WORKING GROUP ON SHIPPING IMPACTS IN THE MARINE ENVIRONMENT (WGSHIP; outputs from 2024 meeting)

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i Executive summary

The shipping industry is the backbone of the global economy, transporting people and goods around the world. A ship is a floating industrial site with environmental impacts that are under active management as well as lesser-known pressures in need of research and management. Methods for holistic management are urgently needed to balance the benefits of the industry with environmental impacts.

The Working Group on Shipping Impacts in the Marine Environment (WGSHIP) draws upon multidisciplinary knowledge to consider the impacts of shipping on the marine environment. WGSHIP continues to develop and apply a holistic framework summarizing the pressures and effects of shipping, which can be used to support cumulative effects assessment and integrated marine management. Each term, the members of WGSHIP complete a spreadsheet reporting template to collect data on recent and ongoing relevant research activities, with more than 80 activities from ten countries reported to date. Antifouling paints, atmospheric deposition, accidents, and noise were the most commonly studied topics; the most common pressure subcategory of interest was nonindigenous species, metals, Polycyclic Aromatic Hydrocarbons (PAHs) contaminants, acidifying substances, and nutrients. The most commonly applied assessment types in the reported research activities were environmental policy, followed by mitigation measures, impact assessment and risk assessment. Exhaust gas cleaning systems (scrubbers) and underwater noise continue to be a focus for WGSHIP members, with increasing interest in anchorages and discharges of grey water. In addition, a number of emerging shipping-related pressures have been identified by WGSHIP experts: plastic debris, turbulent mixing, vessel strikes, alternative fuels, tank cleaning residues, and the potential of incorporating these parameters in Environmental, Society and Governance (ESG) ratings. The group identified the need for holistic assessment of shipping pressures and as a result, submitted a manuscript to a peer-reviewed journal on the mitigation options for noise and the associated benefits and trade-offs incurred in other shipping-related stressors, such as vessel strikes and invasive species transport. In collaboration with WGBOSV (Joint ICES/IOC/IMO Working Group on Ballast and Other Ship Vectors), WGSHIP proposed and chaired a shipping-related theme session at the 2022 ICES Annual Science Conference and members of WGSHIP presented research at the 3rd International Shipping and Environment Conference in 2023.

ii Expert group information

Expert group name	Working Group on Shipping Impacts in the Marine Environment (WGSHIP)
Expert group cycle	Multiannual
Year cycle started	2022
Reporting year in cycle	3/3
Chairs	Cathryn Murray, Canada
	Ida-Maja Hassellöv, Sweden
Meeting venue(s) and dates	15-18 October 2022, Online meeting (17 participants)
	25-29 September 2023, Gothenburg, Sweden (18 participants)
	4-6 November 2024, Athens, Greece (25 participants)

1 Introduction

The shipping industry forms an increasingly important component of the global economy; the volumes of transported goods increased fourfold in the last 50 years (UNCTAD, 2014). While our understanding and regulation of air and oil pollution, and ballast water from shipping has gradually increased, the broader impacts on the marine environment have received less attention. The working group on impacts of shipping on the marine environment (WGSHIP) was formed in 2019 to address the intersection between shipping-related pressures and marine environmental management.

Over its first two terms, WGSHIP worked to support ICES Science Plan Priority II (impact of human activities) and VI (conservation and management science). 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 was summarised by the members of WGSHIP. A template spreadsheet for national reporting was used to collect, to the extent possible, information on recent and ongoing research activities.

WGSHIP has linkages and relationships with other groups, primarily the International Maritime Organization (IMO), a specialised agency of the United Nations responsible for regulating shipping, but also 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. WGSHIP has had cross-participation with other ICES groups, including the Working Group on Ballast Water and other Shipping Vectors (WGBOSV), 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).

In its second term, WGSHIP continued a high level of achievement. In 2022, WGSHIP chaired a theme session, in collaboration with WGBOSV, titled "Steering shipping impact prevention towards holistic marine management" at the ICES Annual Science Conference. Members of WGSHIP conducted new research on the trade-offs and synergies of mitigation measures for underwater noise, resulting in a journal article submission. WGSHIP was active in the 2023 Shipping and Environment conference as well as proposing and supporting a special research topic on the impacts of shipping in a scientific journal. The members of WGSHIP recommend a continuation of the WG with updated and modified draft Terms of References.

2 Conceptual framework for shipping impacts

ToR c - Develop a framework to represent the impacts of shipping on the marine environment, which can be used to guide science advice on the development and implementation of ecosystem-based management

2.1 Development of the framework

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. 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. 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). 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 objective of the European works was to delineate the pressures and stressors identified from different onboard systems, to align with the Descriptors identified in the Marine Strategy Framework Directive (MSFD). Their approach builds upon the classic DPSIR (Driver-Pressure-State-Impact-Response) framework and the pressure categories and sub-categories were further refined by Ytreberg *et al.* 2021.

Starting from a DAPSIR-framework - Driver-Activities-Pressures-State-Impact-Response framework - WGSHIP describes the Activity and Pressure steps for assessment of the environmental impacts of shipping (Figure 2.1). The DAPSIR-framework provides a structure for assessment, and we introduce sublevels of the Activity-Pressure steps: Activities include vessel types, mode of operation, and subsystems, and Pressures are further delineated into Pressure subcategories.

