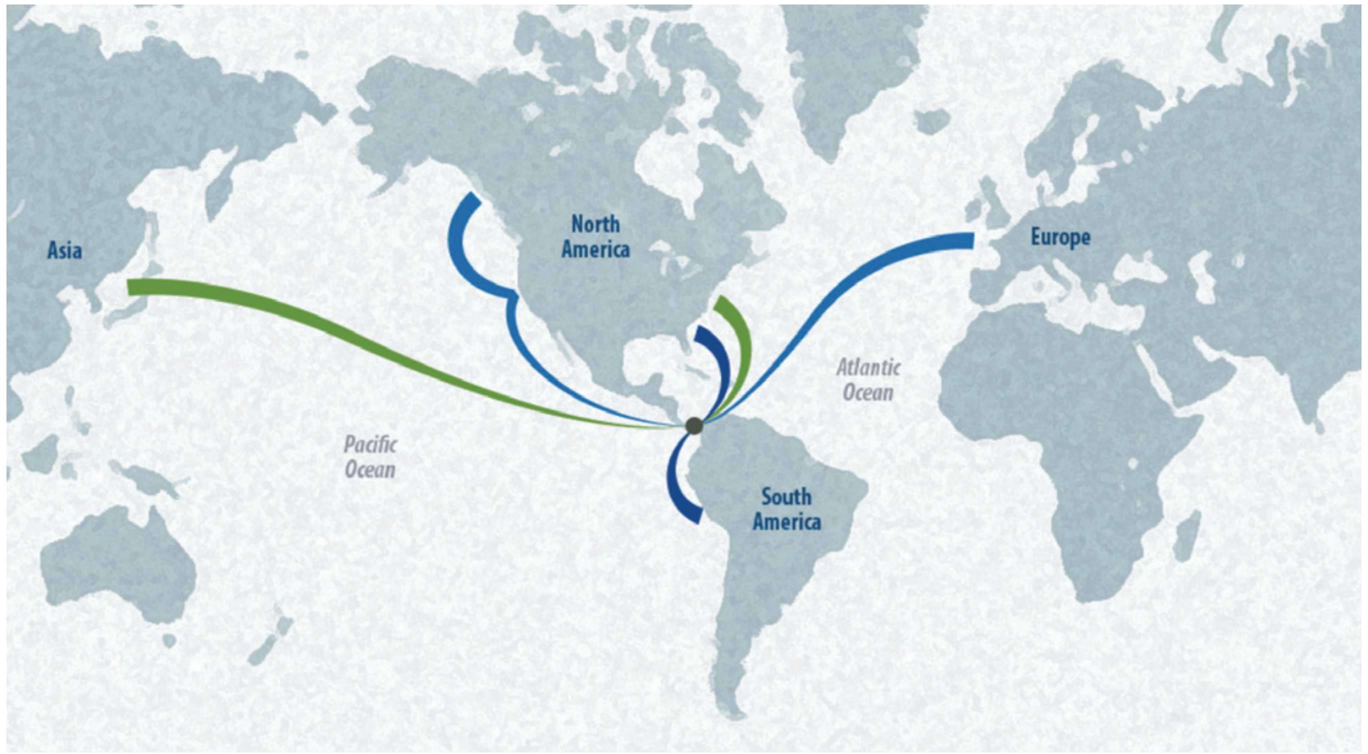


Figure 13: The main trade routes with traffic in the Panama Canal. Source: The Panama Canal Logistics Innovation and Research Center: https://logistics.gatech.pa/en/assets/panama-canal/statistics#.

4.1.2 IMPACTS

Before 2014, vessels entering and exiting the Panama Canal were free to take whichever route they preferred. Traffic fanned out through the Gulf of Panama, covering almost the entire span of navigable waters. Researchers working with humpback whales in Las Perlas Archipelago suspected that this posed a significant risk to humpback whales and artisanal fishing vessels using these same waters. The team analysed the tracks of satellite tagged whales in relation to AIS data showing vessel tracks during the same period to identify the exact moments in time and locations where whales and vessels were at risk of contact. The study showed that 53 per cent of whales had close encounters with a ship, and that whales came within 200m of a vessel on 98 separate occasions over an 11-day period.[49] While whales' maximum speeds averaged 11.2kn, tankers averaged 15kn and cargo ships 17kn, with maximum speeds exceeding 22kn. Bearing in mind that ship strikes are more likely to be fatal for whales if the ship is traveling at speeds greater than 12kn,[166] the authors of the study concluded that these interactions were undoubtedly leading to an unsustainable level of mortality in the population. Although only 13 humpback whale deaths had been officially recorded between 2009 and 2011, this was considered to represent only a small portion of actual mortalities. The lack of a dedicated stranding network at that time in Panama, coupled with the likelihood that struck whales would sink or be carried away by currents or on the bows of vessels, make it likely that a large number of vessel strikes and deaths are unnoticed or never reported.[7,49]

The study also overlaid the vessel tracks in relation to the positions of artisanal/local fishing vessels and determined that the routes and speeds of large commercial tankers and cargo vessels were likely to pose an unacceptable risk to the local fishers (see Figure 14).

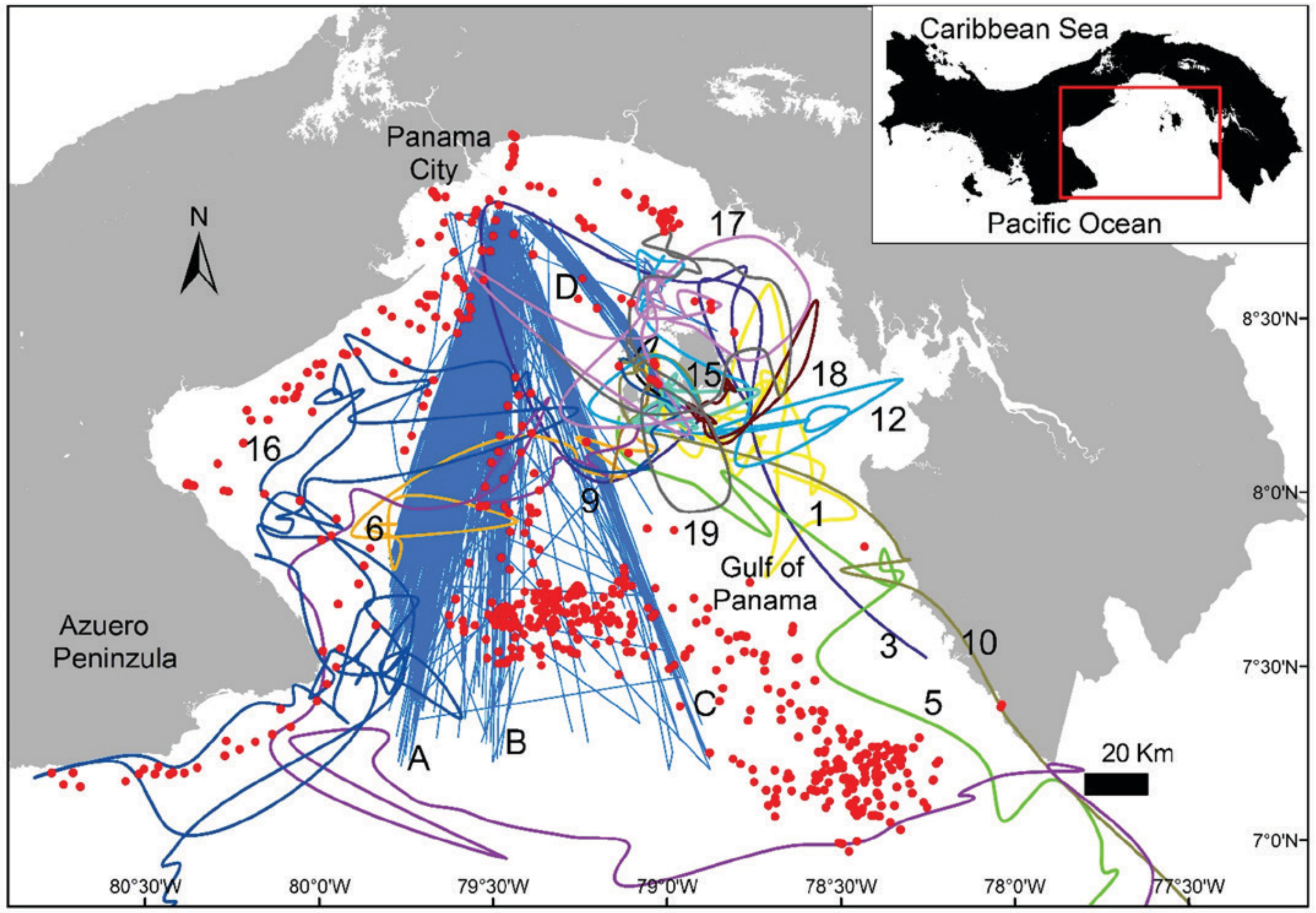


Figure 14: This graphic describes AIS traffic tracks of 892 vessels (blue lines) entering or leaving the Gulf of Panama in September 2009 plotted against tracks of 12 individual tagged humpback whales in Las Perlas, Archipelago, Pacific Panama. Local fishing vessels are indicated as red dots, and four potential existing routes indicated as A-D. Source: H. Guzman

4.1.3 MONITORING MEASURES

The research team used vessel-based surveys to photo-identify individual whales and determine the number of whales using the area, as well as their age, class and behavior in the important breeding habitat. The team also used satellite telemetry to analyze the fine-scale movements of tagged whales in relation to vessel positions, which were determined by purchasing AIS data from a commercial provider. By comparing the real-time tracks and positions of both whales and ships, they were able to determine individual "encounters" during which whales came within 200m of ships. At the time, this was a unique and convincing way of presenting ship-strike risk, reducing the total area where whales and ships could come in contact by more than 90 per cent. This analysis was used to formulate mitigation proposals that would reduce the risk and was also used years later to assess the effectiveness of the measures that were eventually introduced.

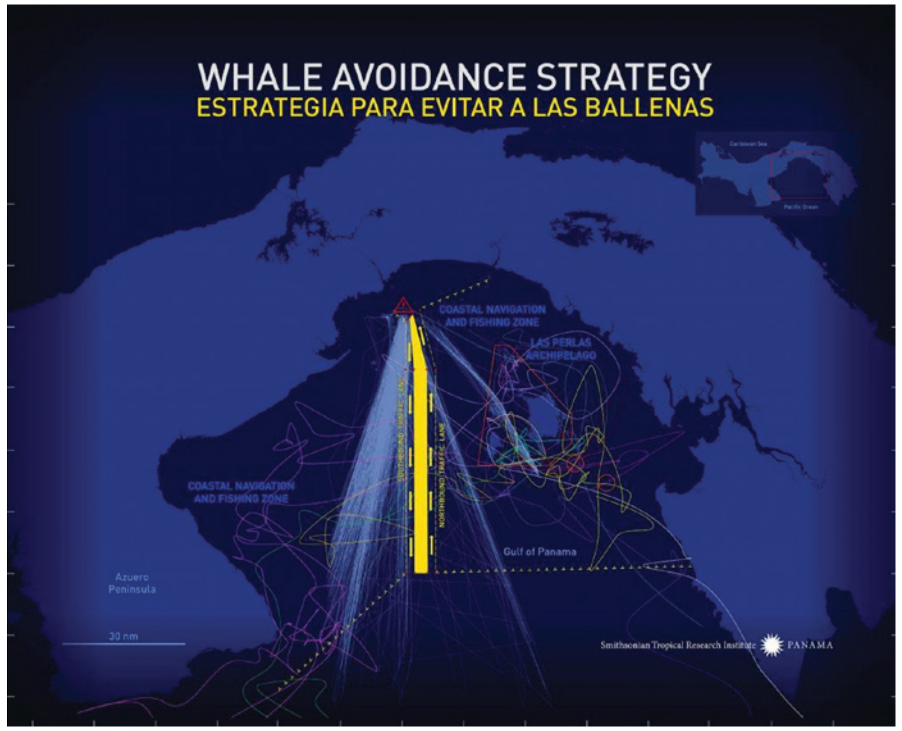


Figure 15: Whale avoidance strategy in the Gulf of Panama. Reproduced with permission from H. Guzman. Graphic credit: Jorge Aleman, Smithsonian Tropical Research Institute, Panama.

4.1.4 MITIGATION MEASURES

After conducting the analysis of whale satellite tracks in relation to ship positions, the research team recommended two clear mitigation measures to reduce the risk to whales and improve safety for both large and small vessels operating in the Gulf of Panama:

- **A Traffic Separation Scheme (TSS)** that would channel in-bound and out-bound traffic from the Panama Canal into separate lanes, each two nautical miles wide, and separated by three nautical miles in a section of the Gulf of Panama roughly 120km (65 nautical miles) long, extending between parallels 8.8ºN and 7.0ºN (Figure 15).
- **A seasonal speed restriction** to 10kn between 1 August and 30 November to reduce the risk of lethal ship strikes during the period of peak density of Southern Hemisphere humpback whales in the area.

