WORKING GROUP ON SHIPPING IMPACTS IN THE MARINE ENVIRONMENT (WGSHIP)

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International Council for the Exploration of the Sea
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H.C. Andersens Boulevard 44-46
DK-1553 Copenhagen V
Denmark
Telephone (+45) 33 38 67 00
Telefax (+45) 33 93 42 15
www.ices.dk
info@ices.dk

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Editors

Cathryn Murray • Ida-Maja Hassellöv

Authors

Amélie Laprade • Andreas Gondikas • Annukka Lehikoinen • Benoit Adam • Cathryn Murray • David Peel • Emmanuel Ponzevera • Eva-Lotta Sundblad • Gauthier Lequeue • Hannah Millar • Ida-Maja Hassellöv • Jacek Tronczynski • Josephine Iacarella • Jessica Redfern • Jose A. Fernandes-Salvador • Jukka-Pekka Jalkanen • Karen de Jong • Kate Brookes • Katja Broeg • Katrin Ewert • Keith Hayes • Lisa Drake • Lorenzo D'Andrea • Marja Koski • Mats Kinnula • Nathan Merchant • Octavio Marin-Enriquez • Raymon van Anrooy • Ross Culloch • Sakari Kuikka • Sarah Bailey • Sylvia Blake • Valérie Dulière • Zuzanna Kochanowicz

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i Executive summary

The Working Group on Shipping Impacts in the Marine Environment (WGSHIP) addresses the ecological impacts of shipping on the global coastal marine environment.

In 2019–2021, the working group aimed to review the current state of scientific knowledge across member countries. Thirty-four members from fifteen countries defined the scope of working group activities to include all vessel types, not limited to merchant mariners. The characteristics and intensity of vessel types may differ, but the pressures and impacts of all vessels may be considered by the working group. Beyond exhaust emissions and ballast water, many shipping-related pressures require increased knowledge and improved assessment of the full set of impacts on the environment in order to support evidence-based marine management.

The group's members conduct research on shipping-related pressures including air emissions, plastic debris, introduction of invasive species, oil spills, turbulent mixing, discharges, vessel strikes, and underwater noise. The report introduces a conceptual framework of shipping pressures under development that can be used to assess the cumulative effects of shipping. The framework was used to structure national reporting on the research activities, gaps, and opportunities for collaboration across member countries. The active areas of research reported across nations were on ballast water, biofouling, and discharge from exhaust gas cleaning systems (scrubbers). The group identified scrubber discharge as a shipping pressure of high priority.

In 2020, the group published a scientific background document on scrubber discharge that was used to support the development of an ICES Viewpoint. Underwater noise was also identified as a high priority pressure and the group is synthesizing information on noise mitigation measures and their synergies and trade-offs across shipping pressures.

Moving into the new term, the working group will continue synthesising and advancing scientific knowledge on current priority shipping pressures and identify emerging pressures of concern in order to support the holistic management of shipping.

ii Expert group information

Expert group name	Working Group on Shipping Impacts in the Marine Environment (WGSHIP)
Expert group cycle	Multiannual
Year cycle started	2019
Reporting year in cycle	3/3
Chairs	Cathryn Murray, Canada
	Ida-Maja Hassellöv, Sweden
Meeting venues and dates	25–27 November 2019, Copenhagen, Denmark (20 participants)
	27–29 May 2020, online (24 participants)
	3–4 November 2020, online (17 participants)
	25–26 May 2021, online (14 participants)
	2–4 November 2021, online (17 participants)

1 Introduction

The global development of shipping largely reflects the patterns of global trade, with the volumes of transported goods having increased fourfold since the 1970s (UNCTAD, 2014). While regulation of air pollution and ballast water from shipping has been gradually strengthened, the corresponding impacts on the marine environment have received less attention. The ICES Working Group on Shipping Impacts in the Marine Environment (WGSHIP) was formed in 2019 to address the intersection between shipping-related pressures and marine environmental management.

In 2019–2021, WGSHIP worked on ICES Science Plan Priority II (impact of human activities) and VI (conservation and management science). The members collectively defined the scope of the working group to include all vessel types, not limited to merchant ships. The characteristics and polluting intensity of different vessel types may vary, but the pressures and impacts of all vessels may be considered by the working group. Areas of active research on shipping-related pressures include chemical pollutants, plastic debris, introduction of invasive species, oil spills, turbulent mixing, scrubber discharge, vessel strikes, and underwater noise.

The breadth and status of research activities related to environmental impacts of shipping in each member country were summarised in the initial three-year term by the members of WGSHIP. The group developed a template spreadsheet for national reporting that was used to collect, to the extent possible, information on recent and ongoing research activities.

Over 2019–2021, linkages and relationships with other groups have developed, including the Food and Agriculture Organization (FAO) of the United Nations, the Protection of the Arctic Marine Environment (PAME) Shipping Expert Group, one of six working groups encompassed by The Arctic Council, and the International Maritime Organization (IMO), a specialised agency of the United Nations responsible for regulating shipping. WGSHIP has had cross-participation with other ICES groups, including the working group on ballast water and other shipping vectors (WGBOSV), the working group on cumulative effects assessment methods (WGCEAM), marine chemistry working group (MCWG), as well as the workshop on methods and guidelines to link human activities, pressures, and state of the ecosystem in Ecosystem Overviews (WKTRANSPARENT).

WGSHIP had a high level of achievement with the preparation and publication of the ICES Scientific Background Document, ICES Viewpoint and the subsequent submission to IMO MEPC 76. In this endeavour, WGSHIP collaborated with members of the ICES working group on Marine Sediments in Relation to Pollution (WGMS) and the Marine Chemistry Working Group (MCWG).

2 Conceptual framework of shipping

Community and public concerns around the varied environmental, social, and cultural effects of shipping have increased, with focus turning from air emissions and ballast water to emerging pressures like underwater noise and discharge of on-board generated waste streams to the sea. The complexity of shipping activities means that holistic understanding of the potential impacts requires a full understanding of the pathways by which shipping activities affect marine ecosystems. Spatio-temporal variations in the pathways of effects can originate with respect to individual ships, between different ship types, and from different modes of operation. In addition to the complexity of shipping behaviours, there is also the possibility of the accumulation of impacts through space and time, as well as interactions among pressures and variations across ecosystems. Therefore, there is a need for a comprehensive understanding of shipping pressures and effects to support impact assessment, cumulative effects assessments and economic valuations.

Members of WGSHIP are actively working on the development of a conceptual framework for the impacts of shipping. Here, we build upon previous models to develop a holistic framework for shipping. The effort builds upon previous efforts from Canada (Hannah *et al.*, 2020), and Europe (Moldanová *et al.*, 2021; Ytreberg *et al.* 2021). The Pathways of Effects framework (Hannah *et al.*, 2020) divides shipping into sub-activities, stressors and potential effects (Figure 1). The European works (Moldanová *et al.*, 2018; J. Moldanová *et al.*, 2021; Ytreberg *et al.*, 2021) are based on the combination of vessel activity data (AIS) and development of emission and discharge factors from different ship types, originating from the Ship Traffic Emission Assessment Model (STEAM); (Jalkanen *et al.*, 2009); (Figure 2). STEAM delivers georeferenced data in terms of emissions to air from exhausts, leakage of specific substances from antifouling paints, volumes of liquid waste streams, and energy/noise. The idea behind the European works is to delineate the pressures and stressors identified from different onboard systems, to the Descriptors identified in the Marine Strategy Framework Directive (MSFD). The approach builds upon a classic DPSIR (Driver-Pressure-State-Impact-Response) framework, and the pressure categories and sub-categories were further refined by Ytreberg *et al.* 2021 (Figure 3).

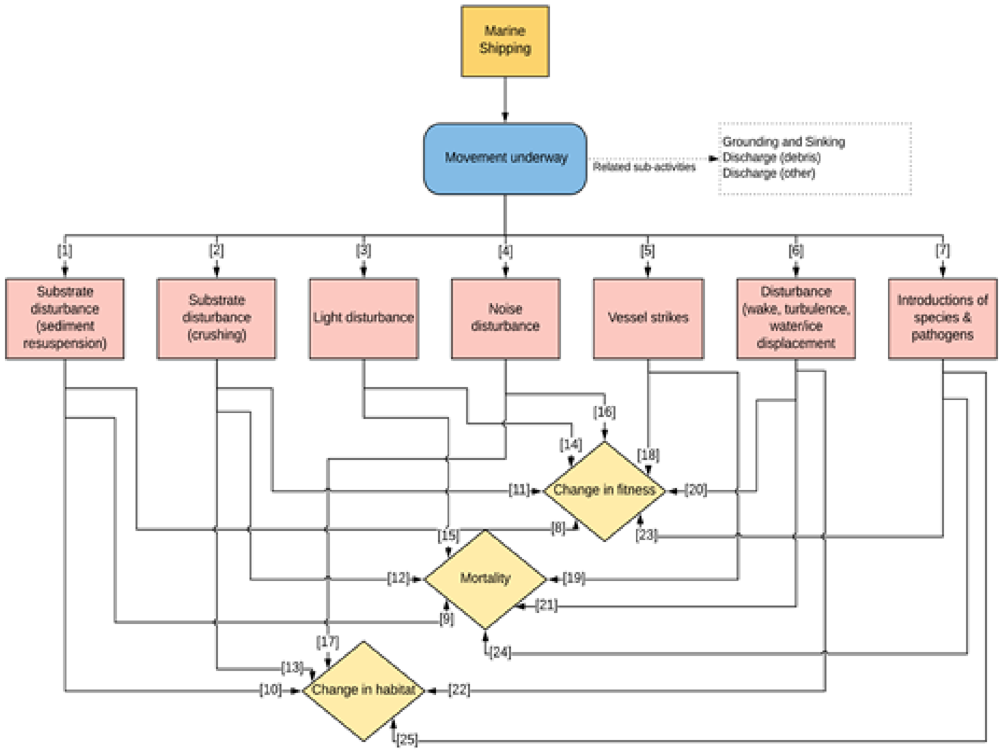

Figure 1. Pathways of Effects diagram for the Movement Underway sub-activity, from Hannah *et al.* (2020).