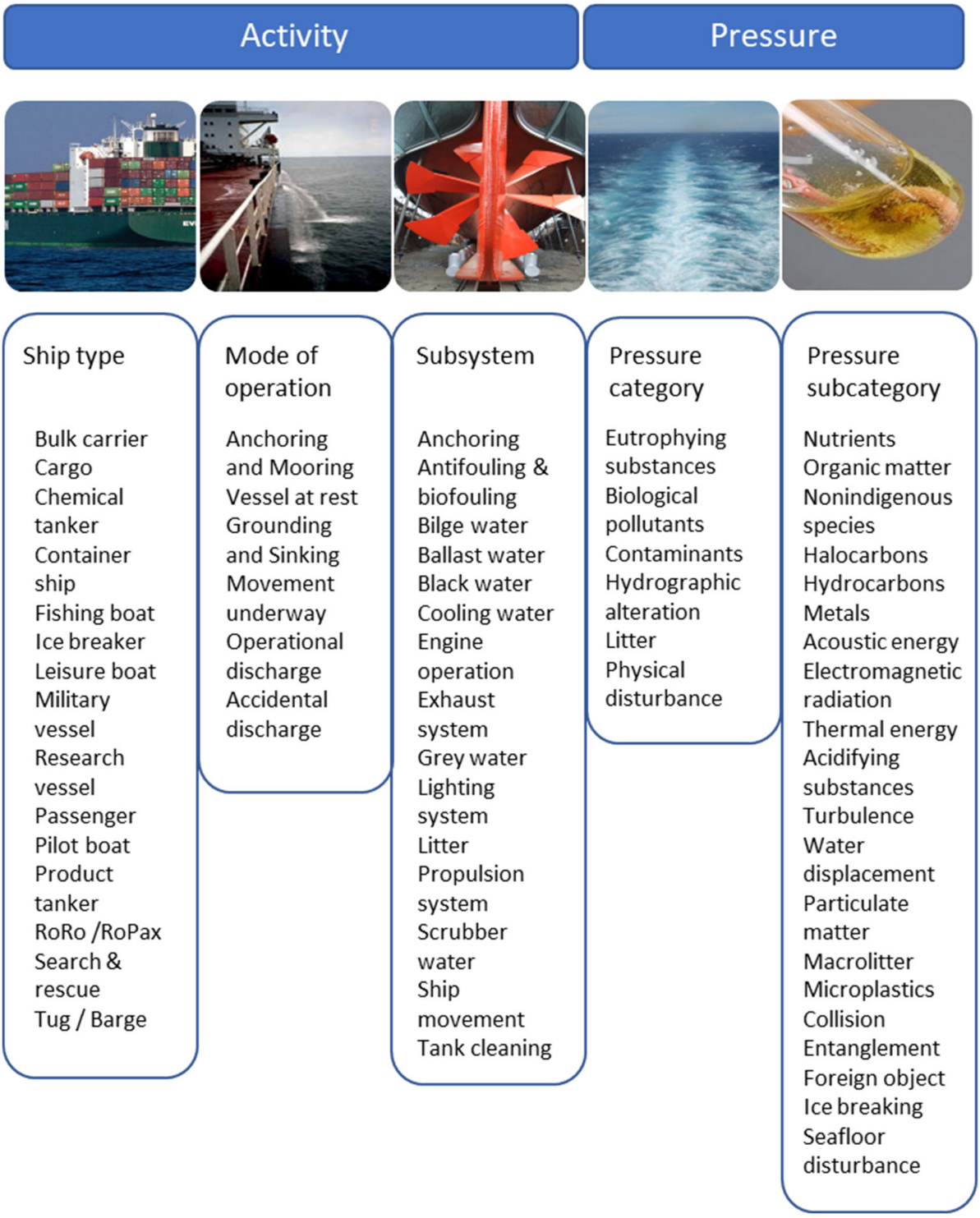

Figure 2.1. Representation of the holistic shipping conceptual framework divided into Ship type, Mode of operation, Subsystem, Pressure category, and Pressure subcategory.

2.1.1 Activity - Shipping sub-activities

Shipping can be further organized at various sub-activity levels: the vessel type, the mode of operation, and/or 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, Research vessels, Passenger ship, Pilot boat, Product tanker, RoRo/RoPax, Search and rescue, Tug/Barge. Descriptions of each type are in Table 2.1 (Arctic Council, 2009; Transport Canada, 2019; Hannah *et al.*, 2020; IMO, 2019).

Table 2.1. Standardised vessel type categories (as in the Fourth IMO GHG study). DWT = Deadweight tonnage, GT = Gross tonnage, TEU = Twenty-foot containers, CBM = Cubic meters, VEH = Vehicles.

Type	Description and size classification
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 to following sizes (DWT): 0-9999; 10000-34999; 35000-59999; 60000-99999; 100000-199999; 200000-+
Chemical tanker	Ships designed and constructed for the bulk carriage of liquids. Chemical tankers are segregated to following sizes (DWT): 0-4999; 5000-9999; 10000-19999; 20000-39999; 40000+
Container	Container ships are cargo ships that carry all their load in large containers. Container carriers are segregated to following sizes (TEU): 0-999; 1000-1999; 2000-2999; 3000-4999; 5000-7999; 8000-11999; 12000-14499; 14500-19999; 20000+
General cargo	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. General cargo ships are segregated to following sizes (DWT): 0-4999; 5000-9999; 10000-19999; 20000+
Liquefied gas tanker	Ships designed to carry gaseous cargoes. These are usually LNG, LPG, CNG or other liquified gases in bulk. Cargoes are usually either under high pressure and/or at cryogenic temperature. Gas tankers are segregated to following sizes (CBM): 0-49999; 50000-99999; 100000-199999
Oil tanker	A ship constructed or adapted primarily to carry oil or similar products in bulk in its cargo spaces. Oil tankers are segregated to following sizes (DWT): 5000-9999; 10000-19999; 20000-59999; 60000-79999; 80000-119999; 120000-199999; 200000+
Other liquids tankers	A ship constructed or adapted primarily to carry other liquids than oil or chemical products (alcohol, caprolactam, molasses, water etc) in bulk in its cargo spaces
Cruise	A ship constructed or adapted primarily to carry passengers, often defined as carrying more than twelve passengers. Passenger cruise ships are segregated to following sizes (GT): 2000-9999; 10000-59999; 60000-99999; 100000-149999; 150000+

