Report

Spread of invasive species via biofouling of marine vessels: A brief assessment

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Report No: 2024:01208

Client:

Norwegian Ministry of Climate and Environment

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KEYWORDS
Invasive species; biofouling; maritime transport; guidelines

VERSION
Version 1.0

DATE
2024-10-29

AUTHOR(S)
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CLIENT(S)
Norwegian Ministry of Climate and Environment

CLIENT'S REFERENCE
Sveinung Oftedal

PROJECT NO.
102029582-11

NO. OF PAGES
61

SUMMARY
Recently the IMO Marine Environmental Pollution Committee (MEPC) adopted Resolution MEPC.378(80) with the aim to establish guidelines that can minimize the transfer of marine invasive species through biofouling of ships. The primary objectives of this brief study included i) to assess and identifying the key marine invasive species whose global spread has been documented to occur via fouling of maritime vessels; ii) to assess and summarising the impacts related to the spread of marine invasive species; and iii) to assess whether the measures set out in MEPC.378(80) can be effective in preventing the further spread of marine invasive species if the Guidelines are made binding. The study indicated that the measures in the MEPC Guidelines have a strong potential for preventing the further global spread of marine invasive species by maritime vessel movements. However, adherence to the Guidelines is presently voluntary, and this potential is unlikely to be reached without some level of regulation implemented by a meaningful proportion of maritime nations and marine environments.

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REPORT NO.	ISBN	CLASSIFICATION	CLASSIFICATION THIS PAGE
2024:01208	978-82-14-07109-2	Unrestricted	Unrestricted

Document history

VERSION	DATE	VERSION DESCRIPTION
1.0	2024-10-22	Final project report

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Abbreviations

List of all abbreviations sorted in alphabetical order:

- **AF** Antifouling
- **AFC** Antifouling Coating
- **AFS** Antifouling system
- **BFMP** Biofouling Management Plan
- **BFRB** Biofouling Record Book
- **CBD** Convention on Biological Diversity
- **IMO** International Maritime Organization
- **IPBES** Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services
- **KLD** Ministry of Climate and Environment
- **MEPC** Marine Environmental Pollution Committee
- **MGPS** Marine Growth Prevention System
- **NIS** Non-Indigenous Species

Executive summary

Over the past decades, vessel-mediated transport and establishment of marine invasive species has been reported globally and it represents a serious threat from ecological and socio-economic perspectives. Maritime traffic, by commercial and recreational vessels, is responsible for the majority of species introductions, both by transport in internal seawater systems such as ballast water and as biofouling on immersed external hull areas.. Once settled, invasive species are very difficult to eradicate, and hence focus should be on assessing and minimising the pathways of transport and spread of organisms so that new introductions can be prevented, both at national and international levels.

07 July 2023, the IMO Marine Environmental Pollution Committee (MEPC) adopted Resolution MEPC.378(80) – the *2023 Guidelines for the Control and Management of Ships' Biofouling to Minimise the Transfer of Invasive Aquatic Species*. The Guidelines aim to minimize the transfer of marine NIS through biofouling on ships by providing a globally consistent approach to maintenance and husbandry of ships' submerged surfaces and structures, including internal systems permanently or temporarily exposed to seawater. At present, the Guidelines are aimed at all stakeholders operating directly and indirectly in the shipping sector and in the marine environment. Adherence to the Guidelines is presently voluntary.

This brief assessment, commissioned by the Norwegian Ministry of Climate and Environment (KLD), first assesses and identifies invasive species whose global spread has been documented to occur via fouling of maritime vessels (Section 2, Task 1).This section also describes the filtering criteria used for gderiving the species list and the limitations associated to these types of assessments.