The authors estimated that these measures would reduce the risk of lethal ship strikes by more than 90 per cent.[49]

Whale research teams often make recommendations in papers published in peer-reviewed journals. However, translating these recommendations into policy would require a new suite of skills and collaborations. The research team formed a good working relationship with shipping industry representatives in the Panamanian Maritime Chamber, including one key ally, a vessel captain from the Panama Canal Authority who had written a thesis focusing on the benefits of a TSS for vessel safety in Panama. This vessel captain became a partner over three years of negotiations with the Panama Maritime Authority, the Panama Canal Authority and the Panama Maritime Chamber. In 2013, the principal researcher and the vessel captain were invited by Panamanian government authorities to present their TSS and speed-reduction proposals to the IMO's Sub-Committee on Safety of Navigation, Communication and Search and Rescue (NCSR). Their proposal was successful and became effective on 1 December 2014. Supporters of the measures, particularly the TSS, saw the enormous benefits to safety of all marine users and protection of sensitive coastal habitats, as well as the benefits to whales and artisanal fishermen.

4.1.5 LESSONS LEARNED

In many ways, the Gulf of Panama case study represents the ideal example of how good science and multi-stakeholder collaboration can lead to effective mitigation of the impacts of shipping on cetaceans. The following lessons can be learned from the original study and follow-up studies and efforts to expand mitigation measures into neighboring regions:

- The original recommendations for mitigation measures were based on convincing and thorough science and sound knowledge and understanding of the IMO tools that were available to mitigate risk.
- Effective collaboration between the research team, industry representatives and national government agencies made it possible to present a strong case to the IMO. While the scientists provided the justification for the proposed measures, the government and industry partners mobilized the necessary support from other IMO members during the meetings where the measure was presented.
- Implementation of the measures was swift after approval in 2014. Follow-up research conducted by the original team indicates that compliance with the TSS is high, with 80 to 90 per cent compliance in 2015 and 2016.[195] Analysis of vessel traffic in those years shows that the TSS has been effective in reducing ship-strike risks for both whales and small artisanal fishing vessels. Ship traffic was condensed from an area of roughly 11,600 km^2 before December 2014 to only 830 km^2 in 2015 and 2016, reducing the potential vessel–whale interaction area by 93 per cent, as predicted in the previous study.[195]
- However, compliance with voluntary seasonal vessel speed reductions is much lower, with only 19 per cent of vessels complying in 2015, and roughly 10 per cent complying in 2016. Authors recommended changing IMO's normative from "recommended" to "mandatory". Although some of the most extreme lack of compliance is tied to large commercial tuna fishing vessels that regularly exceeded 20kn, non-compliance occurred across all sectors. Reasons for this low compliance are thought to be linked to pressures to adhere to schedules, difficulty maintaining low speeds in areas of strong currents, and a general lack of awareness about the seasonal measures, which are not always clearly marked on navigational charts.[195] Citing studies that show increased compliance with voluntary measures if they are accompanied by education, outreach and communication,[167,196,197] the authors recommend improved communication and outreach.
- The studies conducted to date have not yet addressed the possible impacts of shipping-related underwater noise on the whale populations in the Gulf. However, efforts are underway to fund studies using passive acoustic monitoring at strategic locations throughout the Gulf to monitor whale vocalizations as well as shipping noise at different times of year and particularly in relation to rates of compliance with voluntary speed reductions.
- Efforts to repeat this collaboration in neighboring countries have been partially successful. An almost identical study of real-time overlap of satellite tagged whales and AIS-transmitting vessels and strong collaboration between researchers, industry representatives and government agencies led to the IMO approval of an ATBA in Costa Rica. A strong case has also been presented for speed restrictions in the Straits of Magellan off Chile.[198] However, in other countries along the same migratory corridor for whales, where whales and ships are known to co-occur, more work is needed to bring all stakeholders together and translate science into policy.

4.2 RE-ROUTING OF SHIPPING LANES, A MARINE PROTECTED AREA, AND SEASONAL SLOWDOWNS FOR ENDANGERED NORTH ATLANTIC RIGHT WHALES

CASE STUDY AT A GLANCE	
Target species for protection	North Atlantic right whales
Location	Northeast coast of the United States
Primary mitigation measures applied	Re-routing of Traffic Separation Scheme, seasonal and dynamic speed restrictions, Marine Protected Area
Main stakeholders (catalyzing process)	Scientists, government agencies, NGOs
Key stakeholders (implementing measures)	Scientists, government agencies, shipping industry, enforcement agencies
Year first measures implemented	2008

4.2.1 CONTEXT

The Gulf of Maine off the northeast coast of the United States serves as an important feeding ground for multiple species of cetaceans, including the critically endangered North Atlantic right whale, humpback whales, sei whales and fin whales. Some of the richest whale-feeding grounds in this area are found within the Gerry E. Studds Stellwagen Bank National Marine Sanctuary (the Stellwagen Bank Sanctuary), which was established in 1992. Stretching between Cape Ann and Cape Cod at in the southwestern corner of the Gulf of Maine (Figure 16), the Stellwagen Bank Sanctuary protects 2,181 km^2 of open ocean, overlaying a diverse seafloor topography and array of benthic and pelagic habitats that support biological communities broadly representative of the Gulf of Maine.

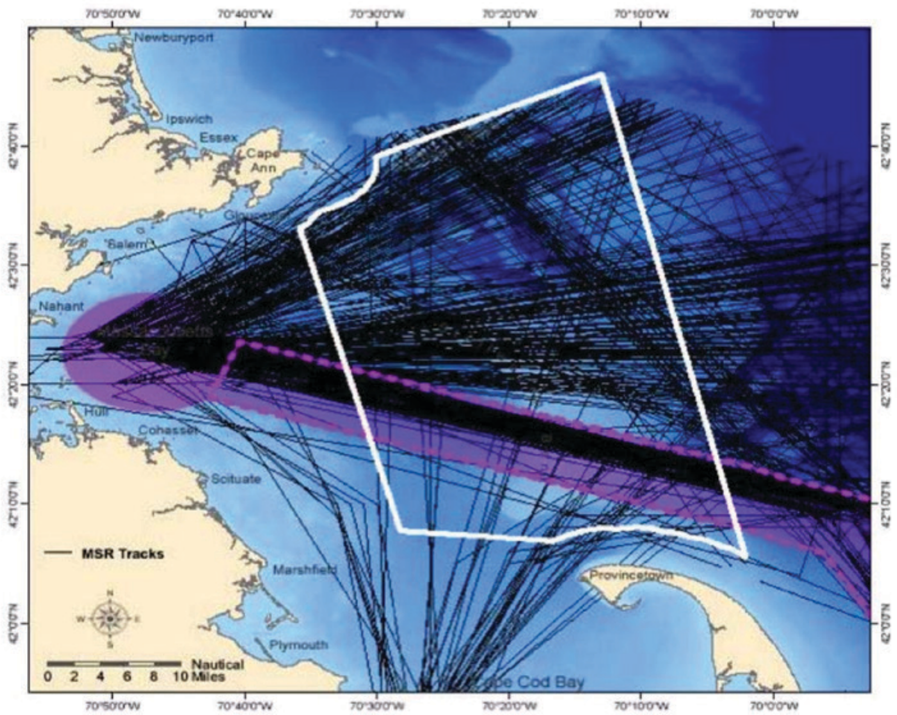


Figure 16: Reported paths of inbound ships (black lines) and the Traffic Separation Scheme (in purple) in relation to Stellwagen Bank National Marine Sanctuary (white boundary). Source: David Wiley

Of the whale species found in this region, the North Atlantic right whale is of greatest conservation concern. Severely depleted by past commercial hunting, the population was gradually recovering in numbers to 2010, until it reached just under 500 individuals, but it is now in decline again with only 365 individuals alive at the end of 2019. The main reasons for decline are attributed to deaths from entanglement in fishing gear and ship strikes.[10,199]

4.2.2 IMPACTS

During the Northern Hemisphere winter, North Atlantic right whales mate and give birth to their young in the warm coastal waters of Georgia and Florida. In the spring, they begin their migration northwards toward the waters off Rhode Island, Massachusetts and Maine. These waters, particularly those of the Stellwagen Bank Sanctuary, provide rich feeding grounds for many whale species. Specialist filter feeders, right whales' preferred prey are small crustaceans called copepods, which are concentrated near the ocean's surface.[21,200] While some right whales occasionally stay in these waters to feed and nurse their calves throughout the summer, most move further north into Canadian waters before the whole population migrates south again in the late fall.[201]

During these migrations, and particularly in the feeding grounds of the Stellwagen Bank Sanctuary, whales are exposed to high densities of vessel traffic approaching and departing the busy ports of Boston and Cape Cod (Figure 16). Ship strikes have been identified as a major cause of mortality for North Atlantic right whales, whose surface-feeding behavior and apparent lack of response to the noise of approaching vessels put them at risk.[21,200] Furthermore, underwater noise from shipping has been shown to contribute to ambient noise levels sufficient to mask right whale communication,[38] and chronic exposure to underwater noise from shipping is believed to have contributed to increased levels of stress hormones in North Atlantic right whales.[89,202] The species was listed as endangered under the United States' *Endangered Species Act* in 1970 and as depleted under the United States' *Marine Mammal Protection Act* in 1973. As such, managers at all levels are obligated to implement measures to address the main threats to the population's recovery. The North Atlantic right whale was also listed as critically endangered on the International Union for Conservation of Nature (ICUN) red list in July 2020.[203]

4.2.3 MONITORING MEASURES

The North Atlantic right whale population may be one of the best-studied whale populations in the world. Its formal recognition as an endangered species in a country with a clear legal framework for protection and recovery has justified funding and resource allocation to multiple means for monitoring both the whales and their environment over the years.

Methods used to monitor the whales include:

- **Aerial surveys:** These are conducted regularly by the United States' National Oceanographic and Atmospheric Administration (NOAA)'s Northeast Fisheries Science Center. Surveys are conducted repeatedly throughout the year using a NOAA Twin Otter aircraft. The plane navigates systematic track lines within 11 primary survey blocks including the Stellwagen Bank. The main objective of the aerial surveys is to document the presence, distribution and abundance of North Atlantic right whales. The surveys have also been used to collect photo-identification data (see below) and evidence of human impacts such as entanglement. Other groups, such as the New England Aquarium and others in the southeast United States also aerially track and record right whales' sightings.

- **Vessel-based surveys:** These are also conducted by NOAA, and a specially equipped research vessel, the R/V Auk, is used to conduct surveys for North Atlantic right whales and other species in the Stellwagen Bank Sanctuary. The vessel also navigates systematic track lines and collects data on right whale distribution and occurrence, but also other species and environmental information.

- **Photo identification:** Photographs of North Atlantic right whales are used to recognize individual whales over time, and photos taken from the air or from vessels with a high deck are ideal as they show the patterns of callosities on the whales' heads, which are as unique as human finger prints. Because the population is so small, and surveys are so frequent, virtually every adult whale in the population has been identified and can be monitored over time. The New England Aquarium maintains the North Atlantic right whale photo-identification catalogue which is hosted by the Right Whale Consortium at the University of Rhode Island. The catalogue includes photos from aerial and ship-based surveys as well as those collected opportunistically, such as through whale-watching expeditions. These photos are used to understand the threats to which individual whales are exposed throughout their life histories.[205,206]

- **Strandings**: When dead whales are reported floating at sea or stranded on shore, they are investigated by veterinary pathologists to determine the cause of death. Scientists from the International Fund for Animal Welfare, UNC-Willmigton and others lead the necropsies teams which conduct these investigations. NOAA's Northeast Fisheries Science Center collaborates with other research organizations to collate information and map trends over time.