Type	Description and size classification
Ferry-RoPax	RoPax ships are built for freight vehicle transport along with passenger accommodation. RoPax ships are segregated to following sizes (GT): 2000-4999; 5000-9999; 10000-19999; 20000-+
Refrigerated bulk	A cargo ship typically used to transport perishable cargo, which require temperature-controlled handling, such as fruits, meat, vegetables, dairy products, and similar items. Reefers are segregated to following sizes (DWT): 2000-5999; 6000-9999; 10000+
Ro-Ro	The roll-on/roll-off (RoRo/RoPax) ship is a ship with ro-ro cargo spaces and passenger accommodation. RoRo ships are segregated to following sizes (GT): 0-4999; 5000-9999; 10000-14999; 15000+
Vehicle	Vessels specially designed for efficient transport of cars (pure car carriers), or variety of cars, trucks, tractors and buses (pure car/truck carriers). Vehicle carriers are segregated to following sizes (VEH): 0-29999; 30000-49999; 50000+
Offshore	Offshore vessels primarily serve the offshore oil and gas sector and are also engaged in offshore construction projects like offshore wind farms
Service - other	Vessels designed to provide support to commercial ships and/or industrial vessels, such as tugs, offshore support vessels, crane barges, diving support boats, fire boats, pilot boats and buoy tenders
Fishing vessel	Any vessel used commercially for catching fish or other living resources of the sea
Military vessel	Military ships and submarines used for the purpose of national defense. 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, oil tanker and/ or pilot boat
Research vessel	Any vessel used for the purpose of scientific research. Depending on the size and purpose, these vessels may have characteristics similar to other vessel categories
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 craft	A leisure or pleasure craft is any boat used only for pleasure activities like fishing, water sports, and entertainment. It also includes a boat
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

The impacts of shipping can also be described according to the sub-activity of the ship (Table 2.2).

Table 2.2. 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 moor-ing buoy system including the subsequent movement of the anchor-ing or mooring buoy system while deployed. This mode of operation 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 sewage discharges, 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 equip-ment malfunctions that release discharges.

Sub-activity - Ship subsystems

Ships have numerous systems on board that each have their own pressures and effects on the marine environment. The shipping framework describes 15 ship subsystems with different magnitude of effects depending on ship size, type, etc. Each type of liquid waste stream is classified as separate subsystems, i.e. Ballast water, Black water (sewage), Grey water, Tank cleaning, Cooling water, Scrubber water, Bilge water and Stern tube oil. Propulsion and manoeuvring (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. The most common types of antifouling coatings are designed to leach toxic biocidal substances to prevent spreading of nonindigenous species from Biofouling, which are here considered separate subsystems. Finally, Anchoring, causing physical disturbance through seafloor scouring, is considered a subsystem of its own.

2.1.2 Pressures

The ship subsystems contribute to pressures categorised as: Eutrophying substances, Biological pollutants, Contaminants, Energy pollutants, Hydrographic alteration, Litter, and Physical disturbance. Pressure categories can be further defined into pressure sub-categories for more specificity. For example, Pressure sub-categories include: Nutrients, Organic matter, Nonindigenous 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 2.3). Categorisation adapted from Moldanová *et al.* (2018), Hannah *et al.* (2020), Moldanová *et al.*, (2021), and Ytreberg *et al.* (2021).

Table 2.3. Pressure sub-categories and descriptions defined in this framework (adapted from Moldanová *et al.*, 2018; Hannah *et al.* 2020; J. Moldanová *et al.*, 2021; Ytreberg *et al.*, 2021).

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)

Pressure sub-category	Description
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 sulfur oxides (SOx)
Turbulence	Turbulence created by the propellers of moving vessels ('propeller wash').
Water displacement	Disturbance of water produced by displacement due to the movement of vessels, includes waves and wake
Particulate matter	Discharge of particle suspensions and colloids or deposition of solid 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 ice-breaking vessels.
Seafloor disturbance	Alteration and disturbance of the seafloor from anchoring activities

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 to structure the national reporting template for the working group members, ensuring the complete set of pressures are listed. The framework has also been used in an analysis of synergies and trade-offs in mitigation actions for underwater noise (see Section 5 Holistic management of shipping impacts.

3 Shipping research inventory

ToR 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

3.1 Overview of research activities

In order to review the global research activities, priorities, trends, and gaps, the members of WGSHIP completed a spreadsheet reporting template to collect data on the recent and ongoing research activities 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. In the second term of WGSHIP, reports were received from ten countries: Canada, Denmark, Estonia, Finland, Germany, Greece, Norway, New Zealand, Sweden, and the United States of America. A total of 80 new research activities were reported for the 2022–2024 time period. There are now 322 research activities captured in the reporting spreadsheet for 2019–2024. A select few of the larger research activities are presented in Table 3.1.