A second part of this assessment summarises the documented impacts related to the spread of invasive species (Section 3, Task 2). This summary is based on the species list generated in Task 1 and provides a brief overview of the main negative impacts related to the establishment of different taxonomic groups from an ecological, economical, and human health perspective. This assessment also discusses how adverse effects related to human health and safety may be underrepresented in the scientific literature due to scarcity of studies focusing on the spread and effects of microorganisms. In fact, while the vast majority of biological invasion research focuses on macro-organisms, relatively little attention has been given to the invasive potential of microorganisms. A more detailed assessment specifically focusing on microorganisms is recommended to derive a comprehensive understanding of impacts. The third part of this report (Section 4, Task 3) is dedicated to the assessment of whether the measures set out in MEPC.378(80) can be effective in preventing the further spread of marine invasive species if the Guidelines are made binding at an international level. The work performed in this task was focused on understanding the ability of mandatory measures to prevent the spread of invasive species through global marine environments. This assessmentdid not distinguished between commercial and recreational/private vessels, and the considerations on the effect of binding measures are based on their application to both categories.

This work has identified 82 marine invasive species that are known to have been spread by domestic and international vessel movements, and that have established invasive populations outside their natural biogeographic ranges. These species belong to eight phyla (predominantly Annelida, Arthropoda, Bryozoa, Cnidaria, and Mollusca) representing a 'high-risk' subset of the >3,000 marine non-indigenous species (NIS) that have been recorded as fouling organisms on ship hulls worldwide. Most of the invasive species identified cause multiple types of impacts that are predominantly ecological and/or economic in nature. Only a few species were implicated in threats to human health and safety, which may in part be a consequence of the under-representation of marine microorganisms in biofouling surveys. For a considerable portion of invasive species, the nature and extent of their impacts have not been quantified or are uncertain. This likely results in an underestimation of actual levels of impact and highlights the need for targeted and empirical impact studies. It is important to highlight that this work was a brief and conservative assessment of invasive species and their impacts. The accuracy of the results is affected by the reliability of the input data sources, how comprehensive the databases are, and the filtering criteria used. A more in-depth literature assessment would likely result in the identification of additional macro-organisms and potentially also micro-organisms that are frequently transported via biofouling and have the potential to cause vast economic and health impacts. The limitations of this work, and the needs for further assessments are discussed in Section 5 (Discussion and conclusions).

The review of the MEPC 378(80)) guidelines highlighted that the suggested measures have a strong potential for preventing the further global spread of marine invasive species by maritime vessel movements. This potential is unlikely to be reached without some level of regulation implemented by a meaningful proportion of maritime nations. If the measures remain voluntary, we expect a relatively low implementation rate, mostly limited to segments of the industry that are well resourced and/or obliged by other needs to clean hulls.. An empirical assessment of the relationship between implementation of the measures and biosecurity risk reduction at a global scale, together with increased efforts towards understanding the distribution, impacts, and treatment/management options for invasive species, is necessary for enabling informed decision-making and priority-setting for the future. Considerations for KLD or other relevant policy making agencies around making the measures binding are presented in Section 5 (Discussion and conclusions).

1 Introduction and main objectives

Over the past decades, movements of vessels within and between global coastal regions have facilitated the introduction and subsequent establishment of thousands of marine species beyond their native biogeographic ranges (Ruiz et al., 2013; Seebens et al., 2013). Vessel-mediated establishment of marine non-indigenous species (NIS) has occurred in ports, marinas, natural/remote environments, protected areas, and offshore islands (Hilliam et al., 2024).

Most recruitment of new organisms to the benthic marine environment occurs via a pelagic, free-floating stage. Once a species has become established on a suitable substrate, this creates a steppingstone for further development, with added risk for the organisms to be transferred and spread via secondary transfer pathways, and therefore establish in new areas (EEA 2021, GloFouling 2022). Furthermore, many macro-organisms establishing on a substrate have associated microorganismal symbionts, including potential pathogenic organisms (Brinkmann et al., 2017; Ein-Gil et al., 2009; Evans et al., 2017; López-Legentil et al., 2015). Once settled, invasive species are very difficult to eradicate, and hence focus should be on assessing and minimising the pathways of transport and spread of organisms so that new introductions can be prevented.