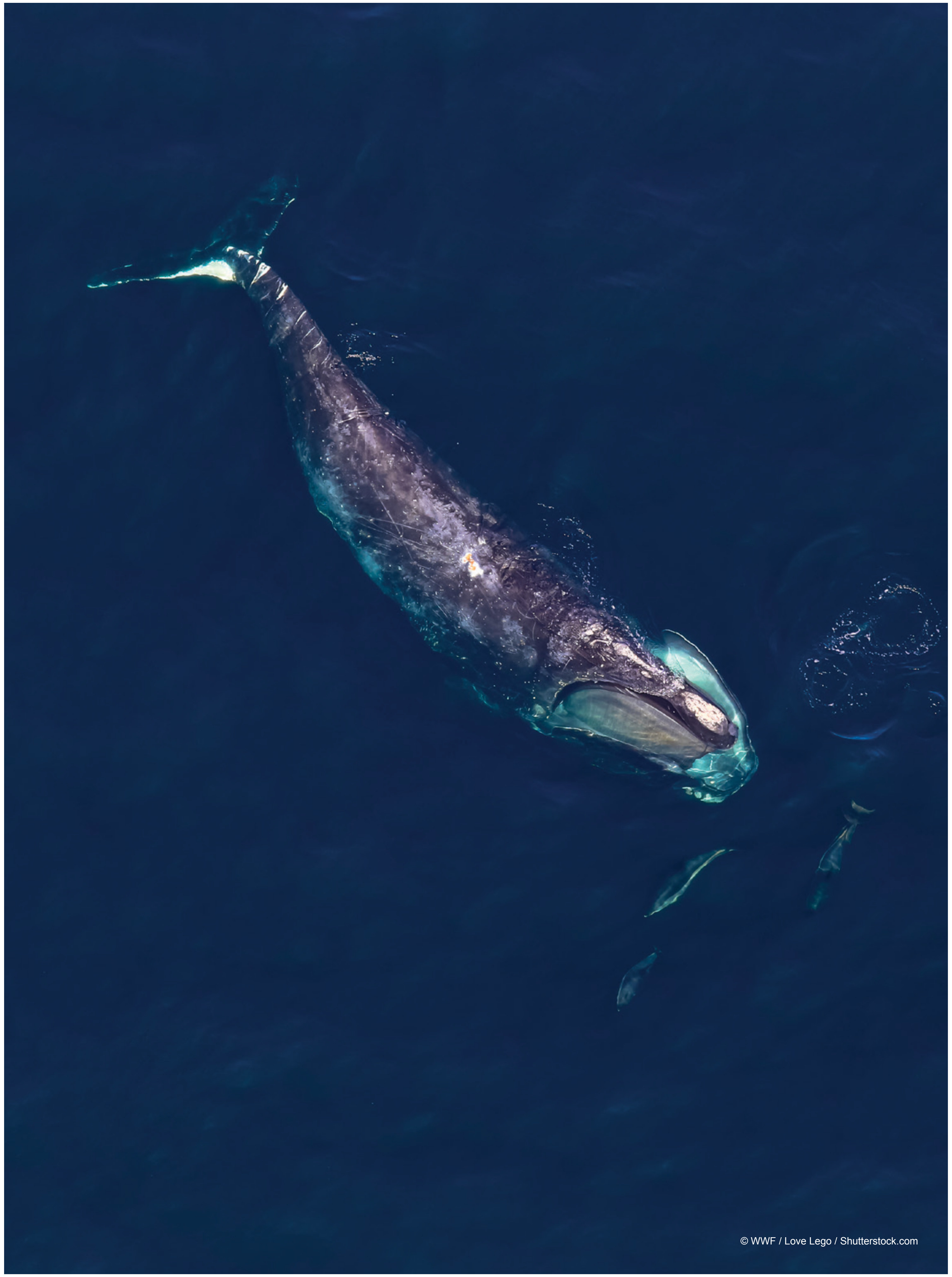
- **Passive acoustic monitoring:** North Atlantic right whales vocalize extensively during the winter and early spring. This makes their detection and monitoring possible by remote hydrophones on the seafloor or by mobile autonomous underwater vehicle (AUVs).[207] Passive acoustic monitoring can also be used toàmonitor human-generated (anthropogenic) noise in the Sanctuary that masks communication between whales.[208,209]

- **Experimental exposure:** Underwater acoustics are also used to test right whales' reactions to exposure to simulated and real ship noise. Findings have demonstrated that whales showed little response to these signals, indicating that they may not engage in any effective avoidance strategy to reduce their risk of being struck.[81]

Measures to monitor vessel traffic and underwater noise include:

- **Passive acoustic monitoring:** Fixed recording systems as well as towed arrays have been used to measure underwater noise in the Stellwagen Bank Sanctuary, with results indicating that ambient noise levels from shipping are high enough to mask whale communication.[38,72]

- **AIS**: AIS data is regularly analyzed to assess vessel traffic in the Stellwagen Bank Sanctuary and co-occurrence of North Atlantic right whales and vessel traffic. This data is used to evaluate measures to reduce the risk of ship strike21 and the efficacy of mitigation measures that have been put in place.[104,211,212]



A North Atlantic right whale (*Eubalaena glacialis*) with dolphins around the head in Stellwagen Bank National Marine Sanctuary.

North Atlantic right whale mother & calf (*Eubalaena glacialis*) off the Atlantic coast of Florida.

4.2.4 MITIGATION MEASURES

Recognizing the threat of ship strikes to North Atlantic right whales as early as the 1990s, voluntary measures were introduced encouraging vessels to slow down in the Stellwagen Bank Sanctuary during the times of year that whales were present. However, ship strikes continued to occur, and it was determined that mandatory measures were required. To ensure that these would be based on sound science and accepted by key stakeholders, including managers, researchers and the shipping industry, 20 stakeholder meetings were organised.[204]

Over eight years, multiple measures were evaluated[210] and ultimately in 2007–2008, new mandatory rulings included multiple measures to reduce risks to right whales. Measures that are in place currently include the following:

- **Seasonal Management Areas with speed restrictions:** As part of NOAA's North Atlantic Right Whale Ship Strike Reduction Rule, two areas were designated by NOAA as right whale Seasonal Management Areas (SMAs), with one of them encompassing much of the Stellwagen Bank Sanctuary.[213] In these SMAs, NOAA has implemented a mandatory speed restriction of 10kn or less for vessels longer than 19.8m (65 feet) during seasonally implemented regulatory periods. As noted above, such vessel speed restrictions have been estimated to reduce ship strike mortality risk levels by as much as 80 to 90 per cent.[104,214]
- **Traffic Separation Scheme (TSS):** In 2007, the IMO, NOAA Fisheries, and the United States Coast Guard collaborated to shift the main approach route through the sanctuary and into Boston Harbor so that it would avoid one of the highest density areas for North Atlantic right and other protected large whales (Figure 17). [215]
- **Licensing:** From 2007 onwards, Liquefied Natural Gas (LNG) carriers accessing two new ports in Massachusetts Bay have been required to slow to 10kn or less in response to real-time acoustic detections of right whales indicating right whale presence within the last 24 hours (see details on real-time detections below).
- **Minimum approach distances:** All vessels are required to maintain a minimum distance of 500m from North Atlantic right whales. This includes fishing vessels and whale-watching vessels, as well as merchant vessels and container ships. Only vessels with valid (research) permits can approach whales more closely.
- **Dynamic Management Areas:** If an aggregation of three or more right whales is sighted outside of a Seasonal Management Area, a Dynamic Management Area (DMA) is established for 15 days.[216] Such sightings are received through the Right Whale Sighting Advisory System (see below) and other sources. Unlike the SMAs above, compliance with DMAs is voluntary. Unfortunately, voluntary measures have been shown to be relatively ineffective.[217]

Further measures to support the above mitigation strategies include:

- **Right Whale Sighting Advisory System (RWSAS):** The RWSAS collects and compiles whale-sighting reports from aerial and ship-based surveys, commercial whale-watching vessels, the United States Coast Guard and other sources (commercial ships, fishing vessels and the general public). Sightings are verified and – if validated – can be used to trigger a DMA (see above). These compiled sightings are used to monitor the effectiveness of the management and mitigation measures above.
- **Mandatory ship reporting systems:** Through a coordinated effort between NOAA and the United States Coast Guard (and adopted by the IMO), all vessels over 300 gross tons must report all whale sightings using INMARSAT C (a two-way satellite communications system used in the maritime industry) to a shore-based station when transiting the key North Atlantic right whales habitats off Massachusetts. Reporting vessels are sent a message containing recent sightings in the area, as well as information about right whales and measures that can be taken to avoid collisions. This system seems to have played a role in reducing ship strikes.[217]

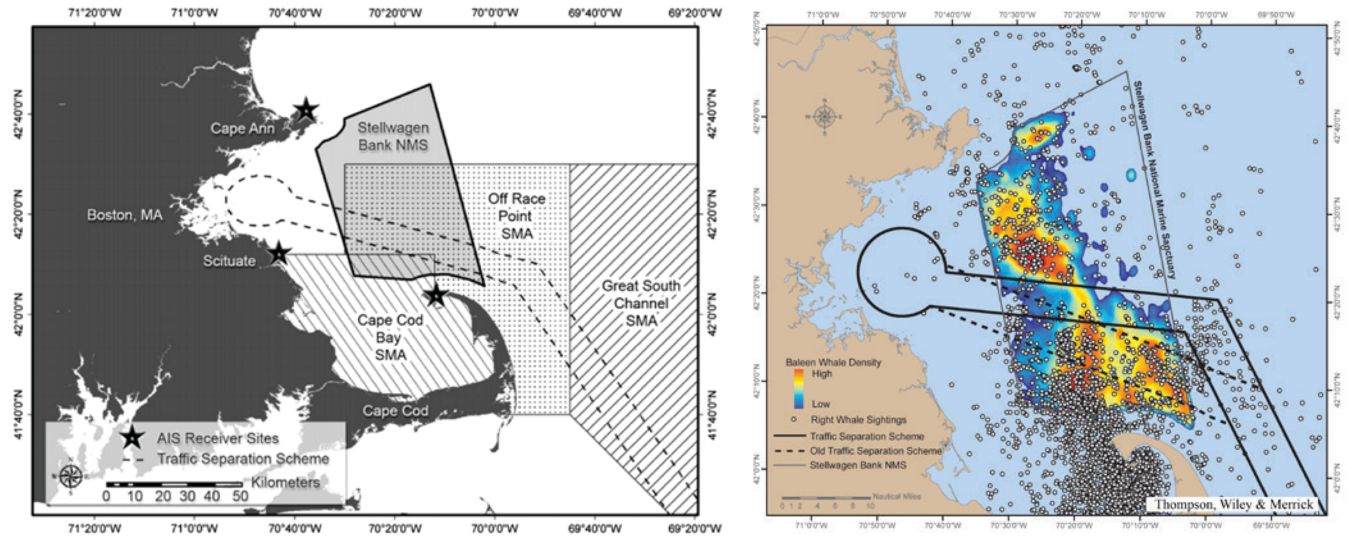


Figure 17: The Stellwagen Bank National Marine Sanctuary and Seasonal Management Areas (SMAs) for endangered North Atlantic right whales (Eubalaena glacialis): Cape Cod Bay SMA, Off Race Point SMA and Great South Channel SMA. The SMAs employ speed restrictions on vessel transits to reduce the risk of lethal strikes to that endangered species. Note that the left-hand figure shows the trajectory of the original shipping lane that transited through the highest recorded densities of right whale sightings (source: Wiley et al. 2011),[167] while the figure on the right shows how the main approach route to Boston Harbor was moved in 2007 to avoid the densest concentrations of North Atlantic right whales (source:David Wiley).

- **Whale Alert:** Whale Alert is a smartphone application (app was first developed by and trialled in the Stellwagen Bank Sanctuary. The app originally targeted the shipping industry, displaying speed-zone regulations and whale management areas on the US Atlantic coast to encourage compliance with existing regulations. Information is displayed in easy-to-read nautical charts with pop-up alerts to serve as reminders when vessels enter regulated areas (Figure 18). The mix of real-time (or near real-time) data projected over the internet to smart phones and tablets made compliance measures much easier to understand and act on. The free app is also available to the general public as a citizen science tool and allow the users to report any sightings of live, dead or distressed whales to the appropriate response agency. For more details see http://www.whalealert.org/. The value of this app is increasing as climate change disrupts historical areas of whale abundance, making broadscale citizen sightings of whale locations extremely important.

Figure 18: A screen image of the Whale Alert smartphone application showing caution areas in green when no right whale is detected and yellow when a right whale is detected. The app includes also NOAA icons (blue dots) for ports and oceanographic data and all mandatory and voluntary management measures e.g., SMAs, mandatory ship reporting, etc.

4.2.5 LESSONS LEARNED

As one of the most endangered whale populations in the world, North Atlantic right whales are a focus of conservation efforts, and the effectiveness of mitigation measures that have been put in place are constantly under review. A few lessons learned and recommendations for future work include:

1. Management measures are easier to implement and enforce if they apply to a distinct geographical area with boundaries, such as a marine sanctuary or an SMA. These boundaries can be clearly marked on maps and shared with vessels through official navigational charts or apps like Whale Alert, and can be enforced by designated authorities, such as the United States Coast Guard.
2. Collaboration between stakeholders such as NOAA (with all of its different subsidiary research and management bodies) the United States Coast Guard and researchers from multiple NGOs, academic institutes and aquariums allows an optimum pooling of resources and expertise to tailor mitigation measures to the whales' distribution, biology and behavior, and to ensure effective implementation and enforcement of the chosen measures.
3. Communication and outreach are critical to effective implementation of mitigation measures, particularly in relation to seasonal or DMAs. Vessels need to know exactly when they are entering these areas and what measures are required within them for compliance to be achieved.[217,218] This requires use of the communication channels that will be most effective and well received by the shipping industry, including channels like NAVTEX and AIS, which are not disruptive, but constantly monitored.[169]
4. Initial compliance with speed reduction measures was low, and outreach and enforcement activities were required to increase awareness and incentives for compliance. A study found that citations and fines were more effective in improving compliance from vessels/companies that had been exceeding speed limits than targeted notifications/letters or direct at-sea radio contact.[218]
5. Intensive monitoring combined with positive reinforcement has also been shown effective at increasing compliance with SMA speed restrictions. Since 2011, Stellwagen Bank Sanctuary and International Fund for Animal Welfare have been conducting a highly successful corporate responsibility program targeting vessel transiting the SMAs that overlap with the sanctuary. The program uses the USCG automatic identification system (AIS) to track ship speeds through the SMAs. Metrics are used to grade ship compliance with the speed requirements of the NOAA ship strike rule and report cards are sent to all ships and companies. Companies receiving 'A+' or 'A' grade are provided a certificate of corporate responsibility suitable for display. The program has been well received by the maritime industry, with many companies showcasing their certificates in corporate newsletters and magazines. The SMA's involved in the program were shown to have the highest compliance of all SMAs.[219]
6. SMAs appear to be effective: A 2014 study found that before the 2007 designation of the SMAs, 13 of 15 (87 per cent) North Atlantic right whales and 12 of 26 (46 per cent) humpback whales killed by ships were found inside the boundaries or within 83km (45 nautical miles) of areas that are now SMAs. In the first five years after speed limits were implemented in the SMAs, no ship strikes to North Atlantic right whales were known to have taken place inside or within 83km of any active SMA.[212] However, another study in the same period concluded that in their entirety, SMAs only encompass 36 per cent of historical right whale vessel-strike mortalities, and increased coverage may be needed to protect whales from ongoing threats.[104]
7. Furthermore, current SMAs were designated based on the distribution of North Atlantic right whales to 2006, which was well documented and fairly stable at the time. However, in recent years, climate change has led to a shift in the distribution of the whales' preferred prey, and whales are now spending more time feeding further north in the Gulf of St Lawrence, where protective measures were not in place until 2017.[220,221] These changes may necessitate bilateral cooperation when populations or species have distributions across national borders, as well as frequent evaluation of measures that are in place to protect whales from ship strikes to ensure they can "follow" potentially shifting concentrations of whales.
8. While the measures seem to be effective in terms of reducing mortality from ship strikes, studies indicate that underwater shipping noise in the Stellwagen Bank Sanctuary is still at levels high enough to mask North Atlantic right whales' vocalizations and communication. One study on the Sanctuary estimated that North Atlantic right whales have lost as much as 63 to 67 per cent of their communication space,[72] although another study found that fin whales, minke whales and humpback whales were even more severely impacted by underwater noise in the Stellwagen Bank Sanctuary.[38]
9. It should also be recognized that the monitoring and mitigation implemented to date has required enormous financial and human resources that may not be available in all areas or for all populations at risk from ship strikes and underwater noise impacts.
10. New technologies may support the implementation of more dynamic mitigation and management measures. For example, self-propelled underwater gliders able to detect whale vocalizations and transmit them in near real time may are being used to detect whales and trigger DMAs without relying on aerial surveys or ship-based visual observations.[222-223]