Table 3.1. Examples of multinational projects on shipping-related research activities reported to WGSHIP in 2022-2024. 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	Assessment types
Evaluation, control and Mitigation of the Envi-Ronmental impacts of shippinG Emissions (EMERGE)	10 countries including Finland, Italy, Sweden, Greece, Portugal, United Kingdom	Antifouling, Atmospheric deposition, Bilge water, Biofouling, Food waste, Grey water, Noise, Scrubber discharge, Sewage, Sludge, Stern tube oil, Metals, Oil, PAHs, Particulate matter,	Cumulative effects, Economic assessment, Impact assessment, Literature review, Mitigation measures, Risk assessment, status evaluation, Vessel movements,
Maritime Data Methods for Safe Shipping (MaD-aMe)	11 countries including Denmark, Finland, Poland, and Sweden	Accidents	Risk assessment, Vessel movements
New GeneRation marinE ENgines and Retrofit solutions to Achieve methane abatement flexibil-itY (GREEN RAY)	11 countries including France, Finland, Italy, Netherlands, Norway, Switzerland, United Kingdom	Other (GHGs, methane)	Environmental policy, Mitigation measures, Status evaluation, Vessel movements
Development and evaluation of noise management strategies to keep the North Sea healthy (DEMASK)	9 countries including Belgium, Netherlands, Denmark, Sweden	Noise	Mitigation measures

Project	Countries involved	Ship subsystems and pressures of interest	Assessment types
Capacity building nexus for monitoring water quality in multi-stressor areas: Pilot study at the Hellenic volcanic arc (nexus monARC)	6 countries including Greece, Belgium, Sweden, Norway	Antifouling, Scrubber discharge water, Sewage, Metals, Nutrients, PAHs, Particulate matter,	Development of monitoring mechanisms involving citizen science

Working group research activities were reported by ship subsystem and pressure, pressure subcategory, and assessment type. Antifouling, atmospheric deposition, accidents, and noise were the most common subsystems of focus for research activities (Figure 3.1). Across the reports, the most commonly studied pressure subcategory was nonindigenous species, metals, PAHs, and nutrients (Figure 3.2). The most commonly applied assessment types in the reported research activities were environmental policy, followed by mitigation measures, impact assessment and risk assessment (Figure 3.3).

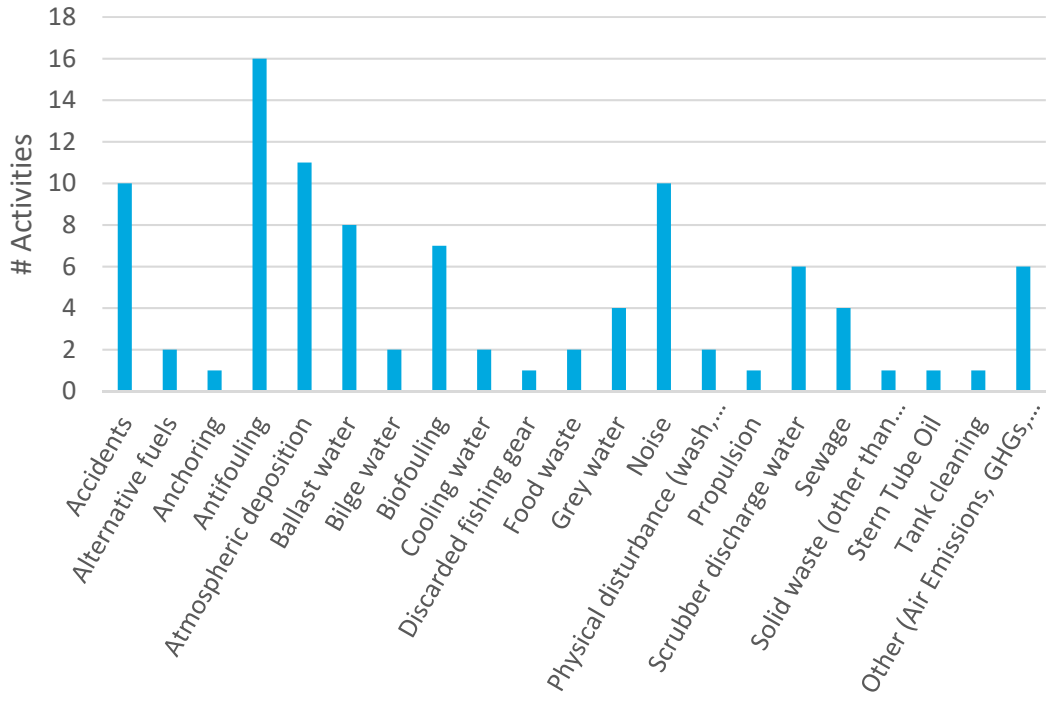

Figure 3.1. Number of research activities focused on shipping driver subsystems, as identified by the working group members and their contacts. This list is not comprehensive because of varying reporting effort and criteria for inclusion across member countries.