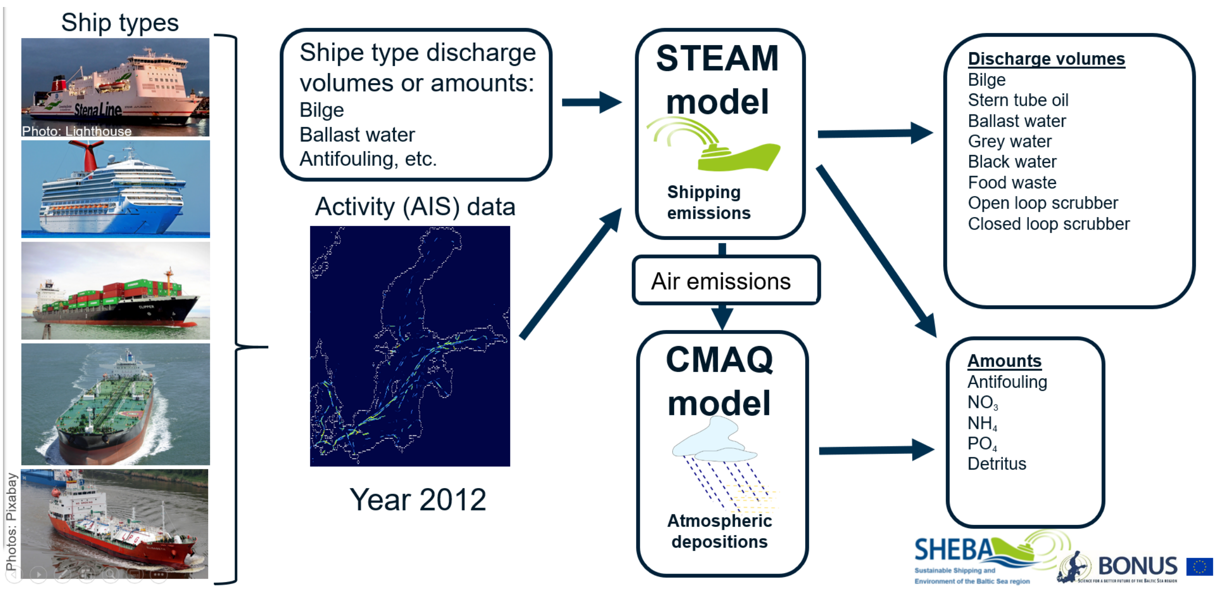

Figure 2. The European approach to modelling environmental pressures from ships, from Moldanová *et al.* (2018).

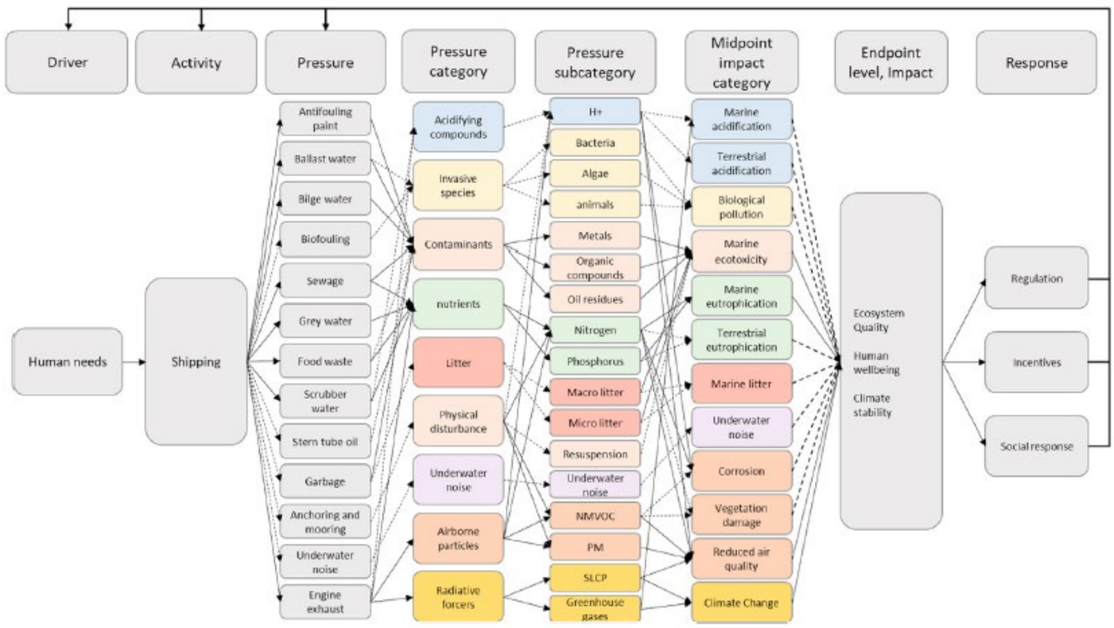

Figure 3. Organization of shipping pressures, impacts, endpoints and responses from Ytreberg *et al.* (2021).

2.1 Driver-Activity-Pressure-State-Impact-Response (DAPSIR) Framework

Starting from a DAPSIR-framework - Driver-Activities-Pressures-State-Impact-Response framework - we here outline the structure of the APS steps for assessment of the environmental impacts of shipping (Figure 4). The DAPSIR-framework provides a structure for assessment, and we introduce sublevels of the APS-steps: Activities include vessel types, mode of operation, and subsystems, Pressures are further delineated in Pressure subcategories and State includes changes as well as cumulative effects.

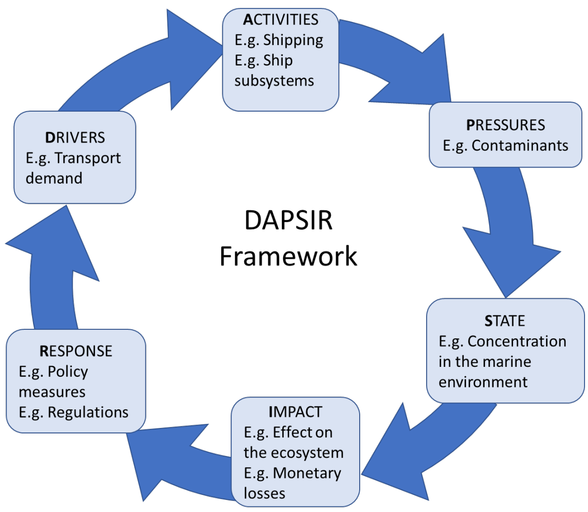

Figure 4. Driver-Activity-Pressure-State-Impact-Response-Framework (DAPSIR) modified after (Hassellöv *et al.*, 2016). The current effort focuses on the Drivers-Pressures-State components and is applicable to all types of shipping. The Impact and Response components will be specific to the area of interest and scope of the study.

2.1.1 Activity - Shipping

The shipping activity can be further organized at the sub-activity level of the vessel type, the mode of operation, and/or at the ship sub-system.

Sub-activity - Vessel type

To describe the activities giving rise to different pressures, it is essential to distinguish the varying types of ship; Bulk carrier, Cargo ship, Chemical tanker, Container ship, Fishing boat, Ice breaker, Leisure boat, Military vessels, Passenger ship, Pilot boat, Product tanker, RoRo/RoPax, Search and rescue, Tug/Barge. Descriptions of each type are in Table 1 (Arctic Council, 2009; Canada;, 2019; Hannah *et al.*, 2020; IMO, 2019).

Table 1. Standardised vessel type categories (Adapted from Arctic Council, 2009; Canada;, 2019; Hannah *et al.*, 2020; IMO, 2019).