Marine NIS have caused substantial environmental, economic, cultural, and even human health related impacts to areas where they have become abundant, as reviewed by Molnar et al., (2008). They can act as habitat engineers and change ecological interactions (Crooks 2009), outcompete native species (Byers, 2000), reduce the profitability of aquaculture and fisheries via impacts on stock or equipment/infrastructure (Soliman and Inglis, 2018), and act as vectors for pathogens and toxins responsible for aquatic fauna or human diseases (Georgiades et al., 2021). The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) recently estimated the *annual* costs arising from the impacts of NIS to exceed 423 billion USD, the magnitude of costs having quadrupled every decade since 1970 (IPBES 2023).

Maritime traffic – by both commercial and recreational vessels - is responsible for half of NIS introductions into European seas since 1949 (EEA 2021). It is estimated that by 2050 global maritime transport volumes will have quadrupled relative to 2010 (Sardain et al., 2019). Vessels can transport marine NIS in internal ballast water and as biofouling on immersed external hull areas or within internal seawater systems (Hewitt and Campbell, 2010; Hewitt et al., 2009). Globally, between 56% and 70% of currently established coastal and estuarine NIS are thought to have arrived via biofouling (Hewitt and Campbell, 2010; Bailey et al., 2020). This is also reflected at regional level, for example in South Africa (48%, Mead et al., 2011), Argentina and Uruguay (45%, Schwindt et al., 2020) and the Galápagos Islands (55%, Carlton et al., 2019).

Given the scale of 'biological invasions' worldwide, actions to manage the spread and impacts of NIS are part of countries' obligations under the Convention on Biological Diversity (CBD). Extensive coordinated international efforts have resulted in mandatory requirements for managing international ballast water, enacted via the International Maritime Organization's (IMO) *International Convention for the Control and Management of Ships' Ballast Water and Sediments*. On 07 July 2023, the IMO Marine Environmental Pollution Committee (MEPC) adopted Resolution MEPC.378(80) – the *2023 Guidelines for the Control and Management of Ships' Biofouling to Minimise the Transfer of Invasive Aquatic Species*. The Guidelines aim to minimize the transfer of marine NIS through biofouling on ships by providing a globally consistent approach to maintenance and husbandry of ships' submerged surfaces and structures, including internal systems permanently or temporarily exposed to seawater. The Guidelines are directed at all stakeholders operating directly and indirectly in the shipping sector, and in the marine environment, including ship designers and shipbuilders, antifouling coating manufacturers and suppliers, states, environmental and regulatory agencies, shipowners, ship operators, port authorities, dry-docking and recycling facilities.

Adherence to the Guidelines is presently *voluntary*. Given the continued importance of biofouling as a vector for the spread of marine NIS (Drake and Lodge, 2007), and the predicted increase in global maritime traffic and trade (Sardain et al., 2019), Norway, together with other countries, is working with the IMO to establish an internationally binding set of regulations that will help minimize biofouling on ships and thereby reduce or prevent the global spread of marine NIS. The Norwegian Ministry of Climate and Environment (KLD) contracted SINTEF and NIVA to assist with this process.

This project had three primary objectives, which were approached as distinct tasks:

1. Assessment and identification of marine invasive NIS whose global spread has occurred via fouling of maritime vessels (Task 1),
2. Assessment and summary of the documented negative impacts related to the spread of marine invasive NIS (Task 2)
3. Assessment of whether the measures set out in MEPC.378(80) can be effective in preventing the further spread of marine invasive NIS if the Guidelines are made binding (Task 3).