4.3 AIR POLLUTION MEASURES WITH CO-BENEFITS FOR REDUCING SHIP-STRIKE RISK AND UNDERWATER NOISE FOR BLUE WHALES

CASE STUDY AT A GLANCE	
Target species for protection	Blue whales
Location	Santa Barbara Channel, United States
Primary mitigation measures applied	Re-routing of traffic away from shore, vessel slowdowns
Main stakeholders (catalyzing process)	Government agencies (issuing new emissions standards), shipping industry (initially to reduce costs)
Key stakeholders (implementing measures)	Ports, scientists, government agencies, shipping industry, scientists and NGOs
Year first measures implemented	2008

4.3.1 CONTEXT

In 2007, five blue whale carcasses were discovered off the coast of California between Santa Cruz and San Diego, of which four showed clear signs of injury consistent with ship strikes.[204] The relatively large number of deaths in this endangered population triggered what is legally termed an "Unusual Mortality Event" (UME) under NOAA's management regime. The United States' *Endangered Species Act* and the *Marine Mammal Protection Act* both have provisions requiring a full investigation and recommendations for management actions under these conditions.

The Santa Barbara Channel, approaching the ports of Long Beach and Los Angeles, hosts some of the highest densities of commercial vessel traffic in the world, and was identified as one of the most high-risk areas for ship strikes to blue whales. In 2006, roughly 6,500 vessels transited through the channel, many at speeds greater than 14kn. The Channel also contains dense krill aggregations, a source of prey for eastern North Pacific blue whales.[224,225] This overlap of intense shipping and prime feeding habitats creates a potentially significant risk of ship strikes, and reducing this threat became a primary aim for the Channel Islands National Marine Sanctuary (Channel Islands Sanctuary).[204]

Concurrently, human population densities, industry and combined terrestrial and marine transportation in the coastal cities of central and southern California were creating significant problems with air quality. Santa Barbara was failing to meet the requirements of the United States' 1990 *Clean Air Act*. The US Environmental Protection Agency required the County to take measures to address this threat to human health and the environment.[226] Emissions from shipping were considered a significant contribution to the poor air quality, so maritime traffic also became a focus of efforts to address air pollution.[227,228]

4.3.2 IMPACTS

Annual stock assessments that are conducted by NOAA's Southwest Fisheries Science Center include reports of injuries and mortalities to cetacean stocks.[229] Together with the large whale ship strikes database maintained by NOAA,[31] these provide strong evidence that ship strikes are a significant source of mortality for blue whales and other baleen whale species on the west coast of the United States.[31] The high number of ship-strike-related blue whale mortalities in 2007 triggered concerted efforts to address this risk, which would also have significant benefits for other whale species using the area and at risk of ship strikes.[204] Risks were thought to be particularly high in the Santa Barbara Channel.[204]

The frequency of shipping noise overlaps with the low frequency calls (15–100Hz) of blue whales,[53] posing a significant risk of masking their communication. This has been evidenced by a study off the coast of California, which found that blue whales were not detected through acoustic monitoring when ships were present, either because they stopped vocalizing in the face of the competing noise, or because their calls were masked altogether.[230]

4.3.3 MONITORING MEASURES

Blue whales are considered endangered under the United States' *Endangered Species Act*, and all whale and dolphin species occurring in the Santa Barbara Channel and off the coast of California are protected under the United States' *Marine Mammal Protection Act*. This requires US government agencies to conduct regular monitoring of cetacean stocks and their habitats.

Methods used to monitor the whales include:

- **Aerial surveys:** Monthly aerial whale surveys in the Santa Barbara Channel are performed by the Benioff Ocean Initiative, to assess if vessels are complying with speed reduction by issuing slowdown advisories by radio and email.
- **Vessel-based surveys:** These are conducted at regular intervals by NOAA's Southwest Fisheries Science Center. Surveys are generally conducted between July and December and follow pre-determined transects to cover the nearshore and offshore waters of California, Oregon and Washington. Surveys were conducted in 1991, 1993, 1996, 2001, 2005 and 2008. Together with aerial surveys, these are used to calculate abundance estimates and to map distributions of cetacean species over time.[229,231-233]
- **Strandings:** When dead whales are reported floating at sea or stranded on shore, they are investigated by veterinary pathologists to determine the cause of death. NOAA collaborates with other research organizations to collate information and map trends over time.
- **Photo identification:** Photographs of blue whales and other whale species observed during vessel surveys are used to recognize individuals over time and track their movements and life histories. Photos of blue whales can also be used to calculate population size using mark-recapture methods.[234] Photo-identification catalogues are curated by NOAA in collaboration with the Cascadia Research Collective, which also collects photos from fishermen and other third parties into one central database (see https://www.cascadiaresearch.org/).
- **Satellite tagging:** Fitting individual whales with satellite tags has yielded valuable information on their seasonal distribution and migration patterns. Combined with remotely sensed data on chlorophyll concentrations and marine productivity, or with AIS data on vessel movements, it has allowed analysis of whales' (feeding) habitat preferences and likely co-occurrence with vessel traffic.[8,235-237]

Measures to monitor vessel traffic and underwater noise include:

- **Passive acoustic monitoring:** From 2007 onwards, research teams have employed a passive broadband high-frequency acoustic recording package to record and monitor shipping noise in the Santa Barbara Channel and to model how whales' communication might be affected by vessel traffic in the Channel Island Marine Sanctuary.[8,173,230]
- **AIS:** Data from Automatic Identification Systems is constantly reviewed and analyzed to assess vessel traffic in the Channel Islands Sanctuary, and has been used to assess the risks of ship strikes to blue whales8 and changes in vessel-generated underwater noise over time.[173,228]
AIS data has also been used in combination with passive acoustic monitoring to better understand the noise signatures of different categories of vessels.[159]

4.3.4 MITIGATION MEASURES

- **Ocean-going Vessel Fuel Rule:** In 2009, the California Air Resources Board implemented the Ocean-going Vessel Fuel Rule (OGV Rule), which required ships to use cleaner burning fuels in the newly designated "California Emission Control Area" in the waters within 45km of California's coastline. Because these cleaner fuels were considerably more expensive, vessels initially took longer routes to avoid these nearshore areas, resulting in a marked decline of underwater shipping noise in blue whale habitats. Reduced shipping activity related to the 2008 financial crisis resulted in a net reduction of 12dB in underwater average noise levels between 2007 and 2010.[173] However, in 2012, the United States adopted the IMO's new clean fuel standard, requiring vessels to use cleaner fuels up to 370km from the coast and eliminating any incentive for vessels to skirt outside the Channel Islands. Vessel traffic in the Channel Islands Sanctuary increased again, with many vessels traveling at speeds of 20kn or more.[227,228]
In 2014, the California Emission Control Area regulations were made more stringent, forcing vessel operators to reduce speed again and use cleaner fuels.
- **Speed reductions:** Voluntary speed restrictions (initially 12kn or slower, and later revised to 10kn or slower) were put in place in the Santa Barbara Channel from 2007 onwards to reduce the risk of ship strikes.[204] These speed reductions are formally recommended by NOAA: "NOAA strongly recommends that vessels 300 gross registered tons or larger transiting the Santa Barbara Channel Traffic Separation Scheme between Carrington Point, Santa Rosa Island and Diablo Point, Santa Cruz Island, do so at speeds not in excess of 10kt" (see https://channelislands.noaa.gov/management/resource/ship_strikes.html). These measures have continued through 2019.
- **Traffic Separations Scheme (TSS):** Following recommendations from the Channel Islands Sanctuary and NOAA, the IMO amended the Santa Barbara Channel TSS in 2013 by reducing the width of the separation zone from two nautical miles to one nautical mile. The change shifted the inbound south lane one nautical mile inshore, thus avoiding the highest documented concentrations of blue whales (Figure 20).

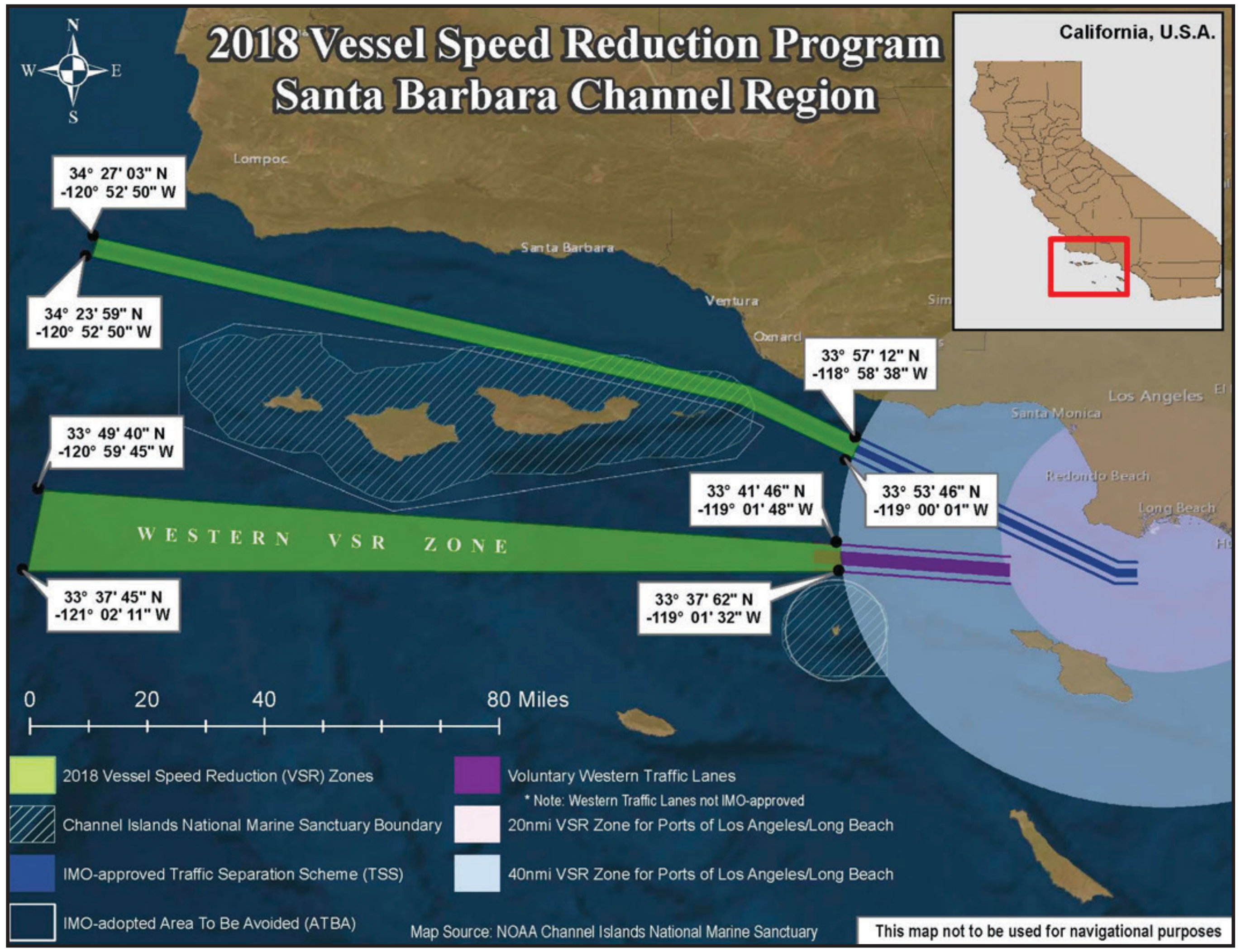


Figure 19: Map of the 2018 Vessel Speed Reduction Program. Source: Ventura County Air Pollution Control District. https://www.ourair.org/wp-content/uploads/2018-06bd-d1-pres.pdf