Vessel type	Description
Bulk Carrier	Ships specifically designed for bulk carriage of ore with additional facilities for alternative, but not simultaneous, carriage of oil or loose or dry cargo. Bulk carriers are segregated into the following: handysize (10 000 to 35 000 DWT), handymax (35 000 to 55 000 DWT), panamax (60 000 to 80 000 DWT), capesize (80 000 DWT and over).
Cargo ship	Ships designed for the carriage of various types and forms of cargo and the combined carriages of general cargo and passengers with 12 or less fare paying passengers.
Chemical tanker	Ships designed and constructed for the bulk carriage of liquids or compressed gas, as in the case of natural gas (Liquefied Natural Gas (LNG) carriers).
Container ship	Container ships are cargo ships that carry all of their load in large containers, in a technique called containerisation.
Fishing boat	Any vessel used commercially for catching fish or other living resources of the sea.
Icebreaker	An icebreaker is a special purpose ship or boat designed to move and navigate through ice-covered waters. For a ship to be considered an icebreaker it requires three components: a strengthened hull, an ice-clearing shape, and the power to push through ice, none of which are possessed by most ships.
Leisure boat	A leisure or pleasure craft is any boat used only for pleasure activities like fishing, water sports, and entertainment. It also includes a boat used for subsistence hunting and fishing or for daily living (for example, in remote areas, going from one village to another).
Military vessels	Military ships and submarines used for the purpose of national defence. Depending on the size and purpose, these vessels may have characteristics similar to other vessel categories, such as search and rescue, fishing boat, ice breaker, leisure boat, and/ or pilot boat.
Passenger ship	Ships that carry passengers, whether for transport purposes only, or where the voyage itself and the ship's amenities are part of the experience. Includes cruise ships and ferries.
Pilot boat	A pilot boat is a vessel specifically used to ferry helmsmen or marine pilots back and forth from harbours to guide ships into or out of port or wherever navigation may be considered hazardous.
Product tanker	A ship constructed or adapted primarily to carry oil or similar products in bulk in its cargo spaces.

RoRo/ RoPax	The roll-on/roll-off (RoRo/RoPax) ship is a ship with ro-ro cargo spaces and passenger accommodation. RoPax ships are built for freight vehicle transport along with passenger accommodation. One of the Ro-Ro ship's most important roles is as a passenger/car ferry, particularly on short-sea routes.
Search and rescue	A search and rescue boat is designed to rescue persons in distress and to marshal survival craft.
Tug / Barge	A tug is a secondary boat which helps in transiting, mooring or berthing operation of a ship by either towing or pushing a vessel towards the port. A barge is a long, flat-bottomed boat for carrying cargo and typically does not have a self-propelling mechanism.

Sub-activity - Mode of operation

Table 2. Different modes of operation, or sub-activities, identified as being associated with shipping within the study scope (Adapted from Hannah *et al.*, 2020).

Mode of operation	Scope
Anchoring and Mooring	The act of deploying and retrieving anchors, or attaching to a mooring buoy system including the subsequent movement of the anchoring or mooring buoy system while deployed., The two main types of anchoring considered are anchoring with a standard temporary anchor and anchoring to a mooring buoy system. This includes commercial vessels at anchor or attached to a mooring buoy, both with, and without, the engine running.
Vessel at rest	Stationary vessels that are at anchor or attached to a mooring buoy system. Vessel lights and engines are usually running but may not be in some instances. Focus is on the vessel itself and excludes effects from anchor and mooring systems, as well as effects from mooring buoy infrastructure, other than when a vessel is moored to it.
Grounding and sinking	Includes: (i) Vessel grounding - when a vessel impacts the seabed or underwater objects; and (ii) Sinking – when a vessel sinks and reaches the seabed to become a shipwreck.
Movement underway	Movement underway refers to the action of a vessel in transit from one port of call to another. While underway, the vessel is under power and travelling through the water (includes icebreaking).
Operational discharge	The release of any substance or object from vessels (liquid/solid) during normal operations. Operational discharges include releases such as black water discharges (sewage), grey water (wastewater), ballast water, and bilge water.
Accidental discharge	The release of any substance or object from vessels (liquid/solid) as a result of accidents. Accidental discharges include oil spills (both small scale fuel spills and large-scale tanker spills), as well as equipment malfunctions that release discharges.

Sub-activity - Ship subsystems

Some ships can be considered as floating industrial sites; for example, large tankers, floating production storage and offloading (FPSOs), fish factories, etc.) or floating cities (e.g. cruise ships). Ships have numerous on board systems that each have their own pressures and effects on the marine environment. The shipping framework describes 15 activities called Ship subsystems, with different magnitude of effects depending on ship size, type, etc. (Figure 5). Each type of liquid waste stream is classified as separate subsystems, i.e. Ballast water, Black water, Grey water, Tank cleaning, Cooling water, Scrubber water, Bilge water and Stern tube oil. Propulsion and maneuvering (including the ship-induced noise, turbulence and waves) and Artificial light from the onboard lighting system represent subsystems giving rise to energy pollution related pressures. Emissions to the atmosphere of exhausts and combustion particles can lead to Deposition on the sea surface, while Solid waste, primarily ground food waste, may be discharged overboard. Some types of antifouling coatings (i.e. fouling release coatings) are designed to leak toxic biocidal substances to prevent spreading of non-indigenous species from Biofouling, which are here considered separate subsystems. Finally, Anchoring, causing physical disturbance through seafloor scouring, is considered a subsystem of its own.

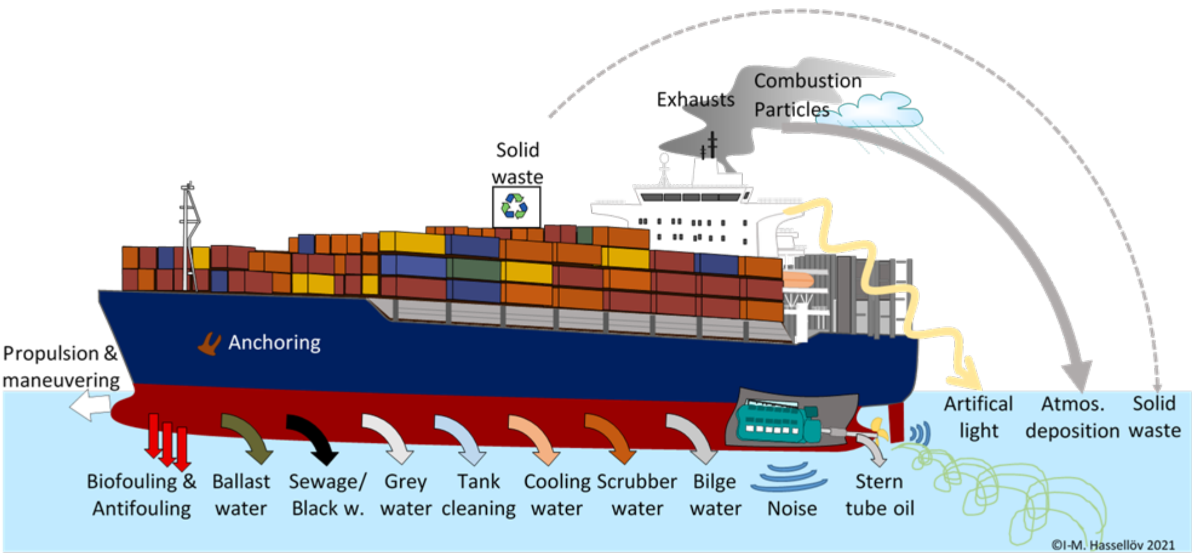

Figure 5. Activity - Ship subsystems giving rise to environmental pressures. The subsystems encompass liquid waste streams, systems giving rise to energy introduction and spreading of contaminants and nonindigenous species. Adapted from (Moldanová *et al.* 2018).

2.1.2 Pressure

The ship subsystems contribute to pressures categorised as: Eutrophying substances, Biological pollutants, Contaminants, Energy pollutants, Hydrographic alteration, Litter, and Physical disturbance (Table 3). Pressure categories can be further defined into pressure sub-categories for more specificity. For example, Pressure sub-categories include: Nutrients, Organic matter, Non-indigenous species, Halocarbons, Hydrocarbons, Metals, Acoustic energy, Thermal energy, Electromagnetic radiation, Acidifying substances, Turbulence, Water displacement, Particulate matter, Macrolitter, Microplastics, Collision, Entanglement, Foreign object, Icebreaking, and Seafloor disturbance (Table 3).

Table 3. Hierarchical relationships of Pressure categories and sub-categories in the shipping conceptual framework, and their link to the MSFD Descriptors.

Pressure category	Pressure sub-category	Link (or *possible link*) to MSFD Descriptors
Eutrophying substances	Nutrients	D5
	Organic matter	
Biological pollutants	Non-indigenous species	D2
Contaminants	Halocarbons, POPs, NMVOCs	D8
	Hydrocarbons, PAHs	
	Metals	
Energy pollutants	Acoustic energy (noise)	D11
	Electromagnetic energy (light)	
	Thermal energy (heat)	
Hydrographic alteration	Acidifying substances	D7
	Turbulence	
	Water displacement	
Litter	Particulate matter	D10
	Macrolitter	
	Microplastics	
Physical disturbance	Collision	D6/D10
	Entanglement	

	Foreign object		
	Ice breaking		
	Seafloor disturbance		

Table 4. Pressure sub-categories and descriptions defined in this framework (adapted from Hannah *et al.* 2020).