The following sections describe our approach, results, and insights relating to Tasks 1 – 3 above. In line with KLD's requirements, our assessments were focused on *invasive* NIS (shortened as invasive species), i.e., those marine animals, plants, and micro-organisms that have documented impacts on native biodiversity, ecosystem services, maritime industries, or human well-being in regions where they have become established (IPBES 2023). Since by far not all NIS become invasive (Williamson and Fitter 1996), particularly Tasks 1 and 2 report on highly restricted subsets of the overall diversity of invasive species established in global waters.

2 Review of marine invasive species spread globally via fouling of maritime vessels (Task 1))

2.1 Objective and approach

The objective of this task was to identify marine invasive species that have been documented to be spread globally through fouling of marine vessels, for use as basis for Task 2. We used the World Register of Introduced Marine Species (WRiMS[1], Costello et al. 2024, accessed 06.05.2024) as the main source of data for Task 2.

WRiMS is a web-based database that records which marine species registered within the World Register of Marine species (WoRMS) database have been introduced deliberately or accidentally by human activities to geographic areas outside their native range. It excludes species that have colonized new locations through natural dispersal (so called 'range extensions'), even if in response to climate change (Seas and coasts (europa.eu)[2]). WRiMS is the most comprehensive database of its kind, containing 7984 taxonomic entries reported as marine NIS. Despite this, there is a high likelihood that the database vastly underestimates the number of NIS and their impact, depending on effort spent on detecting and reporting NIS in different global regions, the assessment of their impacts, and the time elapsed since their first detection. Therefore, the completeness of the database and its reliability should be interpreted conservatively.

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[1] https://www.marinespecies.org/introduced

[2] https://www.marinespecies.org/introduced/

We performed several filtering steps on WRiMS to produce an eventual list of species classified as invasive (meaning already documented as negatively impactful) and likely transported by ship hulls, as follows:

1. We filtered for entries identified to species level (n=3052)
2. We retained species that have a benthic life stage (i.e. the potential to be transported on ship hulls) and that are classified as true marine rather than estuarine or brackish (n=2354). Our argument for this was that by filtering out brackish species we would focus on species transported from marine environments to novel marine environments. However, by filtering-out brackish species, we probably underestimate the number and diversity of invasive species which might tolerate marine conditions.
3. Third, we filtered to exclude species associated with ballasts to focus on species mainly associated with ship hulls (n=406). This choice has the caveat that some species (e.g. the highly invasive *Carcinus maenas or Crassostrea gigas*) may be transported through multiple pathways (including biofouling) but may thus be filtered out of the list due to fouling of vessels not being the most common or most likely vector.
4. We filtered our results to retain only those species classified as invasive (n=86). This has the caveat that species with potentially negative impacts may not have been recorded as invasive if their impact is unknown or if a short time has elapsed since their detection.
5. This final list of 86 NIS both associated with ship hulls and classified as invasive was further manually interrogated to remove records (n=3) which are probably not transported by ship hulls (such as the ctenophore *Mnemiopsis leidyi*) but represent uncertainties in the WRiMS database.

2.2 Results and key considerations

The final list included 83 invasive species. Worldwide ship-fouling associated invasive species are dominated by Annelids (polychaete worms), Arthropods (shrimp, crabs, barnacles) and Molluscs (snails and bivalves). Bryozoans and Cnidarians (corals, hydroids and jellyfish) are the next most common taxa (Figure 1, Table A1.1).

Approximately the same proportions of these taxa are present if the list also includes ship-associated NIS not only classified as invasive (n=202), or invasive species not only classified as associated with ship-hulls (n=460). This suggests that shortcomings in the WRiMS database classifications and completeness for invasiveness and vector types probably do not bias the final list of 83 taxa generated in terms of life-history traits. This further gives us confidence that the assessment of the impact of these 83 invasive species (Task 2) should be relevant even if the final list of species is missing entries due to uncertain classification.