The mitigation measures above are supported by the following management measures and activities:

- **Seasonal whale advisories:** The Channel Islands Sanctuary collaborates with the National Marine Science and Fisheries Service, the United States Coast Guard and the National Weather Service to provide seasonal notices to mariners when whales are present in the Channel Islands. Information is provided via charts and notices.
- **Apps for mariners to improve real-time whale data:** West Coast Whale Alert and Spotter Pro are two apps for this purpose.
- **Stakeholder participation in adaptive management:** The Channel Islands Sanctuary Advisory Council convenes a Marine Shipping Working Group that reviews management measures and make recommendations for improvements.[238]
- **Port-led incentive schemes:** In 2014, the Channel Islands Sanctuary launched an incentive program to support the voluntary speed restrictions put in place by NOAA. By collaborating with local agencies and NGOs, the Sanctuary secured the agreement of seven global shipping companies to slow transits through the Santa Barbara Channel to 12kn or less. This program is being expanded to additional companies and routes. Furthermore, in 2005, the Port of Long Beach initiated a "Green Flag" program, offering up to 25 per cent reduction on docking fees to cargo ships that slow down to 12kn or less within 40 nautical miles of the harbor. In 2008, the Port of Los Angeles also started a Vessel Speed Reduction Incentive Program (VSR IP). The program offers tariff reductions to vessels using the port on the following conditions: *"To be compliant with the VSR speed limit, the vessel's weighted average speed must be 12 knots or less from the 20 nm or 40 nm latitude and longitude positions on each respective route to/from the Port."* The Port publishes compliance details for individual vessels as an added incentive for "good behavior" (see https://www.portoflosangeles.org/environment/air-quality/vessel-speed-reduction-program for more detail). For both ports, vessel speed is measured and recorded by the Marine Exchange of Southern California.

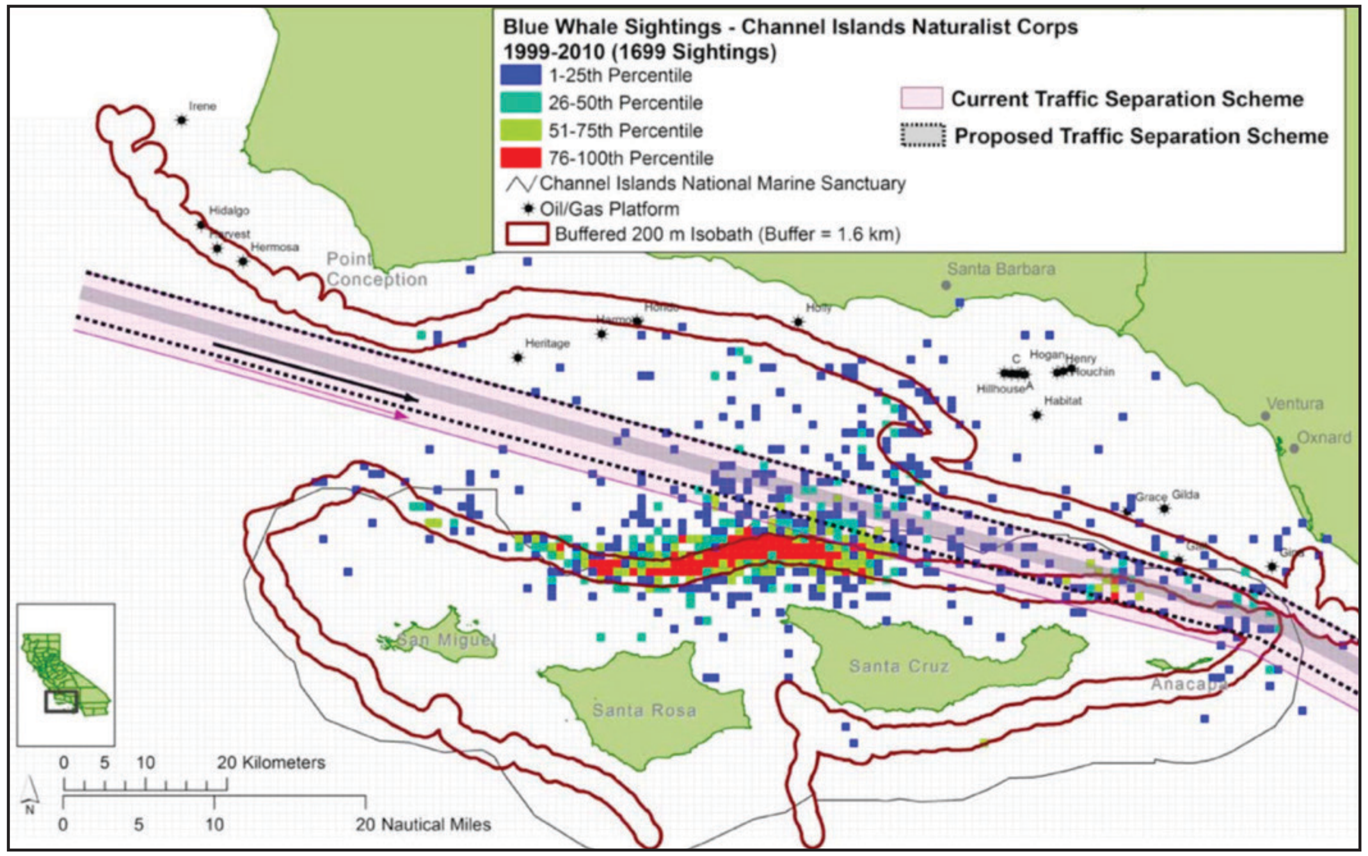


Figure 20: Map showing the 2013 relocation of the Traffic Separation Scheme in the Santa Barbara Channel. The shift one nautical mile further inshore would avoid some of the more densely used blue whale feeding grounds. Source: National Marine Sanctuaries. Resource Protection: https://sanctuaries.noaa.gov/protect/shipstrike/policy.html

4.3.5 LESSONS LEARNED

Overall, mitigation measures undertaken in the Santa Barbara Channel are viewed as successful.

1. The secondary benefits of the measures initially designed to reduce emissions and air pollution from shipping have been clearly shown to reduce the risk of ship strikes to whales. A study published in 2018 demonstrated that large freight vessels decreased their speed by 3 to 6kn between 2008 and 2015, and that vessel speeds in the channel fell from an average of 22.7 miles per hour to 15.4 miles per hour in the same time period. However, changes in speeds and routing varied from one year to the next depending on the strongest incentives that were in place at the time. The study estimates that recent changes led to roughly a 20 per cent reduction in lethal ship-strike risk.[228]
2. The lack of mandatory speed restrictions has resulted in some vessels still traveling at speeds that pose a higher risk of lethal ship strikes,[227,228] with varying rates of compliance, especially outside of the immediate port approach areas.[239] It also places a great deal of importance on the industry/port-led incentive schemes.[227] These schemes are largely driven by a desire to reduce emissions and air pollution, rather than to reduce ship-strike risks. This may be effective in countries or regions with similar clean air targets, and/or with shipping companies concerned with cultivating an eco-friendly image, but less effective in other regions.
3. A study published in 2017 by Rockwood et al. estimated that despite measures being undertaken in the Santa Barbara Channel, ship-strike risks to blue, humpback and fin whales along the west coast of the United States were still 7.8, 2.0 and 2.7 times higher respectively than the calculated sustainable limits for these species. The authors conclude that further monitoring and mitigation are required to adequately protect these species, using a combination of shipping lane modifications and relocations, ship speed reductions and creation of more ATBA in ecologically important areas.[142]
4. One study concluded that when vessels temporarily avoided the channel and moved further offshore, ship-strike risk and underwater noise was reduced in critical blue whale habitats, but may have created increased risks to other species that are generally found further offshore, such as fin whales.[109]
5. These recommendations are further supported by a 2020 study by Redfern et al., which concluded that humpback and blue whale distributions off the coast of California have remained fairly constant between 2008 and 2015, while shipping patterns have varied significantly over that period, causing the ship-strike risk to shift between offshore and inshore locations. The study confirms that this apparent stability of preferred whale habitat for these species means that permanent routing measures or the designation of ATBA are potentially effective. However, some changes in fin whale distribution over the years in relation to oceanographic changes requires constant monitoring and evaluation to ensure that measures remain relevant to species' distribution.[109]
6. As of 2016, the Channel Islands Sanctuary Marine Shipping Working Group determined several areas for future efforts to reduce ship-strike risks, including:
   - Various extensions and/or improvements to routing measures, including expanding the ATBA in the Channel Islands Sanctuary so that it extends to the Western Route south of the Channel Islands, and the designation of a PSSA in the area with region-wide vessel speed restrictions;
   - The use of passive acoustic monitoring to inform dynamic management measures, as well as the use of thermal imaging to detect whales and use detections to trigger management responses;[146,148]
   - The use of more regular aerial surveys and expansion of third-party/mariner reports to better understand whale distribution over time, and the establishment of a single centralized data repository for these sightings.

4.4 PORT-LED INITIATIVES TO REDUCE UNDERWATER NOISE AND VESSEL DISTURBANCE FOR KILLER WHALES

CASE STUDY AT A GLANCE	
Target species for protection	Southern Resident Killer Whales
Location	Transboundary waters of the Northwest Pacific coast (US and Canada)
Primary mitigation measures applied	Port-led initiatives for quieter, cleaner, slower vessels, re-routing of shipping lanes, vessel slowdowns
Main stakeholders (catalyzing process)	Port of Vancouver, public (concerns on killer whales and increased vessel traffic), potential legal implications of damaging designated critical habitat.
Key stakeholders (implementing measures)	ECHO program: Ports, pilots, shipping industry and regulators with support of Advisory Working Group that includes stakeholders noted above plus scientists, First Nation Individuals and conservation groups.
Year first measures implemented	2017

4.4.1 CONTEXT

Killer whales, also called Orcas (for their scientific name Orcinus orca) are long-lived mammals that spend their lives in closely bonded female-led family groups called matrilines. The Pacific Northwest boundary waters between the United States and Canada, around Vancouver Island and the Olympic Peninsula of Washington State, provide important habitats.[240] Southern Resident killer whales are listed as Endangered under Schedule 1 of *Canada's Species at Risk Act*, are designated Endangered under the United States' *Endangered Species Act* and depleted under the United States' *Marine Mammal Protection Act*.

The number of Southern Resident killer whales has hovered between 70 and 99 individuals since 1976, with a current estimated population in the low 70s.[240] They feed primarily on Chinook salmon, and are found in the Salish Sea around Vancouver Island, where they encounter a range of threats including depletion of their preferred prey due to damming of salmon-spawning rivers, contaminants in their environment and prey, and, perhaps most significantly, disturbance from vessel traffic and underwater noise.[84,160,240,241]

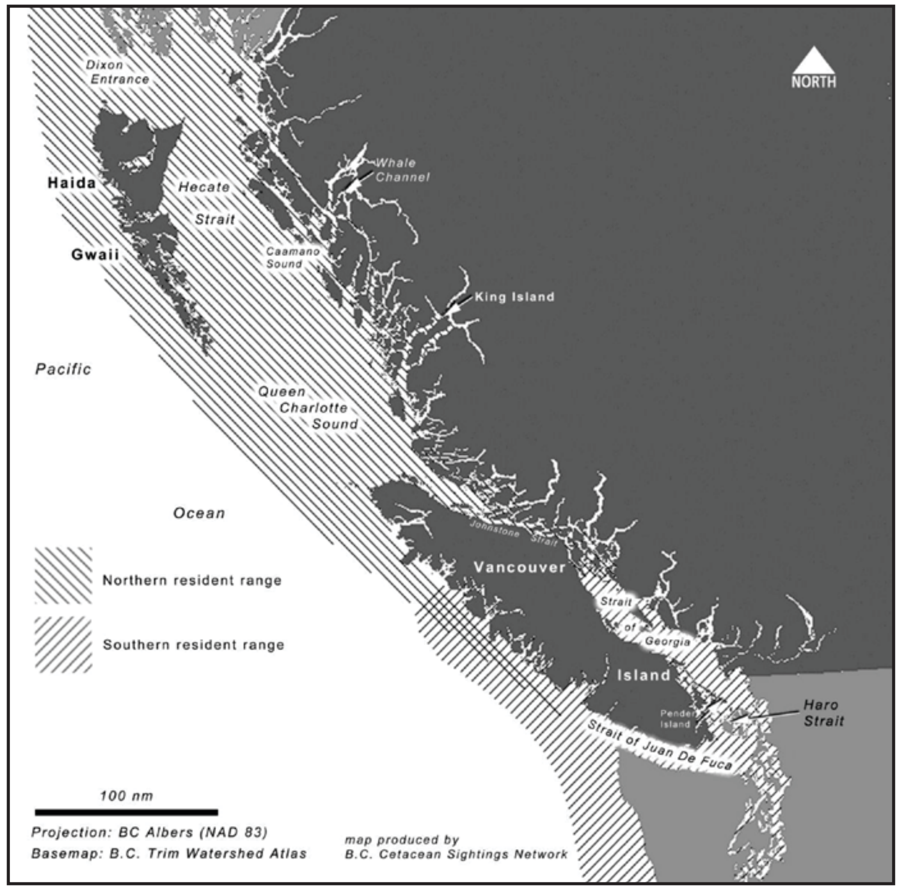


Figure 21: Ranges of threatened Northern Resident Killer Whales and endangered Southern Resident Killer Whales in the transboundary area between the United States and Canada. Source: Fisheries and Oceans Canada. 2018. *Recovery Strategy for the Northern and Southern Resident Killer Whales (Orcinus orca) in Canada*. Fisheries and Oceans Canada, Ottawa. 84pp.