Pressure sub-category	Description
Nutrients	Discharge or deposition of nutrients (including nitrous oxides (NOx) from air emissions)
Organic matter	Discharge of organic matter, primarily effluent and food waste, and organic carbon.
Nonindigenous species	An organism introduced to an area outside its natural range and distribution, that can become established and have a negative impact on the new environment.
NMVOCs, Halocarbons, POPs	Discharge or deposition of Non-methane volatile organic compounds (NMVOCs), halocarbon compounds, including Persistent Organic Pollutants (POPs)
Hydrocarbons, PAHs	Discharge and deposition of hydrocarbon compounds, including Polycyclic Aromatic Hydrocarbons (PAHs)
Metals	Discharge or deposition of heavy metals and radioactive elements from ship subsystems and metal degradation
Acoustic energy (Noise)	Artificial noise associated with commercial vessels. Noise can range from pervasive, low frequency sound from vessel engines or ice breaking to short-term noise from anchor deployment and retrieval. This stressor also includes the vibration associated with particle motion.
Thermal energy (heat)	Temperature change due to local warm water discharge
Electromagnetic energy (Light)	Temporary artificial light associated with the presence of commercial vessels; or conversely, a reduction in light caused by shading from a vessel.
Acidifying substances	Discharge or deposition of acidic substances, such as sulphur oxides (SOx)
Turbulence	Turbulence created by the propellers of moving vessels ('propeller wash').
Waves	Water movement from
Water displacement	Disturbance of water produced by displacement due to the movement of vessels, includes waves and wake
Particulate matter	Discharge or deposition of solid and liquid particles formed during fuel combustion, including black carbon.
Macrolitter	Introduction of ship-borne litter to the marine environment, including consumer products, cargo, containers, and fishing gear

Microplastics	Discharge or release of microdebris, including microplastics and nanoplastics, as components of antifouling paints and grey water, as well as the breakdown of macrolitter.
Collision	Collision of a vessel with mobile organisms while underway (including propellers), also referred to as ship strikes.
Entanglement	The entrapment or entanglement of organisms in anchor or mooring gear.
Foreign object	An object or obstacle affecting or altering habitat, such as a vessel, anchor, or discharged material. Includes aesthetic pollution from the presence of the ship in view.
Icebreaking	Breaking and fragmentation of sea ice as the result of direct contact with icebreaking vessels.
Seafloor disturbance	Alteration and disturbance of the seafloor from anchoring activities.

2.1.3 State

The pressures will give rise to a change in the environmental State. To enable assessment of such changes, the different MSFD descriptors are used (MSFD, 2021). For example, a change of state could be a changed environmental concentration of a certain contaminant. To a large extent, the pressure categories can be linked to State, using the MSFD Descriptors. All eleven MSFD descriptors can be affected by shipping, either directly or indirectly through trophic links:

Descriptor 1. Biodiversity is maintained
Descriptor 2. Non-indigenous species do not adversely alter the ecosystem
Descriptor 3. The population of commercial fish species is healthy
Descriptor 4. Elements of food webs ensure long-term abundance and reproduction
Descriptor 5. Eutrophication is minimised
Descriptor 6. The sea floor integrity ensures functioning of the ecosystem
Descriptor 7. Permanent alteration of hydrographical conditions does not adversely affect the ecosystem
Descriptor 8. Concentrations of contaminants give no effects
Descriptor 9. Contaminants in seafood are below safe levels
Descriptor 10. Marine litter does not cause harm
Descriptor 11. Introduction of energy (including underwater noise) does not adversely affect the ecosystem

Examples of state indicators from the Marine Strategy Framework Directive (MSFD) Good Environmental Status Descriptors for non-indigenous species, contaminants, marine litter and underwater noise (European Commission, 2010) are presented in Table 5. In addition to State changes with respect to individual stressors, the identification of state cumulative change will be context-dependent (European Commission, 2010). Examples of cumulative change indicators that correspond to the state level indicators are presented in Table 5. The proposed Activity-Pressure-State framework is illustrated in Figure 6.

Table 5. MSFD Good Environmental Status Descriptors state level and cumulative change indicators that could be used with the shipping DPS framework.

MSFD Good Environmental Status Descriptors	State Indicator(s)	State Cumulative Change Indicator(s)
D2 Non-indigenous species	Abundance and state of NIS	Environmental impact of NIS
D8 Contaminants	Concentration of contaminants	Loss of species Occurrence and extent of acute pollution events
D10 Marine litter	Trends in amount of litter	Trends in litter ingested by marine animals
D11 Underwater noise	Temporal and spatial distribution of sound sources that exceed harmful levels	Trends in continuous low frequency sound ambient noise level

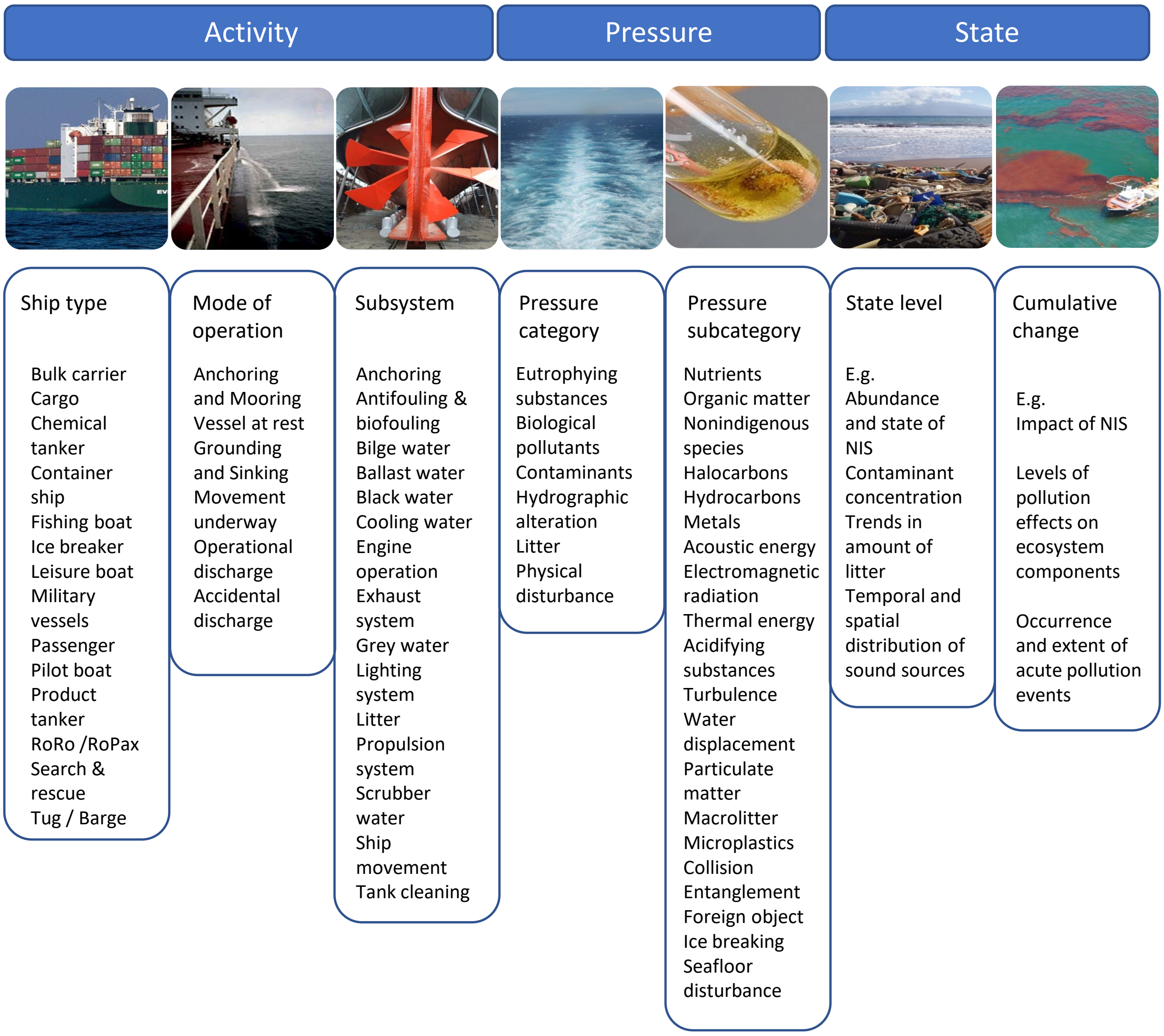

Figure 6. Overall diagram of the shipping Activity-Pressure-State framework with subcategories under Activity, Pressure, and State components.

2.2 Applications of the framework

The framework aims to describe the full set of activities and pressures from shipping. The group has identified differences in the commonly used approaches between countries and will continue working to improve the commensurability and comparability of the framework. This type of conceptual framework is particularly useful in the scoping phase of an assessment, in order to define the components of shipping that are included as well as those that are excluded. This allows a clearer definition and statement of the assumptions and uncertainties associated with the assessment. WGSHIP has used the conceptual framework in an analysis of trade-offs in mitigation actions for underwater noise. It has also been used to structure the national reporting template for the working group members, ensuring the complete set of pressures are listed.