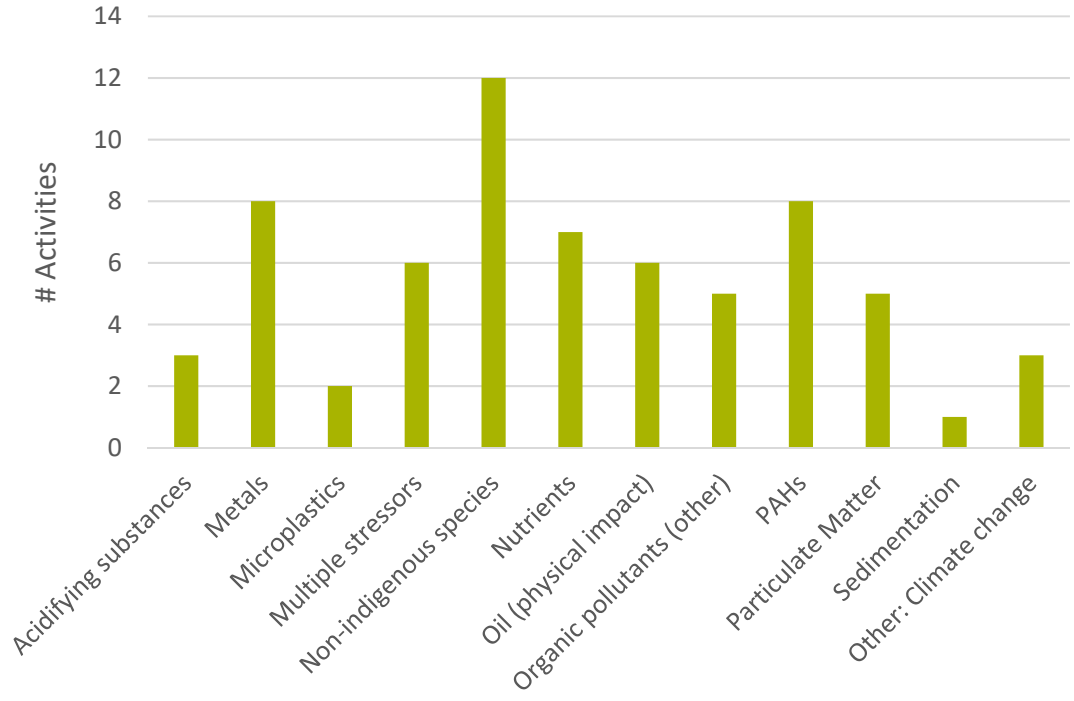

Figure 3.2. Number of research activities focused on shipping pressure sub-categories, as identified by the working group members and their contacts. This list is not comprehensive because of varying reporting effort and criteria for inclusion across member countries.

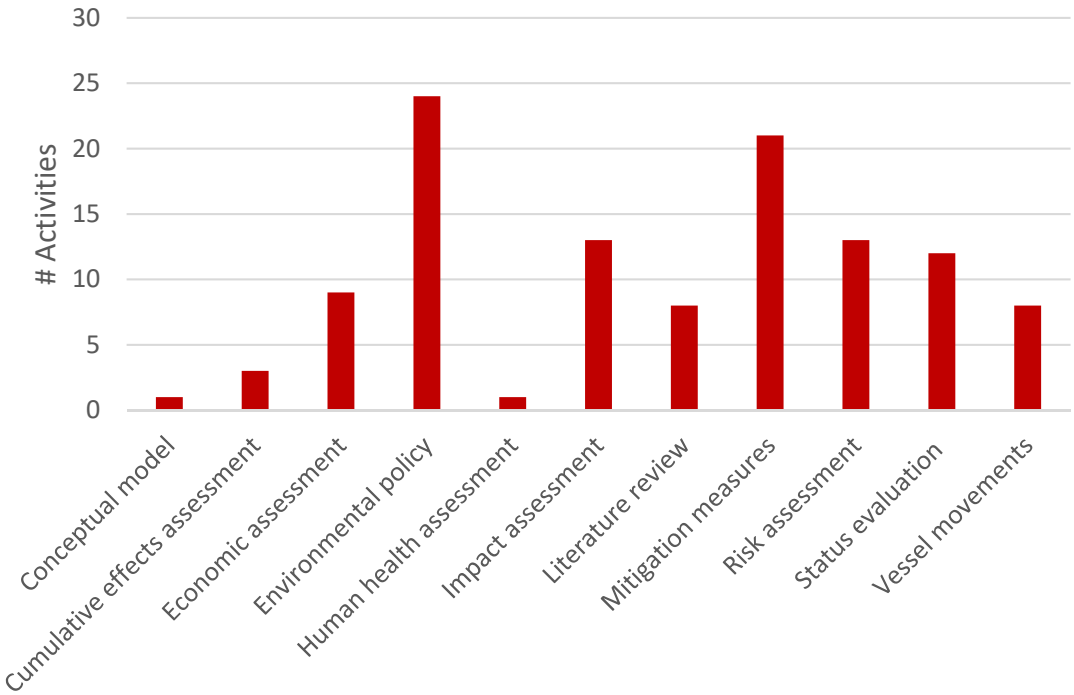

Figure 3.3. Number of research activities reported applying a variety of assessment types, as identified by the working group members and their contacts. This list is not comprehensive because of varying reporting effort and criteria for inclusion across member countries.

4 Emerging shipping-related pressures

ToR d – Identify current and emerging shipping pressures, review state of knowledge and explore possible mitigation strategies for decreasing impacts

4.1 Exhaust Gas Cleaning Systems (Scrubbers)

Stricter global sulfur regulations entered into force in January 2020, incentivizing shipowners to start using fuel with low sulfur content, instead of heavy fuel oil. However, an increasing number of ships are now equipped with exhaust gas cleaning systems, also known as scrubbers, in order to reduce sulfur emissions in the atmosphere and continue using the cheaper heavy fuel oil. Today about 25% of the global bunker consumption consists of HFO in combination with a scrubber. Scrubbers wash out sulfur from the exhausts to meet the limit regarding emissions to air, however large volumes (typically more than 500 m^3/h) of acidified (pH less than 7) seawater are discharged back into the sea. Scrubber water contains high concentrations of toxic polycyclic aromatic hydrocarbons (PAHs) and heavy metals. Recent studies highlight the ecotoxic effects of these components and shed light on their transport through microparticles (e.g. Jönander *et al.* 2023, Gondikas *et al.* 2025). As highlighted in the ICES Viewpoint: *Scrubber discharge water from ships – risks to the marine environment and recommendations to reduce impacts*, 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). Based on the scientific consensus provided in the background document, ICES recommended avoidance of discharge of scrubber water in the marine environment, and instead support a shift to cleaner low-sulfur fuel oils (ICES, 2020).