The transboundary waters between British-Columbia (BC) and US in the Salish sea also support Biggs Killer Whales, Humpbacks, Minke whales as well as Gray Whales, which are also vulnerable to ship strikes and underwater noise from vessel traffic in the area. Concerns about ship-strike risks and vessel-generated underwater noise have featured in both Canada and the United Sates' recovery plans for these species,[240,242] but addressing threats requires collaboration and input from a range of industry and other non-government stakeholders.

4.4.2 IMPACTS

Vessel traffic in the Pacific Northwest transboundary area has been shown to have potentially serious impacts on resident killer whales' behavior and is thought to play a role in the Southern Resident killer whales' continued low numbers.[238] Due to their popularity as targets of both commercial and recreational whale watching, Southern Resident killer whales are regularly surrounded by small- to medium-sized craft, in addition to being exposed to high densities of passenger ferries traveling between the mainland and islands in the Salish Sea, and even larger vessels traveling to and from the ports of Vancouver and Seattle. Impacts from both small and large vessels have been studied and mitigated. Here we focus on impacts from large commercial vessels.

Studies focusing on the impact of larger ships on the resident killer whale populations conclude that whales are frequently in close proximity to ships, and that noise generated by these ships extended into the higher frequency ranges used by toothed cetaceans including killer whales, potentially interfering with their communication and echolocation.[158] Exposure levels to URN from different categories of vessels, ranging from recreational vessels to tug boats and container vessels, were high in the killer whales' core habitat in the Salish Sea.[160] The risk of ship strikes resulting from the co-occurrence of whales and ships in these narrow straits between islands has also been modeled and deemed to be significant for fin, humpback and killer whales.[243]

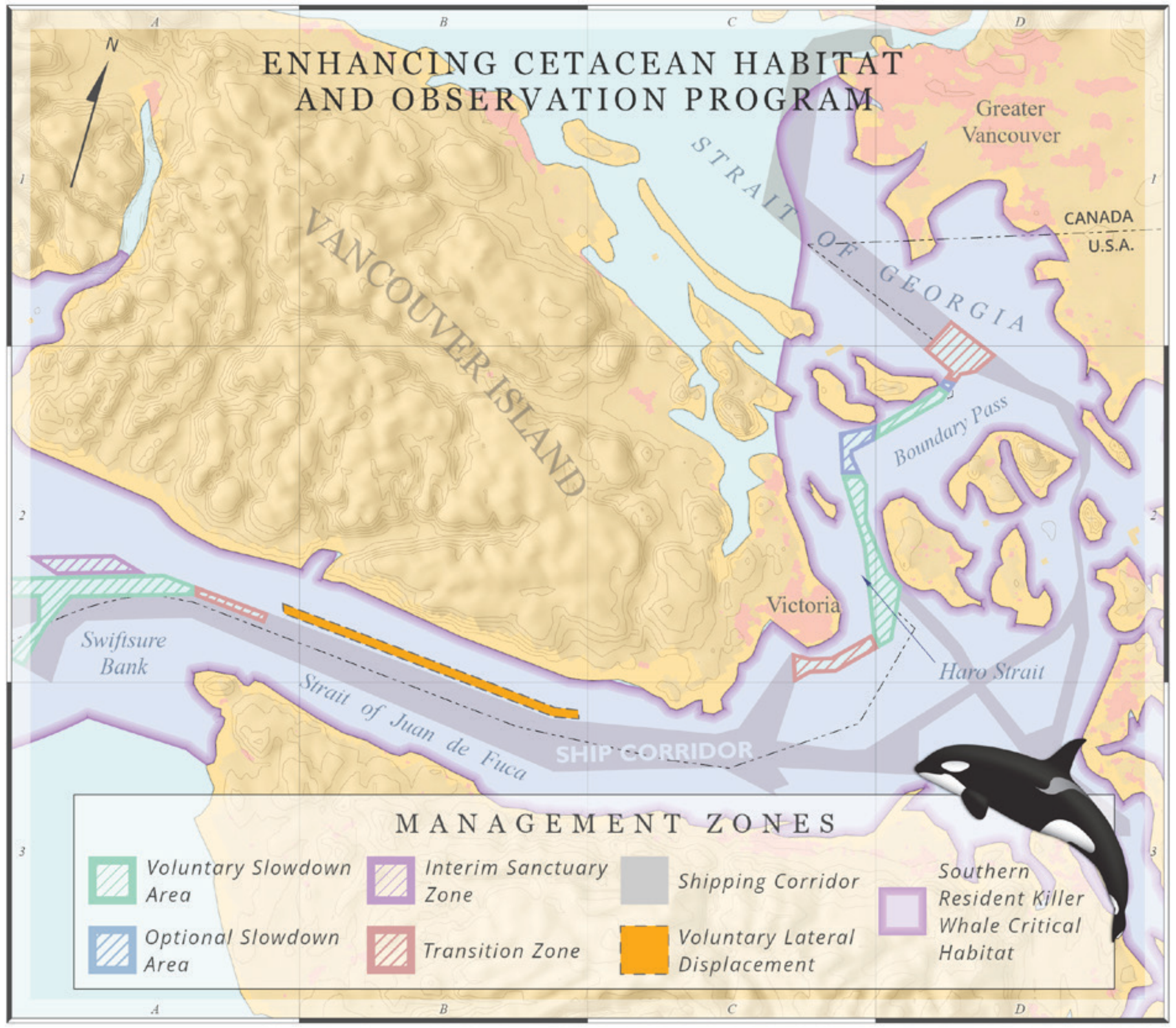


Figure 22: Cetacean-use areas and shipping intensity off the Canadian west coast. The ECHO program focuses on the cumulative effects of commercial shipping activity on at-risk whales along the southern coast of British Columbia.

4.4.3 MONITORING MEASURES

Southern Resident Killer Whales and their habitat are monitored through a range of initiatives undertaken by Canadian and US government authorities, research institutions and NGOs.

Monitoring of killer whales and other whale species in the region is conducted through:

- **Aerial surveys:** Transport Canada's National Aerial Surveillance Program and Fisheries and Oceans Canada's National Fisheries and Enforcement Surveillance Program both include aerial surveillance to monitor whales, as well as vessel compliance with mitigation measures. These focus more on small vessels engaged in commercial and recreational whale watching than large vessels.
- **Vessel surveys:** Vessel surveys are undertaken by different research groups, including government agency scientists, to monitor killer whale distribution, behaviour, and health, and to document the distribution and (seasonal) movements of other whale and dolphin species in the area. These include broad-scale line transect survyes,[244] as well as studies that include focal follows of individual whales or groups of whales to monitor their behavior in response to various conditions (presence or absence of vessels, noise, etc).[86]
- **Health assessments of killer whale populations:** Health studies are being conducted using drones and aerial photogrammetry to asses body condition.[245]
- **Passive acoustic monitoring:** Passive acoustic monitoring is used to detect whale vocalizations throughout the core resident killer whale habitat at different times of year[244] and to detect changes in their vocal behavior in the presence of vessels.[247]
- **Citizens and citizen science groups:** The Saturna Island Marine Research Education Society Marine Research and Education Society (SIMRES) in Canada and Beam Reach in the US have hydrophones in the water. Several citizen science enthusiasts track daily movements of Southern Resident killer whales with informal observation networks that include information from the whale watching fleet.

Monitoring of vessel traffic in whale habitat is achieved through:

- **Aerial surveys:** These surveys are conducted by Transport Canada and Fisheries and Oceans Canada to monitor vessel compliance with regulations.
- **Passive acoustic monitoring:** This is used to measure shipping noise and ambient noise in heavy shipping lanes and in core whale habitat.[248]
- **Vessel surveys/coast guard:** Whale watching and recreational vessels are monitored by NGOs, including the Whale Museum's Soundwatch program in the US,[249] Cetus' Straitwatch program in Canada, and government agencies responsible for enforcement of regulations.
- **AIS:** AIS is used to monitor large vessels using the area, and to map their movements and densities in relation to whale distribution.[250,251]
- **BC Coast Pilots:** BC coast pilots are present on all large commercial vessels coming into the port of Vancouver. During the slowdown period, pilots provide a report of vessel speeds as well as vessels participating in slowing down.

4.4.4 MITIGATION MEASURES

Mitigation measures employed to reduce the impact of vessel traffic on resident killer whale populations in the transboundary region of the Northwest Pacific include several implemented by the Canadian and US governments, as well as by ports and shipping companies.

- **Speed reductions:** Speed reductions have been encouraged and implemented by several ships using the Vancouver Port. Through the Vancouver Fraser Port Authority-led Enhancing Cetacean Habitat and Observation Program (ECHO), the Port led a voluntary slowdown initiative through the narrow Haro Strait, which was trialled for the first time in 2017 and shown to be an effective way of reducing shipping-generated underwater noise,[248] leading to subsequent trials in 2018, 2019[252] and 2020.
- **Routing measures:** In 2018, Vancouver Port (again through its ECHO program) collaborated with Transport Canada, supported by the United States Coast Guard, Fisheries and Oceans Canada, the Canadian and US marine transportation industry, to implement a trial to move vessel traffic as far south as possible in the inshore area and outbound shipping lane of the Strait of Juan de Fuca to avoid overlap between ships and whales and reduce underwater noise in killer whale feeding areas.
- **Vessel quieting technology:** The Port of Vancouver commissioned a comprehensive review of the methods that could be applied to reduce underwater noise generated by ships[179] and provides financial incentives for ships to apply these methods by offering reduced docking fees.

These mitigation measures are supported by the following management measures and programs:

- **Port-led ECHO Program:** The Vancouver Fraser Port Authority launched its ECHO program in 2014. ECHO Advisory Working Group consists of members drawn from various vessel sectors of the shipping industry, federal regulators, First Nation individuals, researchers and conservation groups. The program has worked with the advisory working group to develop a common understanding of the underwater noise impacts on Southern Resident killer whales and potential solutions through commissioning research and assessments to inform the program. Since 2017 the program has undertaken trials to slowdown vessels in killer whale habitat and/or move vessels away from killer whale habitat. Main elements of the program that incentivize ship owners to reduce ship-strike risk and shipping-related underwater noise are (see https://www.portvancouver.com/environment/water-land-wildlife/echo-program/ for more detail):
  - » The creation of awareness-raising tools for ship owners and other stakeholders to incentivize and facilitate the implementation of measures to reduce vessel impacts on vulnerable whales, including infographics, identification guides and a "whales in our waters" tutorial developed with BC Ferries in partnership with OceanWise.
  - » Voluntary slowdown trials through the Haro Strait and Boundary pass. These were conducted in collaboration with research teams that were able to monitor the impact of these trials and publish them in peer-reviewed journals;[248,250]
- **Swiftsure Bank voluntary ship slowdown trial.** Beginning in 2020, the ECHO Program is coordinating a voluntary slowdown trial off the southwest coast of Vancouver Island, a known area of importance for Southern Resident Killer Whales and other marine mammals.
- **Sightings reporting networks in British Columbia and the United States:** These include the B.C. Cetacean Sightings Network, which is supported by the WhaleReport Alert System (WRAS) smart phone app. Sightings reported through this app are used to alert commercial mariners in the area to encourage them to slow down below propeller cavitation speed or take evasive action.
- **A voluntary inshore lateral displacement trial** in the Strait of Juan de Fuca;
- **Port Incentive Program – EcoAction:** Incentives for quiet ships through the offering of reduced harbor fees for vessels that can demonstrate the application of noise-reduction measures (including slowdowns, certificates of quiet ships from classification societies etc – see Appendix 1 and Section 3.5 for more detail). Participating vessels have been steadily increasing over the years;