3 Review of national research

3.1 Survey on research activities considering the environmental impacts of shipping

In order to assess the global research priorities, trends, and gaps, the members of WGSHIP designed a spreadsheet reporting template to collect data on the recent and ongoing research projects studying the environmental impacts of shipping. The WGSHIP members added shipping-related environmental research activities that they were involved in and circulated the spreadsheet to colleagues and contacts. The snowball effect allowed additional contacts to be suggested but the results do not represent all shipping-related research in each country.

National spreadsheet reports were received from ten countries: Australia, Canada, Denmark, France, Finland, Germany, Greece, Norway, Sweden, and the United States of America. A total of 234 research activities were reported. The research activities mentioned in more than one of the reports are presented in Table 6.

Table 6. Examples of multinational projects on shipping-related research reported to WGSHIP by multiple member countries in 2019–2021. This list is not comprehensive because of varying reporting effort and criteria for inclusion across member countries.

Project	Countries involved	Ship subsystems and pressures of interest	Assessments
AIRCOAT	FIN / GER	Antifouling, Biofouling, Noise, Metals, Particulate Matter	Economics, Environmental policy, Mitigation measures, Status evaluation, Vessel movements
COMPLETE (+ PLUS)	FIN / GER / SWE	Antifouling, Ballast water, Biofouling, Metals, Multiple stressors, Nonindigenous species	Conceptual model, Cumulative effects, Economic assessment, Environmental policy, Literature review, Mitigation measures, Risk assessment, Status evaluation, Vessel movements
H2020 EMERGE	FIN / SWE / NOR / ESP / PRT / ITA / GRE / AUT / CYP /GBR	Antifouling, Atmospheric deposition, Ballast water, Bilge water, Food waste, Grey water, Noise, Sewage, Sludge, Stern Tube Oil, Metals, Multiple stressors, Oil (physical impact), PAH:s, Particulate Matter	Cumulative effects assessment, Economic assessment, Impact assessment, Literature review, Mitigation measures, Risk assessment, Status evaluation, Vessel movements
ShipTRASE	SWE / GER	Scrubber discharge water, Atmospheric deposition, Acidifying substances, Metals, Nutrients, POPs, PAHs, Particulate Matter	Economics, Environmental policy, Impact assessment, Risk assessment

IMAROS	NOR / FRA	Oil (physical impact), PAHs	Environmental policy, Impact assessment, Mitigation measures, Risk assessment
SCIPPER	GRE / FIN / GER	Atmospheric deposition, PAHs, Particulate Matter	Economics, Environmental policy, Impact assessment, Literature review, Mitigation measures, Status evaluation, Vessel movements

Working group research was reported by ship subsystem, pressure sub-category, and assessment type. Ballast water, biofouling, antifouling, and scrubber water were the most common subsystems included in national reports (Figure 7). Across the reports, the most commonly studied pressure subcategory was acoustic energy (noise), followed by particulate matter, multiple stressors, nutrients and organic matter, and metals (Figure 8).

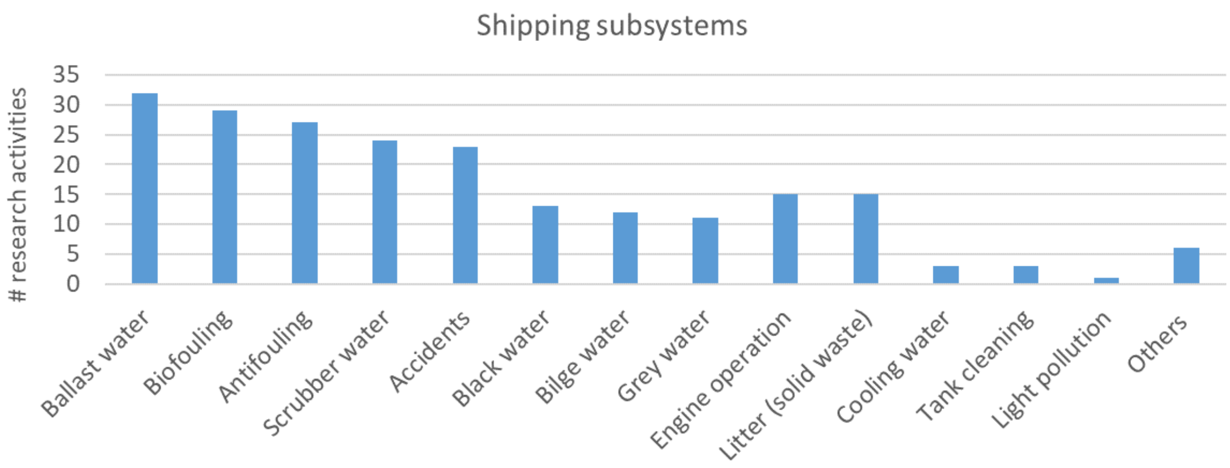

Figure 7. Number of research activities focused on different shipping driver subsystems, as identified by the working group members and their contacts. The category “Others” included anchorages and dredging.

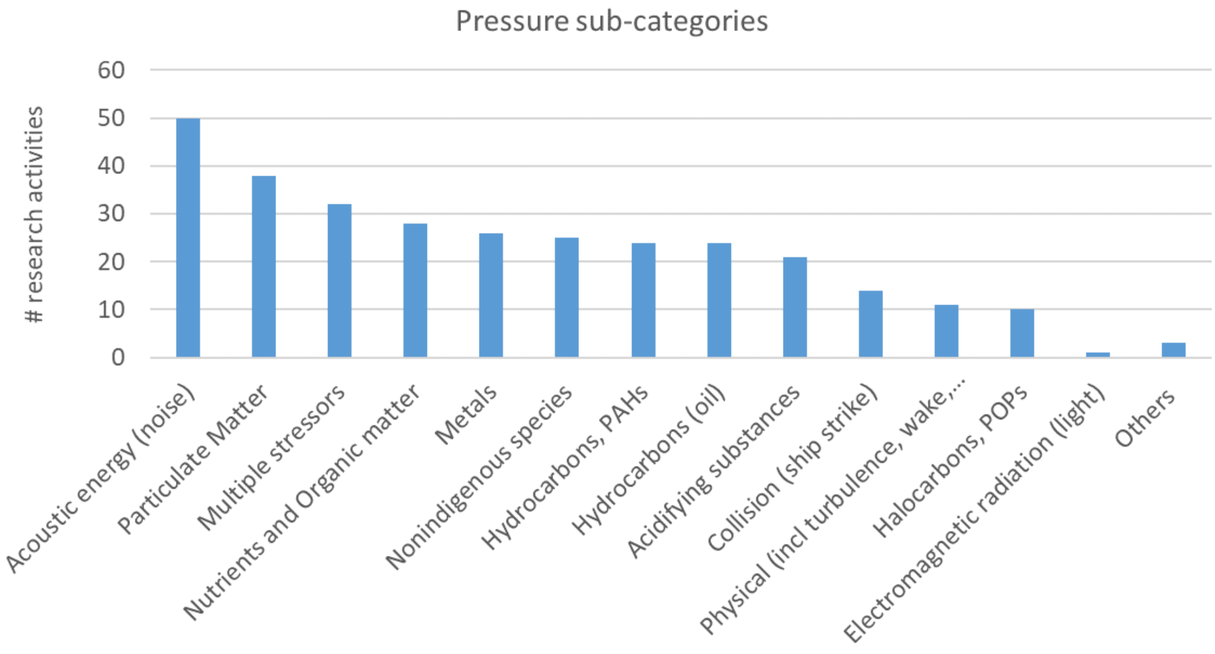

Figure 8. Number of research activities focussed on shipping-related pressure sub-categories of interest, as identified by the working group members and their contacts. The category "Others" included hull cleaning particles, hazardous materials spills and radioactive materials.

The most commonly applied assessment type in the reported research activities was vessel movements, followed by environmental policy, impact assessment and risk assessment (Figure 9).

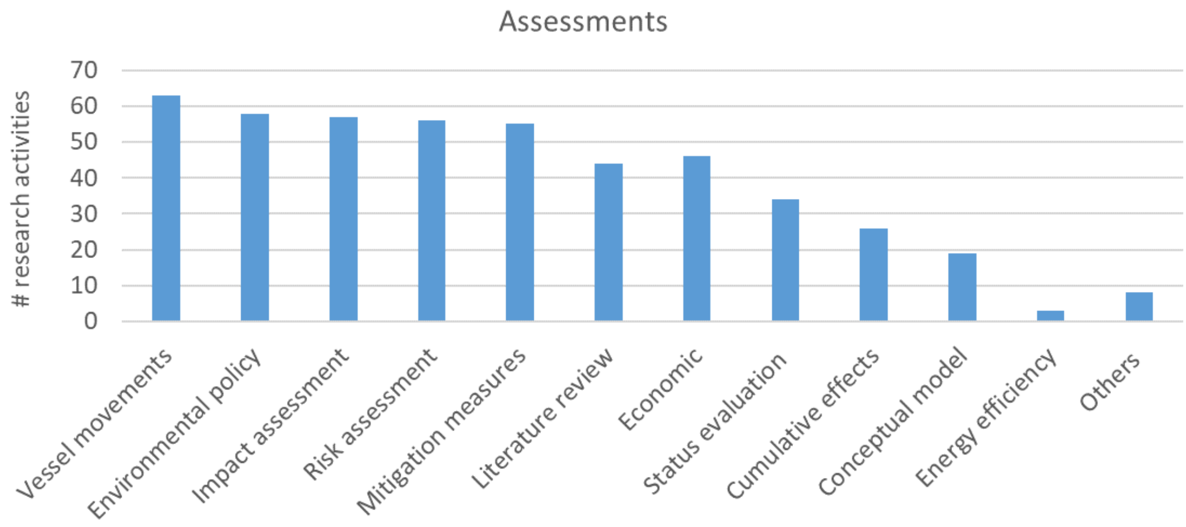

Figure 9. Number of research activities applying different assessment types, as reported by the working group members and their contacts. The category "Others" included life cycle analysis (LCA) of fuels, Modal shift, Climate change, and Port state control.