Since the publication of the background document and advice, further scientific studies have been conducted, bringing a better understanding of the environmental impacts from scrubber discharges. WGSHIP members were involved in the scrubber-related research projects ImpEx (Germany) and EMERGE (EU Horizon 2020). The results of these projects have been submitted and considered in the IMO for the discussions about regulation of scrubber discharges. Denmark, Finland and Sweden have banned the discharge of scrubber effluent to the sea on their territorial seas, closer than 12 nautical miles from the coastline. Discharge of open loop scrubber effluent is banned from July 1st 2025 onwards, closed loop discharge will be banned in 2029. Even if regional or global bans have not been agreed yet at the IMO, several national bans exist, e.g. in China, Turkey, Belgium, Egypt, Oman, France, Ghana, Malaysia and Mexico (ICCT 2023). Also, several countries have introduced local restrictions for specific ports, even if scrubber discharge in territorial waters is allowed (e.g. Port of Vancouver, Canada).

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). The pervasive nature of shipping noise pollution has raised concern that it can cause widespread behavioural and physiological effects with consequences at the population and ecosystem level (Slabbekoorn *et al.*, 2010; Tyack, 2008; Kok *et al.* 2024). 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). The Arctic was identified as an area of rapid shipping noise increase,

and Covid19 pandemic reduced the noise emissions from ships only temporarily (Jalkanen *et al*., 2022).

The members of WGSHIP continue to engage in research and policy activities related to underwater noise associated with shipping. A sub-group of WGSHIP has been working on a manuscript submitted to the peer-reviewed literature reviewing the trade-offs and synergies of potential noise mitigation measures on other shipping-induced pressures (see section 5 for more details). The interdisciplinary expertise of WGSHIP was crucial to the development of this manuscript.

4.3 Anchorages

Anchorages are required globally to allow ships to wait before entering ports and harbours to discharge or load cargo. Historically, anchorages have been established through custom and practice, without surveying and assessing the proposed areas for suitability or impact.

Commonplace vessel anchoring practices are not globally regulated. Increased shipping traffic over the past decades has intensified port congestion and anchorage use, and with a four-fold increase in shipping trade predicted by 2050, there is a need to engage in research exploring options for a sustainable maritime future and realisation of greener shipping corridors. To achieve more sustainable and lower-impact shipping corridors, the external costs of anchoring must be internalized into environmental management. Yet, anchoring practices remain unmeasured, undocumented, and unregulated.

The consequences of vessel anchoring may include habitat destruction, loss of ecosystem function (e.g., carbon storage) and resuspension of sediments, likely causing carbon release and remobilisation of buried contaminants (e.g., heavy metals, microplastics, etc.). Hannah and colleagues (2024) described the full range of ecological, cultural and socio-economic effects that anchoring can cause. Recent research conducted by the WGSHIP members has shown that anchoring practices have adverse consequences for marine ecosystems due to physical disturbance by anchors (Watson *et al.* 2022). Sediment mixing and overturn by anchoring is comparable to benthic trawling, a well-known driver of seafloor habitat destruction. Anchor dragging can also damage existing seafloor infrastructure. Anchoring represents a human impact that can be feasibly managed to mitigate damage to the marine environment (e.g. by low-impact anchor designs, permanent moorings or optimising port logistics to reduce the need for anchorages). Ongoing work from the multidisciplinary team from WGSHIP is crucial to integrate real-time observations, laboratory experiments and ecosystem models to validate the impacts of anchoring on a range of spatial and temporal scales, offering a unique opportunity to characterise the full impact of ship anchoring in the marine environment.

4.4 Grey water

Grey water consists of drainage from dishwashing, showers, laundry, baths and washbasins. It can be held in a separate tank onboard a ship or mixed with the sewage in a joint tank, implying large variability of the grey water constituents and making it challenging to sample (Mujingni *et al.* 2024). If grey water is mixed with the sewage, then it may be subject to sewage treatment. Grey water discharge from ships is not regulated by the IMO and it can be discharged directly to the sea. There are some local bans for grey water discharge, like that in the USA and Finland. Grey water may contain bits of food, detergents, cleaning agents and nutrients, cosmetics, and microplastics and is linked directly to the human activities occurring onboard. For this reason, passenger ships are the largest source of grey water, reaching up to 70% of the global discharges of grey water (HELCOM, 2024).

4.5 Other emerging pressures

In addition to those mentioned above, a number of emerging shipping-related pressures have been identified by WGSHIP experts - plastic debris and byproducts (micro- and nanoplastics), introduction of invasive species, turbulent mixing, vessel strikes, and tank cleaning residues. Further, the shift to alternative low- or no-carbon fuels as part of the IMO GHG reduction strategy will create a need to investigate the emissions of new pollutants. These include methane, formaldehyde, ammonia and nitrous oxide which are either directly emitted as combustion products, unburnt fuel, or as a byproduct of emission abatement technologies. Discussion of these emerging pressures promotes collaboration and cooperation across national research borders.

5 Holistic management of shipping impacts

ToR e - Review and identify methods for holistic management of shipping impacts, considering possible trade-offs across impact types

5.1 Underwater noise synergies and trade-offs

Underwater noise from shipping is increasingly recognised as a significant pollutant which can have a range of detrimental effects on marine organisms. However, ships impact marine life in more than one way. From a management perspective, a holistic approach could provide a more successful way to minimise the impact of ship traffic than sequential, single-pressure mitigation. A sub-group of WGSHIP members assessed how other shipping pressures are affected by six noise mitigation measures: ship speed restriction, rerouting, convoying, frequent hull/propeller cleaning, ship quieting technologies, and incentivising fewer, larger ships. The expert group presented and applied a framework to evaluate the synergies and trade-offs in the implementation of mitigation measures to better consider cumulative effects and advance effective, and holistic management. Using expert judgement and peer-reviewed literature each of the proposed mitigation measures was evaluated to determine whether they are likely to have synergistic or trade-off effects on the impacts from other shipping pressures, the scale of the effect, and the strength of the evidence.