CANADIAN WEST COAST

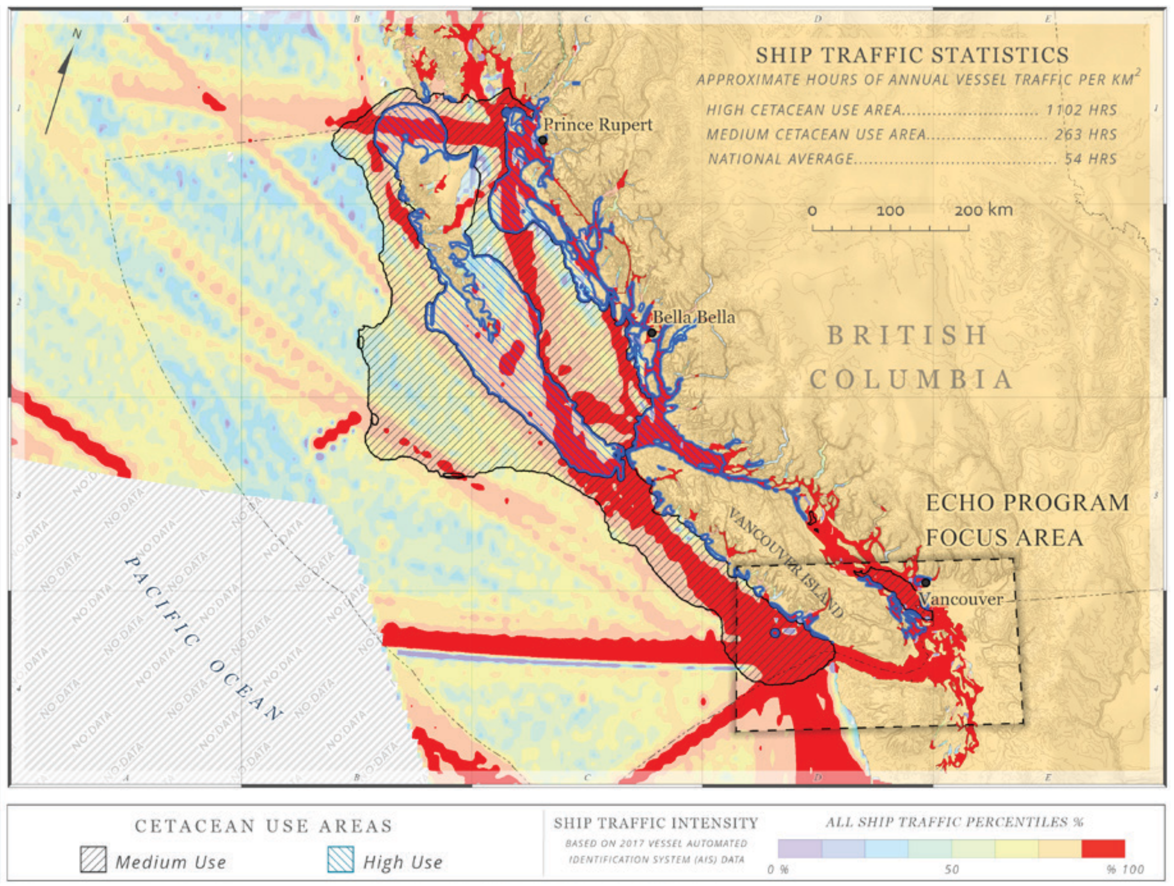


Figure 23: Voluntary management measures in southern resident killer whale critical habitat established by the ECHO program.

4.4.5 LESSONS LEARNED

The geography of the Pacific Northwest, with its restricted straits and multiple islands, makes it difficult to apply mitigation measures that successfully keep vessels away from whales. The ports of Vancouver and Seattle cannot be accessed without navigating these relatively narrow water ways, and options for moving shipping lanes are limited. In the absence of international or national regulation to mandate slowdowns or areas to be avoided, the shipping industry, incentivized by one of the main ports in the region, has played a major role in reducing threats. Reflections and lessons learned to date include:

- Passive acoustic monitoring studies to measure the noise reduction resulting from the 2017 voluntary slowdown trial concluded that the trial was effective in reducing mean broadband underwater noise source levels for container ships (11.5dB), cruise vessels (10.5dB), vehicle carriers (9.3dB), tankers (6.1dB) and bulkers (5.9dB).[250] Another study of the same trial determined that the slowdowns led to a 22 per cent reduction in "potential lost foraging time" for southern resident killer whales, which could have increased to a 40 per cent reduction if all vessels had complied to reduce speeds to 11kn or less. Slower vessel speeds effectively reduced underwater noise in the targeted area despite longer passage times.[248]

- The success of the trials may be linked to their focus on specific restricted geographical areas and the time frame of the trials, which focused on the time of year that Southern Resident killer whales are most likely to be present in the approaches to the Vancouver Port (July to October). Monitoring and reporting of the trials' effectiveness also provides important incentives for voluntary participation and compliance in subsequent years.

- The continued implementation of the measures each year since 2017 has been possible with strong cooperation and trust built within the ECHO program and its Advisory Working Group that brings together industry, regulators, First Nation Individuals, scientists and conservation groups. Since 2017, the ECHO program has adapted its approach to find more optimal outcomes for speed reduction while minimizing costs of slowdown to shipping operations and increasing participation levels. Advancements since 2017 have included implementation of a dynamic start and stop to the slow down period based on the presence of Southern Resident killer whales in the area, expansion of the slowdown area, refinement of slow down speed regime. The federal government has also provided modest financial reimbursements to offset on extra pilotage fees and costs incurred by vessel for slowing down.

- One of the concerns around industry-led measures is that they are not enforceable and have required an enormous investment of time and money by the Port of Vancouver and industry to coordinate and implement. It is also costly to maintain and operate the acoustic monitoring infrastructure and science assessments required for such a program. Part of the concerns around continued sustainability of the measures and resourcing was allayed by a conservation agreement that the Port and Shipping Industry associations signed in 2019 with the Government of Canada to continue to undertake the measures to reduce threats to Southern Resident killer whales until 2024 through the ECHO program. The conservation agreement is a commitment to continue to implement the ECHO program and its measures for a 5-year period in an adaptive way with improvements and funding commitments. However, there is no legal or other implications for failing to implement the agreement.

- For now, the ECHO program continues to demonstrate that voluntary slowdown and rerouting measures are achieving high rates of participation and threat reduction from existing levels of shipping. Nonetheless, Southern Resident Killer Whales in the Salish sea continue to face increases of shipping and port development. Operational measures can only do so much even if they are mandatory. Relevant national and international authorities should consider setting noise reduction goals or limits for noise pollution and expedite the passage of requirements for much quieter vessels.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5. CONCLUSIONS:
WHAT WE HAVE LEARNED AND WHAT WE CAN RECOMMEND

The case studies and literature reviewed in this report allow us to draw out a few key lessons about the mitigation measures that are most likely to be effective in reducing the risk of ship strikes and the impact of shipping-generated underwater noise on cetaceans.

These lessons allow us to distil recommendations for best practice that policymakers and other stakeholders around the globe can bear in mind when addressing the impacts of shipping in their own contexts:

LESSON

The literature and case studies reviewed here all concur that some form of place-based management is most effective in reducing ship-strike risks in identified high-risk areas, particularly where cetaceans have relatively stable distributions. The most effective measure is to designate areas where vessel traffic is prohibited, thus removing the risk that ships encounter whales or disrupt whales' critical life functions with vessel-generated underwater noise. ATBA and TSSs are measures that the IMO can use to ensure vessels stay away from whales. Where it is not possible or practical to prohibit vessels from important habitat, the designation of MPAs or other management areas with clear boundaries can make it easier to implement and enforce specific mitigation measures. This is especially true if the boundaries fall within the Exclusive Economic Zone of a nation that has designated resources for monitoring of compliance with measures.

RECOMMENDATIONS

- **Use IMO routing measures wherever possible and practical:** In areas where a high degree of co-occurrence between vessel traffic and whales has been determined to present a threat to whales, national and regional policymakers should follow IMO procedures to present proposals for the endorsement and implementation of routing measures (summarized in Section 3.2.1).
- **Designate MPAs or well-defined management areas where specific mitigation measures can be implemented:** The creation of MPAs or clearly defined management areas that encompass important whale or dolphin habitat can make it easier for task teams to implement, monitor and effectively enforce measures to reduce threats from shipping in those areas. They can also make it easier for shipping industry stakeholders to understand when they are entering sensitive habitat.

LESSON

Slowing vessels down to speeds of 10kn or lower is viewed by many as a key way to reduce the impacts of shipping on whales and the environment in general.[125] Where slowdowns have been systematically implemented, the risk and actual incidence of ship strikes has been reduced[104,214] and underwater noise has also significantly decreased.[248,253] Slowdowns are the single most effective and practical measure to reduce the impacts of shipping on cetaceans, with further justifications linked to other lessons and recommendations below. Slowdowns can be voluntary and industry-led or incentivized, as demonstrated in the Santa Barbara and Vancouver case studies, or mandated by legislation, as demonstrated in the Stellwagen Bank Sanctuary case study. There is a growing body of support to make slowdowns globally mandatory through the IMO.

RECOMMENDATIONS

- **Encourage speed restrictions in known whale habitats:** Stakeholders at all levels, whether local, national, regional or international, should work to encourage and implement slowdowns to 10kn or less in areas where vessels and whales overlap in densities that incur a significant risk of ship strikes.

LESSON

Examples of successful mitigation efforts have invariably involved extensive collaboration between a range of stakeholders, starting with scientists who provide evidence of risks or scale of impact to cetaceans, and relying on industry and policymakers to incentivize and/or mandate mitigation measures. Policymakers can be local (e.g. MPA managers), national or international (e.g. IMO). A wider range of stakeholders can be involved in analyzing evidence, evaluating monitoring and mitigation options, and implementing and enforcing chosen strategies.

RECOMMENDATIONS

- **Use science-based risk assessment and solutions:** Mitigation measures must be based on the best science available to ensure that they adequately address the threats based on whales' distribution and behavior, as well as the distribution and speed of vessels in areas of potential co-occurrence. This needs to expand to areas where little targeted cetacean research has been conducted, but cetaceans are known or suspected to be found in areas with dense vessel traffic. Risk modeling and assessments should also find ways to incorporate the long-term impacts of exposure to underwater noise in terms of increased energy budgets required to avoid sound sources or prolonged increase stress levels that may impact individual and population-level fitness.
- **Use data to support the precautionary principle:** In "data-poor" contexts, where whales and ships are known to co-occur but data on whale distribution and habitat use is limited, what has been learned in a well-studied region (either from the same species or a closely related species with similar behavior) can be used to model habitats and distributions until case-specific data can be collected.[100] In settings where data does not indicate predictable distributions of cetaceans that would ensure the effectiveness of routing measures through the IMO, permanent speed restrictions can be implemented to immediately reduce risks.
- **Encourage multi-stakeholder collaboration:** Collaboration between researchers, industry, civil society, policymakers and enforcement agencies is most likely to lead to effective measures. Where cetacean populations migrate across national borders, multi-lateral cooperation is needed to ensure successful management. Case studies demonstrate that this collaboration works best when it is formalized by the formation of panels or commissions that include representation from different sectors. In some settings, these may be led by government bodies or MPA managers, while in others they may be led by port authorities or research organizations.

LESSON

There are many marine areas where cetacean populations have used the same habitat either seasonally or year-round for decades, and these areas can be clearly defined for management. However, climate change is leading to oceanographic changes that in turn affect the timing and location of whales' migrations and alter many species' preferred feeding habitats. Changes to the world economy and global pandemics can have significant impacts on the patterns and densities of shipping traffic. Mitigation measures need to be designed so that they can adapt to these changes, for example, when whales arrive at feeding grounds two weeks earlier than expected, or vessels change their routes to avoid emissions regulations.

RECOMMENDATIONS

- **Continually monitor and evaluate:** This ensures that existing measures remain effective, and new measures make use of good monitoring methods as outlined in Section 3.1. Where budgets and capacity allow it, regularly timed ship or aerial line transect surveys are effective means to monitor the distribution and abundance of cetacean populations. However, measures of relative abundance or encounter rates are sufficient to detect distribution or density changes, and surveys to obtain this data need not be as time- or cost- intensive as those designed to estimate absolute abundance. Satellite tagging studies can offer more refined insight into a whale's movements in relation to shipping traffic, but only for a limited time and a limited number of individuals. Passive acoustic monitoring can be used to assess cetaceans' locations, and vocal behavior in relation to shipping noise, and the levels of URN they are likely to receive from shipping. Monitoring of vessel traffic is becoming increasingly sophisticated with the use of AIS, land-based stations and/or passive acoustic monitoring, and underwater noise can and should also be continually monitored in important cetacean habitats, high-density traffic areas and where new shipping routes may become available due to changing environmental conditions.
- **Be adaptive:** Adaptive management will allow policymakers to review data from monitoring efforts and adjust mitigation measures as and when required. Adaptation will be easier if collaborative and formalized structures are in place to coordinate communication between relevant stakeholders.

LESSON

The North Atlantic right whale case study illustrates that even once mandatory speed reduction measures are in place to mandate vessel speed reductions, compliance can be low and may require years of targeted and effective outreach and communication.

RECOMMENDATIONS

Choose and develop communication tools for effective implementation and compliance: Whether measures are voluntary or mandatory, shipping companies and pilots must be made aware of when and where management measures are in effect. This is particularly the case for dynamic management measures that may be triggered by whale presence.[169,218] A combination of rewards or incentives for compliance and negative consequences for non-compliance may be required.[33,239]

LESSON

The Santa Barbara case study indicates that when vessels temporarily avoided the channel and moved further offshore, ship-strike risk and underwater noise was reduced in critical blue whale habitats, but may have increased risks to other species further offshore.[109] Other studies show that shipping routes that reduce ship-strike or underwater noise risks for one nearshore species such as humpback whales, may actually increase the risk for species like fin whales with an offshore distribution.[254]

RECOMMENDATIONS

- **Consider multiple species when designing mitigation:** While a focus on a particular endangered species may be useful to motivate stakeholders to act, data and science used to inform mitigation strategies should consider the distribution and behavior of all whale species as well as other taxa (e.g. seals, sea-lions, marine turtles) in a particular area. This will ensure that designating an ATBA or shifting shipping lanes from an area that is important for one species does not displace risk onto another species.