3.2 Shipping Research - Conference Polls

WGSHIP also co-hosted a session on the impacts of shipping at the 2021 ICES Annual Science Conference, with WGBOSV. A total of 17 presentations were submitted and discussed during the session, summarised by the word cloud below (Figure 10). The submitted presentations fell roughly into four general themes related to shipping research:

1. Biological pressures, e.g., aquatic invasive species
2. Physical pressures, e.g. noise pollution and wake
3. Chemical pressures, e.g., pollutants
4. Synthesis

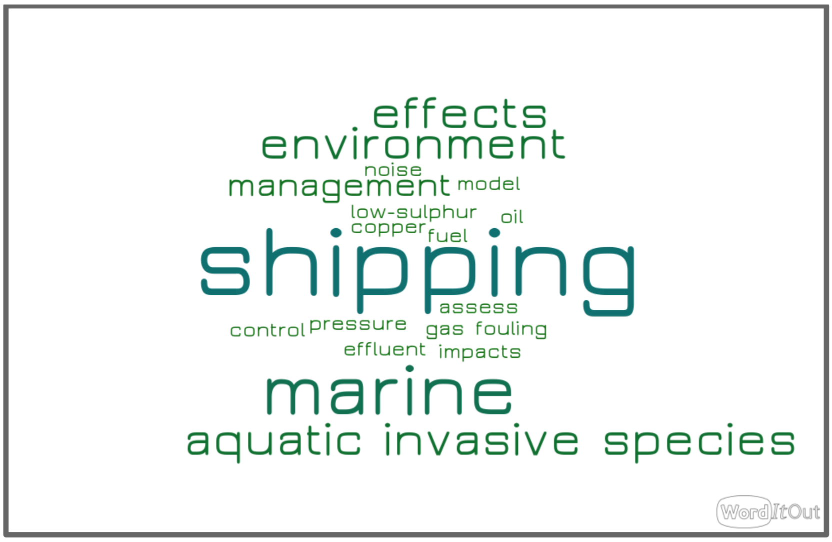

Figure 10. Word cloud illustrating the diversity of themes discussed at the ICES ASC 2021 theme session on the impacts of shipping.

During the live session, two polls were posed to the participants. The first question was posed in advance of the session: "If you are actively engaged in commercial shipping research, please type your area of research (e.g. scrubber water, cumulative effects, biofouling, policy, oil spill)". From the 19 responses, most delegates were involved in ballast water or antifouling research (Figure 11). This was followed by cumulative effects and aquatic ecotoxicology. Fewer delegates listed engagement in oil spill, noise, or microplastic research. One respondent was from outside the field ("not engaged").

The second poll question asked the delegates about environmental risks: "Which shipping pressure poses the highest risk to the marine environment?". The 16 responses were more varied than the first question (Figure 12). Noise, airborne/carbon emissions, and pollution were the most frequent answers.

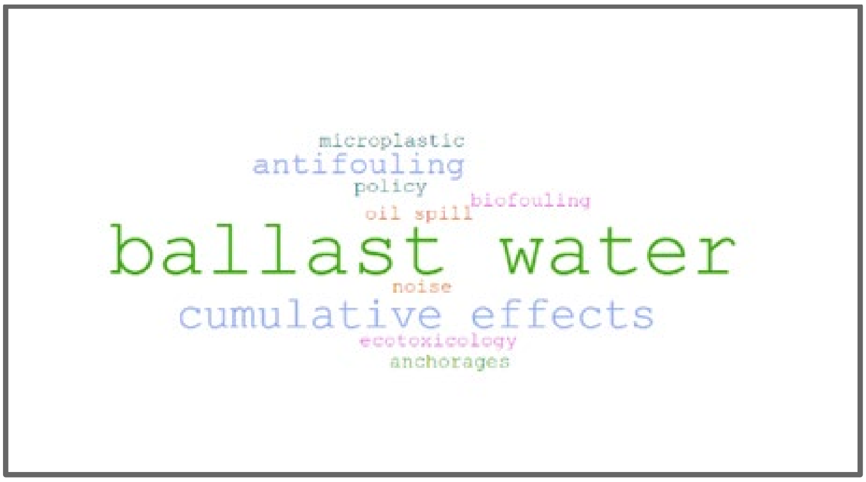

Figure 11. ICES ASC theme session delegates' research areas (from the answer to Poll Question 1).

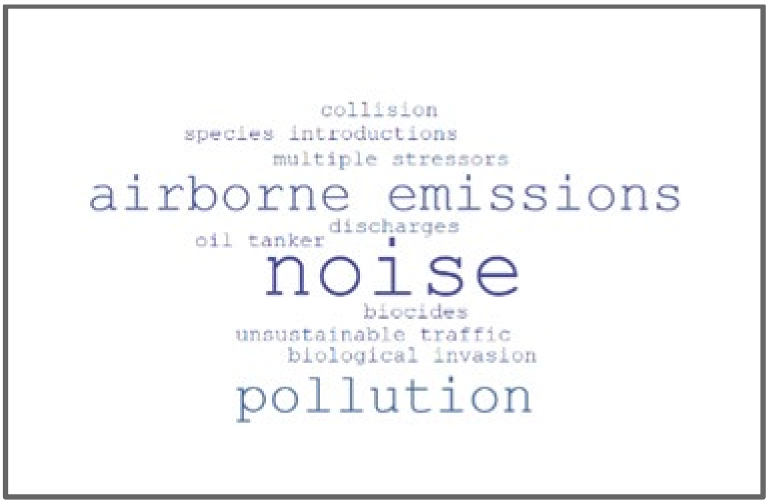

Figure 12. ICES ASC delegates' self-identified research areas (from the answer to Poll Question 2).

3.3 Next steps

During the next term, WGSHIP members plan to improve on the national reporting template (Section 3) by comparing it to the shipping conceptual framework once it is completed (Section 2). The current template was created prior to the development of the framework and as a result, there are some subsystems and pressures missing from the reporting structure. WGSHIP members will strive to achieve more complete reporting (additional countries, and more comprehensive survey of projects within each country). The results will be used to identify research gaps and potential collaborations, and to set priorities and terms of reference for the next term of the working group.

4 Priority shipping-related pressures

The members of WGSHIP are actively researching a number of shipping-related environmental pressures. Areas of active research on shipping-related pressures include liquid waste streams (e.g. scrubber discharge), air pollution, greenhouse gases, plastic debris, introduction of invasive species, oil spills, turbulent mixing, vessel strikes, and underwater noise. The group identified current and emerging pressures of interest. In particular, scrubber water discharge and underwater noise are pressures with active collaboration within WGSHIP. Pressures of emerging interest include a recent shift in use of so-called hybrid fuel oils (with unknown toxicity and low compatibility with oil spill cleanup technology), Per- and Polyfluoroalkyl Substances (PFAS) in fire extinguishing products and their potential use in ship fire drills, microplastics in antifouling paint, and tank cleaning residues. The active research on exhaust gas cleaning systems (scrubbers) and underwater noise are summarised below.

4.1 Exhaust Gas Cleaning Systems (scrubbers)

Since stricter global sulphur regulations entered into force in January 2020, ships are not allowed to continue to use heavy fuel oil. However, an increasing number of ships are now being equipped with an exhaust gas cleaning system, also known as a scrubber, to allow for continued use of the cheap heavy fuel oil. Scrubbers wash out sulphur from the exhausts to meet the limit regarding emissions to air, however large volumes (typically more than 500 m^3/h) of acidified (pH~3) seawater are discharged back into the sea. Citing the natural buffer capacity of seawater to withstand pH change, scrubber manufacturers claim that scrubbers turn harmful sulphur oxides into harmless sulphate in the marine environment. While it is true that the end product is sulphate, acidification can occur, especially if scrubbers are used in semi-enclosed areas. Scrubber water contains high concentrations of toxic polycyclic aromatic hydrocarbons (PAHs) and heavy metals. As highlighted in the ICES Viewpoint: *Scrubber discharge water from ships – risks to the marine environment and recommendations to reduce impacts*, the few percent of ships operating with scrubbers completely dominate the contaminant load from all shipping related liquid waste streams from all ships operating in a sea area (Hassellöv *et al.*, 2020) . Against this background, ICES recommended avoidance of discharge of scrubber water in the marine environment, and instead support a shift to cleaner low-sulphur fuel oils (ICES, 2020).