Overall, speed reduction has mostly synergies with only weak trade-offs in the other shipping pressures. Frequent hull and propeller cleaning has fewer synergies, but also very few trade-offs, whereas convoying is expected to be the measure with the most trade-offs with other pressures. Re-routing and the incentivization of fewer larger ships have mostly unclear outcomes, because this will depend on the circumstances of implementation. The conclusion was that carefully considered and thoughtfully implemented mitigation measures can lead to multiple benefits across shipping pressures. The manuscript was submitted to a journal for consideration in December 2024.6 Achievements, Collaborations and Future Directions

5.2 Highlights of WGSHIP activities

The breadth and status of research activities related to shipping and shipping-related pressures in each member country were summarised by WGSHIP. The inventory of shipping research includes projects from Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece, New Zealand, Norway, Sweden, United Kingdom, and the United States. The group continues to use a template spreadsheet for shipping research reporting to collect information on members and their networks' activities.

Underwater noise, chemical, and biological pollution continue to be a focus of research activity within the group. A number of emerging shipping-related pressures have been identified by WGSHIP experts - physical disturbance from anchorages, ship-induced methane emissions, turbulent wake, plastic debris, introduction of nonindigenous species, oil spills, turbulent mixing, vessel strikes, alternative fuels and tank cleaning residues. Discussion of these emerging pressures promotes collaboration and cooperation across national research borders.

The group identified the need for holistic assessment of shipping pressures and as a result, prepared a manuscript for journal publication on the mitigation options for noise and the benefits and trade-offs incurred in other shipping-related stressors, such as vessel strikes and

nonindigenous species transport. The manuscript has been submitted to a special issue in Marine Pollution Bulletin.

5.2.1 Conference Theme Session

In collaboration with WGBOSV, WGSHIP proposed and chaired the theme session L "Steering shipping impact prevention towards holistic marine management" at the 2022 ICES Annual Science Conference. Conveners included Okko Outinen (Finland), Cathryn Murray (Canada), and Ida-Maja Hassellöv (Sweden). The session hosted ten flash presentations and a poster. The submissions were of good quality and addressed chemical, biological and energy pollution from shipping, as well as holistic management approaches on multiple shipping pressures. The live theme session was headlined by two keynote presentations from Jukka-Pekka Jalkanen (Finnish Meteorological Institute) and Georg Engelhard (CEFAS), who provided alternating perspectives on multiple shipping pressures to initiate discussion.

5.2.2 Shipping Research Topic

WGSHIP successfully proposed a special Research Topic in the journal Frontiers in Marine Science (as the ICES Journal of Marine Science did not accommodate a special issue on shipping pressures and impacts). The Research Topic was open in conjunction with the third Shipping and Environment Conference in Gothenburg, September 2023. Group members served as Topic Editors for the Research Topic and manuscript submissions were open until March 2024 (https://www.frontiersin.org/research-topics/56020/shipping-pressures-and-impacts-on-the-marine-environment). The topic consolidated seven papers, including original research, review, and a policy brief on various aspects of shipping research and as of December 2024, had more than twenty thousand views and downloads.

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- Possenti, L., de Nooijer, L., de Jong, C., Lam, F. P., Beelen, S., Bosschers, J., ... & Reichart, G. J. 2024. The present and future contribution of ships to the underwater soundscape. Frontiers in Marine Science 11: 1252901.
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- Jönander, C., Egardt, J., Hassellöv, I. M., Tiselius, P., Rasmussen, M., & Dahllöf, I. 2023. Exposure to closed-loop scrubber washwater alters biodiversity, reproduction, and grazing of marine zooplankton. Frontiers in Marine Science 10: 1249964.
- Ferrà, C., & Scarcella, G. 2023. Assessment of the current status and effectiveness of area-based conservation measures banning trawling activities in the Adriatic Sea. Frontiers in Marine Science 10: 1213211.
- Menéndez-Teleña, D., Soto-López, V., Bartolomé, M., González Arenales, M., Montes, H. J., Ardura, A., & Garcia-Vazquez, E. 2023. Alien species established in the Bay of Biscay suggest significant contribution of both fouling and dry ship compartments. Frontiers in Marine Science 10: 1245320.
- Scianni, C., Georgiades, E., Mihaylova, R., & Tamburri, M. N. 2023. Balancing the consequences of in-water cleaning of biofouling to improve ship efficiency and reduce biosecurity risk. Frontiers in Marine Science 10: 1239723.

5.2.3 Shipping & Environment Conference

The 2023 WGSHIP annual meeting was held in conjunction with the 3rd International Shipping and Environment Conference in Gothenburg, Sweden, 27–28 September 2023. Members of WGSHIP served on the Shipping and Environment Conference Scientific Committee and presented oral presentations and posters to the conference. WGSHIP group members attending in person visited the towing tank facility at RISE/SSPA, providing a naval architecture perspective on environmental pressures and impacts of shipping. A visit to Chalmers' maritime simulators gave insight into the operational perspective of ship propulsion and navigation.

5.3 WGSHIP member activities

Individual WGSHIP members provided technical input to a number of activities at the International Maritime Organization during 2022–2024 (as part of their national delegations). The regulation of scrubber discharges at international level has been discussed at the IMO as Output 1.23 "Evaluation and harmonization of rules and guidance on the discharge of discharge water from EGCS into the aquatic environment, including conditions and areas" in the environment-related Committees MEPC and PPR.

Similarly, the IMO has implemented an *International Convention for the Control and Management of Ships' Ballast Water and Sediments* to minimize the global spread of harmful aquatic organisms and pathogens by shipping; after an initial experience-building phase, the MEPC is now conducting a holistic and systematic review of the Convention, to develop a package of improvements to the Convention and its instruments. Further, improvements in biofouling management (to minimize the transfer of invasive aquatic species) were achieved through the adoption of the *2023 Guidelines for the control and management of ships' biofouling to minimize the transfer of invasive aquatic species* and ongoing development of corresponding *Guidance on the in-water cleaning of ships' biofouling*; the MEPC will consider a proposal to develop a mandatory framework for the management of biofouling at its 83rd session in April 2025.