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LESSON

The concept of "Dynamic Avoidance" requires clear definition and understandings of the settings in which it is likely to be effective, and when it is likely to be ineffective. A system that alerts managers and vessels to the seasonal presence of whales can be effective in reducing risk, as demonstrated by the Dynamic Management Areas implemented for North Atlantic right whales. However, schemes that rely on on-board observers or technology to provide real-time alerts to whales in ships' paths may not be effective for large vessels that are unable to quickly change course and speed. Furthermore, unplanned slowdowns or re-routing measures are likely to be more disruptive to shipping or ferry transport schedules than permanent schedule changes that take into account slower transit times.[181]

RECOMMENDATIONS

- **Advocate for permanent or seasonal measures where possible over real-time dynamic avoidance measures:** Real-time alert systems are useful to alert marine users to the presence of whales in a wider management area and thus trigger seasonal or dynamic management measures that require all vessels in the area to slow down. However, only smaller, more manoeuvrable vessels will be able to effectively implement any system that operates on the assumption that an individual vessel will be able to effectively avoid a whale or group of whales based on a real-time observation or report.

LESSON

In the absence of global or national mandatory routing measures, slowdowns or noise-reduction measures, mitigation can be driven by industry. These have proven extremely effective in the case studies featured here from Vancouver and Santa Barbara. However, if we rely on industry to fund research and incentivize mitigation, effective measures are likely to be limited to the regions where resources, capacity and awareness are abundant. This may leave many of the world's most vulnerable cetacean populations at risk.

RECOMMENDATIONS

- **Encourage port-led incentive measures and industry certification schemes:** Port authorities are encouraged to maintain and/or develop partnerships and incentive schemes that support research and monitoring and incentivize vessels using their ports to adhere to measures that reduce underwater noise and ship-strike risk. At the same time, it may be useful to consider other ways to facilitate voluntary industry initiatives to reduce the risks they pose to cetaceans. For example, inclusion of ship-strike and underwater-noise measures in the Formal Safety Assessment Framework used by the IMO (see Sebe et al. 2019).[255]

- **Encourage member states to support a review of the IMO guidelines to reduce underwater noise from shipping, so that these incorporate new technology and are implemented on a broader scale by member states and industry stakeholders:** Research shows that implementation of the 2014 voluntary measures to reduce underwater noise from shipping is low and therefore not effective. Stakeholders at all levels should be collaborating with the IMO to work toward updating and refining these guidelines and ensuring that they are more widely implemented. Efforts are underway to encourage the IMO to consider mandatory adoption of the 2014 voluntary guidelines to reduce underwater noise from shipping[123,256,257] and adopt a resolution on slow steaming for global fleets. These efforts should continue.[256,257]

- **Encourage the development of quantifiable noise-reduction targets and/or noise thresholds for the IMO, the EU and other bodies with the mandate to regulate shipping and/or set the standards for "Good Environmental Status":** The IWC has recently convened experts to help develop recommendations on a realistic IMO noise-reduction target.[258] The EU has also commissioned research and advice on developing noise thresholds that can help determine whether a marine environment meets Good Environmental Status criteria for underwear noise.[259] As these efforts by the EU continue, expert groups and member states should make the approaches and methods developed to regulate underwater noise under the EU Marine Strategy Framework Directive publicly available, so non-EU countries can consider implementing similar initiatives.

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APPENDIX 1:

SUMMARY OF VESSEL MODIFICATIONS AND MAINTENANCE ACTIONS THAT CAN REDUCE UNDERWATER NOISE

Table 2: Summary of vessel modifications and maintenance actions that can reduce underwater noise. Adapted from Envirochem Hemmera, *Vessel Quieting Design, Technology, and Maintenance Options for Potential Inclusion in EcoAction Program Enhancing Cetacean Habitat and Observation Program.* 2016, Vancouver Fraser Port Authority. p. 38.

VESSEL QUIETING METHODS	DESCRIPTION OF TECHNOLOGY AND POTENTIAL UNDERWATER NOISE REDUCTION MECHANISMS
Kappel propellers	The tips of this propeller are smoothly curved towards the suction side of the blades. This reduces cavitation.
New blade section propellers (NBS)	A high propulsive performance and compact propeller. The diameter is approximately 5 per cent smaller and the weight is approximately 20 per cent lower than conventional propellers. This might provide higher efficiency and reduce cavitation.
Propeller Boss Cap Fins (PBCF)	Small fins attached to the propeller hub and designed to reduce the magnitude of the hub vortices, thereby recovering the lost rotational energy and reducing cavitation.
Propeller Cap Turbine	This propeller comprises several hydrofoil-shaped blades integrally cast into the hub cap. Energy from the rotating fluid coming from the propeller hub is recovered, resulting in energy savings but a link to underwater noise reduction is unconfirmed.
Twisted rudder	The propeller is designed to account for the swirling flow from the propeller. This may increase propeller efficiency but a link to underwater noise reduction is unconfirmed.
Rudder fins	The propeller is designed to recover some of the rotational energy. This may increase propeller efficiency but link to underwater noise reduction is unconfirmed.
Costa Propulsion Bulb (CPB)	The propeller is integrated hydrodynamically with the rudder by fitting a bulb to the rudder in line with the propeller shaft. This is claimed to reduce underwater noise.
Schneekluth duct	Designed to improve the flow to the upper part of the propeller, which causes the formation of cavitation at the blade tips to be less pronounced, resulting in lower pressure pulse levels. This may increase efficiency of propellers and reduce cavitation by improving wake inflow.
Mewis duct	These ducts aim to improve flow into the propeller, but few details are available. This may improve the wake, increase the propeller efficiency and reduce cavitation/vibration.
Simplified compensative nozzle	This design improves the flow into the propeller. The improved efficiency is achieved by re-shaping the nozzle (more vertical or cylindrical shape, as opposed to circular) to improve uniformity of wake flow into the propeller. This may increase propeller efficiency and reduce propeller noise.
Grothues spoilers	These spoilers consist of a small series of curved fins attached to the hull just ahead of the propeller. They straighten the flow into the propeller, thereby improving the propeller efficiency, and potentially reduce propeller noise.
Pre-swirl stators/vortex generators	Vortex generators are added appendages used to improve the wake flow, which can reduce propeller vibration and cavitation.
Air injection to propeller and bubble curtains	A bubble curtain is a system that produces bubbles in a deliberate arrangement and the bubbles act as a barrier or a curtain, breaking or reducing the propagation of sound from the propeller or the hull. Air injection can be used to minimize cavitation erosion in propeller ducts.
ALTERNATIVE FORMS OF PROPULSION TO CONVENTIONAL PROPELLERS	
Water or pump jet	A system that creates a jet of water for propulsion. This type of propulsion could potentially reduce noise or create a noise at different frequencies relative to conventional propellers and requires further research.
Podded drivers	Propellers placed in pods that can be rotated to any horizontal angle (azimuth), making a rudder unnecessary. This type of propulsion could potentially reduce noise relative to conventional propellers and requires further research.

VESSEL QUIETING METHODS	DESCRIPTION OF TECHNOLOGY AND POTENTIAL UNDERWATER NOISE REDUCTION MECHANISMS
Regular propeller cleaning/repair	Propeller cleaning and repairs done in dry dock or underwater using divers. This can reduce propeller cavitation and reduce turbulence, which increases efficiency.
Regular cleaning of the hull	Hull cleaning done in dry dock or underwater using divers. This can reduce turbulence and therefore related noise.
HULL COATING	
Decoupling coating	A layer of material, generally consisting of visco-elastic tiles, typically a few centimeters thick and containing air cavities, which reduces the radiation efficiency of the hull and thus reduces transmission of underwater noise from the hull into the water.
Anti-fouling paints	Coatings and other methods generally used to prevent fouling of the hull. Reduced fouling improves water flow and reduces turbulence-related noise.
Non-stick coating	
Biocides	
Differential electrical charge	
Prickly coating	
PROPELLER AND DEVICES DESIGNED, SELECTED OR MODIFIED TO REDUCE CAVITATION AND IMPROVE WAKE FLOW (DESCRIPTIONS ADAPTED FROM ACCOBAMS, 2013)	
HIGH SKEW PROPELLERS	This propeller has the combined effect of causing the blade to pass through the varying wake field (particularly near the top of the cycle) in a more gradual manner, improving the cavitation pattern on the blades.
CONTRACTED AND LOADED TIP PROPELLERS (CLT)	These propellers are designed with an end plate which reduces the tip vortices, thereby enabling the radial load distribution to be more heavily loaded at the tip than with conventional propellers. Therefore, optimum propeller diameter is smaller, and cavitation may be reduced.
VESSEL QUIETING METHODS	DESCRIPTION OF TECHNOLOGY AND POTENTIAL UNDERWATER NOISE REDUCTION MECHANISMS
Twin propeller arrangement	Propellers placed in pods that can be rotated to any horizontal angle (azimuth), making a rudder unnecessary. This type of propulsion could potentially reduce noise relative to conventional propellers and requires further research.
USE OF QUIETER ENGINES	
Steam/gas turbines	Steam or gas turbine systems.
Diesel-electric	Diesel-electric systems. These are quieter than conventional two-stroke diesel engines.
LNG-fuelled, gas and steam turbine powered (COGAS), and electrically driven	This combination of technologies is used in a type of vessel to drive the engine and could lead to engine noise reductions relative to conventional engines.
REDUCTION OF ON-BOARD ENGINE AND MACHINERY NOISE	
Elastic mountings	Flexible mounts that connect two parts and are used for vibration isolation to reduce noise.
Structural reinforcements	Structural reinforcements of the main engine foundations. These reinforcements reduce onboard vibration transmission to the hull.
Hull form design or modification	A well-designed hull form will require less power for a given speed, which is likely to result in less noise. Such a hull will also likely provide a more uniform inflow to the propeller, thereby increasing the propeller's efficiency, and reducing noise and vibration caused by the uneven wake flow. This will further reduce the underwater noise.

APPENDIX 2:

IWC SUMMARY TABLE OF SHIP-STRIKE MITIGATION MEASURES IMPLEMENTED WORLDWIDE

Table 3: Summary of ship-strike mitigation measures implemented worldwide. Source: International Whaling Commission, available on https://iwc.int/ship-strikes. Further details of the measures given as examples can be found in SC/65b/HIM05, with a bibliography of studies relating to these examples, including evaluations of effectiveness, in SC/66a/HIM04.

MEASURE	SITUATION TO WHICH IT MIGHT BE APPLIED	IMPLEMENTATION PROCESS (AND OBSERVATIONS)	EXAMPLES
KEEPING VESSELS AWAY FROM WHALES			
Permanent routing measures through TSS, ATBA or port approach routes	Long-term patterns of whale distribution are sufficiently predictable and well understood to enable a robust analysis of the risk reduction that might be achieved.	Implemented through IMO or national regulation if within territorial sea. Proposals should follow the IMO process including data on the problem, the risk reduction achieved and implications for shipping. (Generally well respected by industry.)	Bay of Fundy, Canada Boston, USA California, USA Panama Cabo de Gata, Spain
Seasonal routing measures	Similar requirements to permanent routing but applicable where there are strong seasonal patterns in whale distribution	As above	Roseway Basin, Canada Great South Channel, USA
Recommended (voluntary) routes	Similar requirements to permanent routing through TSS or ABTA but not mandatory	Implemented by IMO or coastal state as a non-mandatory measure	Peninsula Valdez, Argentina Hauraki Gulf, New Zealand Glacier Bay, USA Ports on US east coast
Short-term (days – weeks) and Dynamic routing measures	Implemented in response to short- term observations of whale aggregations or known high risk areas. Need almost real-time reporting systems that can identify such aggregations	Voluntary measures that need to be communicated to mariners. (Can be difficult to encourage compliance.)	DMAs off US east coast Gibraltar Strait, Spain
SLOWING VESSELS DOWN			
Permanent speed restriction zones	Long-term patterns of whale distribution are predictable and well understood but routing measures are not practicable.	Can be voluntary or mandatory if implemented in national waters.	East coast of USA (mandatory) Glacier Bay, USA Hauraki Gulf, New Zealand
Seasonal speed restriction zones	As above but applicable where there are strong seasonal patterns in distribution	As above	Panama California, US Peninsula Valdez, Argentina
Dynamic Management Areas for speed restrictions	Implemented in response to short- term observations of whale aggregations or known high risk areas. Need reporting systems that can identify such aggregations	Voluntary measures that need to be communicated to mariners. (Can be difficult to encourage compliance.)	US east coast
AVOIDANCE MANOEUVRES			
Real-time alerting tools to warn vessels of the presence of whales or aggregations that allow vessels to alter course or slow down	A rapid reporting network of whale sightings or acoustic detections alerts all vessels transiting an area to the locations of whales so that they can alter course or slow down	Individually designed and implemented reporting systems	REPCET, ACCOBAMS, Mediterranean Sea WhaleAlert, Boston USA
Observations from the vessel that allow avoiding action to be taken	Only effective for vessels capable of rapid manoeuvres to avoid whale sightings (e.g. vessels of a few thousand GT or less)	Additional dedicated observers, education and outreach to mariners	Many initiatives

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