4.2 Underwater noise

Anthropogenic noise is recognized as a global source of environmental pollution and shipping is the most widespread and persistent source of noise underwater. Shipping is currently the primary vehicle of global trade and a future focus on increased marine transport to mitigate climate impacts of road traffic will likely add to its importance (high level panel report). Projected growth in large vessel traffic would substantially increase levels of shipping noise in the coming decade (Kaplan & Solomon, 2016). The pervasive nature of shipping noise pollution has raised concern that it can cause widespread behavioural and physiological effects with consequences at the population level (Slabbekoorn *et al.*, 2010; Tyack, 2008). In Arctic regions sea ice retreat is opening up new shipping routes, which is likely to lead to increased noise-levels in previously pristine areas (Ladegaard *et al.*, 2021).

WGSHIP has been working on a manuscript to be submitted to the peer-reviewed literature reviewing the trade-offs and synergies of potential noise mitigation measures on other shippinginduced pressures. The interdisciplinary expertise of WGSHIP is crucial to the development of this manuscript.

5 Achievements, Collaborations and Future Work

5.1 Achievements

WGSHIP had a high level of achievement with the preparation and publication of the ICES Scientific Background Document, ICES Viewpoint and the subsequent submission to IMO MEPC76. The achievements of WGSHIP in the first term include the following:

- WGSHIP Networking Session at ICES Annual Science Conference 2019. "Global impacts of shipping" Co-convened by Canada and UK: Sarah Bailey and Silvana Birchenough.https://www.ices.dk/events/asc/asc2019/Pages/Shipping.aspx.
- Joint ICES/PICES Session at PICES Annual Meeting 2019. "The impacts of marine transportation and their cumulative effects on coastal communities and ecosystems". Co-convened by Canada and Japan: Cathryn Murray, Sarah Bailey and Hideaki Maki.
- Exhaust Gas Cleaning Systems Background Document and Viewpoint published. Hassellöv, I.-M., Koski, M., Broeg, K., Marin-Enriquez, O., Tronczynski, J., Dulière, V., Murray, C., Bailey, S., Redfern, J., de Jong, K., Ponzevera, E., Belzunce-Segarra, M.J., Mason, C., Iacarella, J.C., Lyons, B., Fernandes, J.A. and Parmentier, K. 2020. ICES Viewpoint background document: Impact from exhaust gas cleaning systems (scrubbers) on the marine environment (Ad hoc). ICES Scientific Reports. 2:86. 40 pp. http://doi.org/10.17895/ices.pub.7487
- Support for ICES advice on scrubber discharge water. ICES. 2020. ICES VIEWPOINT: Scrubber discharge water from ships – risks to the marine environment and recommendations to reduce impacts. In: Report of the ICES Advisory Committee, 2020. ICES Advice 2020, vp.2020.01, https://doi.org/10.17895/ices.advice.7486.
- ICES scrubber discharge water Intervention presented at IMO MEPC76 June 2021
- ICES Annual Science Conference 2021 Theme Session "The impacts of marine shipping and their effects on coastal communities and ecosystems", Co-convened by WGSHIP and WGBOSV: Cathryn Murray, Lisa Drake, and Ida-Maja Hassellöv, 17 presentations
- WGSHIP presentations at ICES working groups: WGCEAM meeting September 2020, WGIEASG October 2020
- WGSHIP presentations at PAME Shipping Expert Group. September 2020
- WGSHIP presentation at OSPAR EIHA. October 2020
- Accepted for ICES Annual Science Conference 2022 - Theme Session "Steering shipping impact prevention towards holistic marine management", Co-convened by WGSHIP and WGBOSV: Ida-Maja Hassellöv, Cathryn Murray, and Lisa Drake
- WGSHIP presentation at OSPAR MIME. November 2021

5.2 Collaboration

Beyond the working relationships established between the scientific experts within the working group, WGSHIP has developed working relationships with the ICES working groups on ballast water and other shipping vectors (WGBOSV), cumulative effects assessment methods (WGCEAM), as well as the workshop on methods and guidelines to link human activities, pressures and state of the ecosystem in Ecosystem Overviews (WKTRANSPARENT). In the work on the scrubber discharge background document, WGSHIP collaborated with members of the ICES

Working Group on Marine Sediments in Relation to Pollution (WGMS) and the Marine Chemistry Working Group (MCWG).

WGSHIP has linkages and makes contributions to PAME Shipping Expert Group, the International Maritime Organization (IMO) and the Food and Agricultural Organization (FAO), as well as the OSPAR Commission, the mechanism by which fifteen national governments & the European Union cooperate to protect the marine environment of the North-East Atlantic.

5.3 Concluding remarks and future work

Moving into the new term (2022–2024), the working group will continue its work to advance scientific knowledge on priority shipping pressures and to identify emerging pressures of interest in order to support the holistic management of shipping. WGSHIP recommends a continuation of the WG with modified Terms of References (ToRs).

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Annex 1: List of participants

WGSHIP 2021 participation

Name	Institute	Country (of institute)	Email
Amélie Laprade	Transport Canada	Canada	amelie.laprade@tc.gc.ca
Andreas Gondikas	National and Kapodistrian University of Athens	Greece	andreas.gondikas@gmail.com
Annukka Lehikoinen	Kotka Maritime Research Center	Finland	annukka.lehikoinen@merikotka.fi
Cathryn Murray	Fisheries and Oceans Canada	Canada	cathryn.murray@dfo-mpo.gc.ca
David Peel	CSIRO Commonwealth Scientific and Industrial Research Organisation	Australia	david.peel@data61.csiro.au
Emmanuel Ponzevera	IFREMER French Research Institute for Exploitation of the Sea	France	emmanuel.ponzevera@ifremer.fr
Eva-Lotta Sundblad	Swedish Institute for the Marine Environment	Sweden	eva-lotta.sundblad@havsmiljoinstitutet.se
Floris Goerlandt	Dalhousie University	Canada	floris.goerlandt@dal.ca
Gauthier Lequeue	Federal Public Service Mobility and Transports	Belgium	gauthier.lequeue@mobilit.fgov.be
Hannah Millar	Marine Scotland Science	Scotland	hannah.millar@gov.scot
Ida-Maja Hassellöv	Chalmers University of Technology	Sweden	ida-maja@chalmers.se
Jacek Tronczynski	IFREMER French Research Institute for Exploitation of the Sea	France	jacek.tronczynski@ifremer.fr
Jessica Redfern	New England Aquarium	USA	jredfern@neaq.org
Jose A. Fernandes-Salvador	AZTI, Marine Research, Basque Research and Technology Alliance (BRTA)	Spain	jfernandes@azti.es
Josephine Iacarella	Fisheries and Oceans Canada	Canada	josephine.iacarella@dfo-mpo.gc.ca
Jukka-Pekka Jalkanen	Finnish Meteorological Institute	Finland	jukka-pekka.jalkanen@fmi.fi
Karen de Jong	Norwegian Institute of Marine Research	Norway	karen.de.jong@hi.no

Kate Brookes	Marine Scotland Science	Scotland	kate.brookes@gov.scot
Katja Broeg	Bundesamt für Seeschifffahrt und Hydrographie	Germany	katja.broeg@bsh.de
Katrin Ewert	Bundesamt für Seeschifffahrt und Hydrographie	Germany	katrin.ewert@bsh.de
Keith Hayes	CSIRO	Australia	keith.hayes@data61.csiro.au
Lisa Drake	SGS	United States	lisa.drake@sgs.com
Lorenzo D'Andrea	Università degli studi di Roma - Tor Vergata	Italy	dandrea.lorenz@gmail.com
Marja Koski	DTU Aqua	Denmark	mak@aqua.dtu.dk
Mats Kinnula	Gard Marine Insurance Company	Finland	mats.kinnula@gard.no
Nathan Merchant	CEFAS	United Kingdom	nathan.merchant@cefas.co.uk
Octavio Marin-Enriquez	Bundesamt für Seeschifffahrt und Hydrographie	Germany	octavio.marin@bsh.de
Raymon van Anrooy	Food and Agriculture Organization of the United Nations (FAO)	Italy	raymon.vananrooy@fao.org
Ross Culloch	Marine Scotland Science	Scotland	ross.culloch@gov.scot
Sakari Kuikka	University of Helsinki	Finland	sakari.kuikka@helsinki.fi
Sarah Bailey	Fisheries and Oceans Canada	Canada	sarah.bailey@dfo-mpo.gc.ca
Sylvia Blake	CEFAS	United Kingdom	sylvia.blake@cefas.co.uk
Valérie Dulière	Royal Belgian Institute of Natural Sciences	Belgium	vduliere@naturalsciences.be
Zuzanna Kochanowicz	Transport Canada	Canada	zuzanna.kochanowicz@tc.gc.ca