In the regional Conventions, HELCOM and OSPAR, the scrubber topic has been on the agenda during the last years. Here, protection measures are in development as part of their environmental strategies (BSAP and NEAES).

Finally, members of WGSHIP have contributed to a new graduate course on shipping impacts https://www.linkedin.com/feed/update/urn:li:activity:7259111849193848833/.

5.4 WGSHIP member publications

The members of WGSHIP authored 46 scientific publication between 2022 and 2024 (list below). The members names are presented in bold font.

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5.5 Concluding remarks and future work

Moving into the new term (2025–2027), 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.

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Annex 1: List of participants

WGSHIP 2024 meeting

NAME	INSTITUTE	COUNTRY
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Andreas Gondikas	National and Kapodistrian University of Athens	Greece
Annukka Lehikoinen	Kotka Maritime Research Center	Finland
Cathryn Murray (chair)	Fisheries & Oceans Canada	Canada
Fani Sakellariadou (one-time guest)	University of Piraeus	Greece
Georgios Gkotsis (one-time guest)	University of Athens	Greece
Ida-Maja Hassellöv (chair)	Chalmers University of Technology	Sweden
Jose Fernandes	AZTI Basque Research and Technology Alliance	Spain
Jukka-Pekka Jalkanen	Finnish Meteorological Institute	Finland
Karen de Jong	Institute of Marine Research	Norway
Katerina Karditsa (one-time guest)	National and Kapodistrian University of Athens	Greece
Katja Broeg	Bundesamt für Seeschiffahrt und Hydrographie	Germany
Konstantina Manifava (one-time guest)	National and Kapodistrian University of Athens	Greece
Konstantinos Louzis (one-time guest)	National and Kapodistrian University of Athens	Greece
Leonidas Ntziachristos (one-time guest)	Aristotle University of Thessaloniki	Greece
Lisa Drake	SGS North America	USA
Marja Kaarina Koski	DTU Aqua – National Institute of Aquatic Resources	Denmark
Marta Ribo Gene	Auckland University of Technology.	New Zealand
Michael Tsatsaronis (one-time guest)	National and Kapodistrian University of Athens	Greece
Nicole Heibeck	Bundesamt für Seeschiffahrt und Hydrographie	Germany

Octavio Marin	Bundesamt für Seeschiffahrt und Hydrographie	Germany
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Sarah Bailey	Fisheries & Oceans Canada	Canada
Stefanos Chatzinikolaou (one-time guest)	University of Piraeus	Greece
Sylvia Blake	CEFAS	United Kingdom

WGSHIP 2023 meeting

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WGSHIP 2022 meeting

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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 work on ToRs and generate deliverables as listed in the Table below.

	Meeting dates	Venue	Reporting details	Comments (change in Chair, etc.)
Year 2022	4 May 9 May 11 May	Online meeting		
	14–17 November	Online meeting		
Year 2023	25–29 September	Gothenburg, Sweden		
Year 2024	12–13 June	Online meeting;	Report by 15 December to SCICOM	
	4–6 November	Athens, Greece		

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; 2.2;	3 years	Report to ICES. Respond to advice requests, as applicable.
b	Review data to represent environmental shipping pressures at regional and global scales.	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.	2.1; 2.2; 2.7	3 years	Technical paper or peer-reviewed manuscript. Pipeline proposal for inclusion of shipping pressures metric in Ecosystems Over-views.
c	Develop a framework to represent the impacts of shipping on the marine environment, which can be used to guide science advice on the	A framework of the many shipping pressures and effects is needed to structure assessments and communicate the full	2.1; 2.2; 6.1	2 years	Technical paper or peer-reviewed manuscript

	development and implementation of ecosystem-based management.	suite of shipping-related pressures.			
d	Identify current and emerging shipping pressures, review state of knowledge and explore possible mitigation strategies for decreasing impacts.	While regulation of air emissions from shipping has gradually been strengthened, the corresponding impacts on the marine environment have received less attention. The environmental impacts of shipping noise and the use of scrubbers have been the topic of recent discussion at the Environment Committee (IMO).	2.1; 2.7; 6.1	3 years	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; 6.3	3 years	Peer-reviewed manuscript on trade-offs and synergies associated with management of underwater noise

Summary of the Work Plan

Year 1	Working on all ToRs, but with special focus on ToRs a, c, e
Year 2	Working on all ToRs, but with special focus on ToRs b, d,
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. As ICES and advice requestors are striving for more holistic ecosystem based management, the need for metrics and greater understanding of impacts of shipping on the marine environment is growing. The WGSHIP ToRs are aligned with the ICES Science Plan and aim to report their outcomes directly to ICES in their final report, as well as contribute to Ecosystems Overviews and ICES Annual Science Conference, where relevant. Thus, the activities of WGSHIP can be considered to be of high priority.
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 had participation from more than 30 members in its first term, and is expected to grow during this second term. Participation has included experts from ICES member countries and also from countries with similar scientific expertise (e.g. Australia).
Secretariat facilities	Standard EG support.
Financial	No financial implications.
Linkages to ACOM and groups under ACOM	There are currently no obvious direct linkages.
Linkages to other committees or groups	There has been a close working relationship with MCWG/WGMS and WGBOSV. Potential or occasional linkages with WGCEAM, WGSFD, WGMHM, WGMPCZM, WGBEC.
Linkages to other organizations	Occasional linkage with the Arctic Council PAME Shipping Expert Group and potential linkages with 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.