WGSHIP 2020 participation

Name	Institute	Country (of institute)	Email
Andreas Gondikas	National and Kapodistrian University of Athens	Greece	andreas.gondikas@gmail.com
Cathryn Murray	Fisheries and Oceans Canada	Canada	cathryn.murray@dfo-mpo.gc.ca
Emmanuel Ponzevera	IFREMER	France	Emmanuel.Ponzevera@ifremer.fr
Eva-Lotta Sundblad	Swedish Institute for the Marine Environment	Sweden	eva-lotta.sundblad@havsmiljoinstitutet.se
Gauthier Lequeue	Federal Public Service Mobility and Transports	Belgium	gauthier.lequeue@mobilit.fgov.be
Hannah Millar	Marine Scotland Science	Scotland	Hannah.Millar@gov.scot
Ida-Maja Hassellöv	Chalmers University of Technology	Sweden	ida-maja@chalmers.se
Jacek Tronczynski	IFREMER	France	Jacek.Tronczynski@ifremer.fr
Jessica Redfern	New England Aquarium	United States	jredfern@neaq.org
John Hildebrand	Scripps Institution of Oceanography	United States	jahildebrand@icloud.com
Jose Fernandes	Plymouth Marine Laboratory	United Kingdom	jfernandes@azti.es
Josephine Iacarella	Fisheries and Oceans Canada	Canada	Josephine.Iacarella@dfo-mpo.gc.ca
Julie Kellner	ICES secretariat	ICES	julie.kellner@ices.dk
Karen de Jong	Institute of Marine Research	Norway	karen.de.jong@hi.no
Lisa Drake	SGS North America – Environment, Health and Safety	United States	lisa.drake@sgs.com
Lorenzo D'Andrea	University of Rome Tor Vergata	Italy	dandrea.lorenz@gmail.com
Marja Koski	DTU Aqua – National Institute of Aquatic Resources	Denmark	mak@aqua.dtu.dk
Mats Kinnula	Oy Gard (Baltic) Ab	Finland	Mats.Kinnula@gard.no
Octavio Marin	Bundesamt für Seeschiffahrt und Hydrographie	Germany	Octavio.Marin@bsh.de
Raymon Edward van Anrooij	The Food and Agriculture Organization of the United Nations	Italy	raymon.vananrooy@fao.org
Roland Cormier	Helmholtz-Zentrum Geesthacht	Germany	Roland.Cormier@hzg.de
Ross Culloch	Marine Scotland Science	Scotland	Ross.Culloch@gov.scot
Sarah Bailey	Fisheries and Oceans Canada	Canada	sarah.bailey@dfo-mpo.gc.ca
Valèrie Dulière	Royal Belgian Institute of Natural Sciences/OD Nature	Belgium	vduliere@naturalsciences.be

WGSHIP 2019 participation

Name	Institute	Country (of institute)	Email
Benoit Adam	Federal Public Service Mobility and Transport	Belgium	benoit.adam@mobilit.fgov.be
Cathryn Murray	Fisheries and Oceans Canada	Canada	cathryn.murray@dfo-mpo.gc.ca
David Peel	CSIRO Marine and Atmospheric Research	Australia	David.Peel@data61.csiro.au
Eva-Lotta Sundblad	Swedish Institute for the Marine Environment	Sweden	eva-lotta.sundblad@havsmiljoinstitutet.se
Hjalti Hreinsson	Protection of the Arctic Marine Environment	Iceland	hjalti@pame.is
Ida-Maja Hassellöv	Chalmers University of Technology	Sweden	ida-maja@chalmers.se
Jessica Redfern	New England Aquarium	United States	jredfern@neaq.org
John Hildebrand	Scripps Institution of Oceanography	United States	jahildebrand@icloud.com
Jose Fernandes	Plymouth Marine Laboratory	United Kingdom	jfernandes@azti.es
Josephine Iacarella	Fisheries and Oceans Canada	Canada	Josephine.Iacarella@dfo-mpo.gc.ca
Julie Gjedsig Grauslund	Danish Maritime Authority	Denmark	jgg@dma.dk
Karen de Jong	Institute of Marine Research	Norway	karen.de.jong@hi.no
Katja Broeg	Federal Maritime and Hydrographic Agency of Germany	Germany	Katja.Broeg@bsh.de
Keith Hayes	CSIRO Marine and Atmospheric Research	Australia	Keith.Hayes@data61.csiro.au
Lisa Drake	SGS North America – Environment, Health and Safety	United States	lisa.drake@sgs.com
Lorenzo D'Andrea	University of Rome Tor Vergata	Italy	dandrea.lorenz@gmail.com
Marja Koski	DTU Aqua – National Institute of Aquatic Resources	Denmark	mak@aqua.dtu.dk
Mats Kinnula	Oy Gard (Baltic) Ab	Finland	Mats.Kinnula@gard.no
Nathan Merchant	Centre for Environment, Fisheries and Aquatic Resources	United Kingdom	nathan.merchant@cefas.co.uk
Raymon Edward van Anrooij	The Food and Agriculture Organization of the United Nations	Italy	raymon.vananrooy@fao.org
Sakari Kuikka	University of Helsinki	Finland	sakari.kuikka@helsinki.fi
Sarah Bailey	Fisheries and Oceans Canada	Canada	sarah.bailey@dfo-mpo.gc.ca
Valèrie Dulière	Royal Belgian Institute of Natural Sciences/OD Nature	Belgium	vduliere@naturalsciences.be

Annex 2: WGSHIP resolution

The **Working Group on Shipping Impacts in the Marine Environment** (WGSHIP), chaired by Cathryn Murray, Canada, and Ida-Maja Hassellöv, Sweden, will be established and will work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2019	25–27 November	ICES HQ, Copenhagen, Denmark		
Year 2020	27–29 May 3–4 Nov	by corresp/ webex		- Incoming co-chair: Ida-Maja Hassellöv, Sweden. - 2020 physical meeting cancelled - remote work
Year 2021	25–26 May 2–4 November	Online meeting	Final report by 15 December to SCICOM	

ToR descriptors

ToR	Description	Background	Science plan codes	Duration	Expected Deliverables
a	Conduct strategic planning through review of national research on shipping interactions with the environment and report on priorities, knowledge gaps and opportunities for further collaboration.	ICES strategic plan Goal 2: understand the relationship between the impact of human activities (e.g., shipping) and marine ecosystems to estimate pressures and impacts and develop science-based sustainable pathways.	2.1; 2.5;	2 years	Report to ICES. Respond to advice requests, as applicable.
b	Review the intensity, geographical scope, and trends in current and future global shipping activity, including those in the Arctic and in/near marine protected areas.	The distribution and intensity of commercial shipping is increasing and there is a growing need to assess and mitigate the impacts of vessel activities on the marine environment, especially in areas of enhanced protection. The Arctic is one such area but there are a number of other productive sea areas where the shipping intensity has increased to an extent where impacts on the environment are becoming obvious.	2.1; 2.4; 2.7	2 years	Technical paper or peer-reviewed manuscript.

c	Review and evaluate methods to assess the effect of shipping on the marine environment, including cumulative effects..	Cumulative effects assessment is needed to address the sheer volume and frequency of vessel movements, the interaction and summation of multiple impact pathways, and effects which overlap spatially and manifest through time.	2.1; 2.2; 6.1	3 years	Input on the general applicability or otherwise of such methods to IMO or national regulators through meeting participation, correspondence group and/or technical paper or peer-reviewed manuscript.
d	Review and identify possible mitigation strategies for decreasing noise (from shipping) in general and specifically in sensitive areas.	The impact of noise has been the topic of discussion at the Environment Committee (IMO) for years. In parallel quite a lot of research has been carried out and it is time to summarize the knowledge and recommend action and further research.	2.1; 2.7; 6.1		Input on the general applicability or otherwise of such strategies to IMO or national regulators through meeting participation, correspondence group and/or technical paper or peer-reviewed manuscript.
e	Review and identify methods for holistic management of shipping impacts, considering possible trade-offs across impact types.	Vessel activities can have transboundary impacts and successful mitigation efforts require coordination and collaboration between trade partners. Methods for holistic management are urgently needed to balance the benefits of industry with environmental impacts.	6.1; 6.2	3 years	ICES Viewpoint

Summary of the Work Plan

Year 1	Working on all ToRs, but with special focus on ToRs a, b
Year 2	Working on all ToRs, but with special focus on ToRs c, d, e
Year 3	Report on all ToRs

Supporting information

Priority	The work of the Group forms the scientific basis for advancing knowledge related to the impacts of shipping on the environment. It is anticipated that advisory requests could soon be received concerning shipping impacts, thus it is high priority to establish a Group to address any new requests.

Resource requirements	The research programmes which provide the main input to this group are already underway, with resources provided by national governments and scientific funding agencies. The additional resources required to undertake activities in the framework of this group are negligible.
Participants	The Group has had expressions of interest from more than 30 members.
Secretariat facilities	Standard secretarial support.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	Development of ICES Viewpoint in collaboration with ACOM
Linkages to other committees or groups	Potential linkages with WGBOSV, WGITMO, WGSFD, WGMHM, WGMPCZM, IEASG
Linkages to other organizations	Potential linkages with Arctic Council, the Baltic Marine Environment Protection Commission (HELCOM), European Maritime Safety, Agency (EMSA), International Maritime Organization (IMO), National Oceanic and Atmospheric Administration (NOAA), North Pacific Marine Science Organization (PICES), OSPAR Commission and UNEP Oceans and Seas Program. In addition, the outcomes are relevant to other national and international organizations involved in the development of regulatory policies.