Caution is especially required in the interpretation of the final list given that microorganisms are absent (with one exception) while they almost certainly are transported as part of the fouling community. In addition, our choice to filter out brackish species will certainly have resulted in a lower number and diversity of invasive species. An example of this is that the list is missing the brown macroalgae *Undaria pinnatifida* which exists in the WRiMS database as an invasive brackish species associated with ship hulls (Epstein & Smale 2017). This is just one example of why a larger scale study is required given that this species is present on the Invasive Species Specialist List of the 100 most invasive species (Lowe et al. 2000).

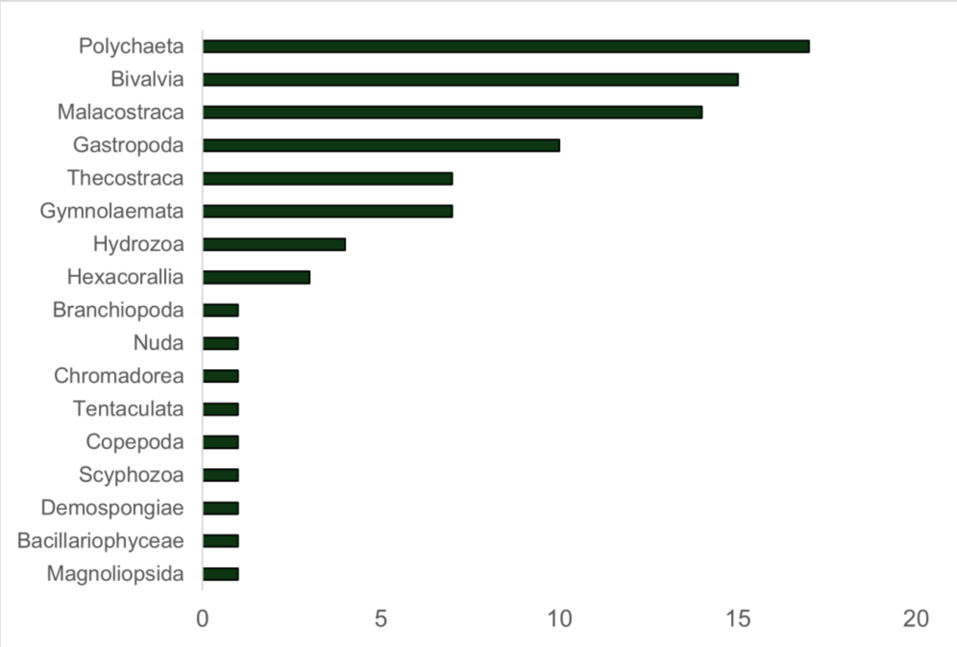

Figure 1. Counts of Class for the final filtered list of 83 NIS both associated with ship hulls and classified as invasive in WRiMS.

It should be that the list generated is a conservative estimate of invasive marine species associated with ship hull biofouling that highlights limited research into invasive marine species and their uncertainties of transport and effects in the marine environment. The species highlighted are only those most high-profile cases which are well documented and classified today. Given that a lag time exists in discovery and identification of impact, the situation surrounding invasive species is clearly more severe and unknown than is currently appreciated. This is especially likely to be the case concerning microorganisms. Although less information of microbial biofouling communities on vessels is available, this pathway is likely to be important. Microbes may have a dual role in the spread of invasive species; Evans et al. (2017) proposed that ascidian microbial symbionts may contribute to host adaptation to new environments, and it has further been suggested that the potential of bacteria to be invasive might be higher than the potential of other organisms, due to their abundance and tolerance to shifting environmental conditions (as reviewed by Hess-Erga et al. (2019).

3 Review of the negative impacts caused by marine invasive species spread globally via fouling of maritime vessels (Task 2)

3.1 Objective and approach

The key objective of this task was to conduct a literature review to assess and summarise the negative impacts e related to the spread of invasive species by using the review of existing data conducted in Taks 1 as a basis. The species list with relative taxonomic information (from Task 1) was used to review and summarise the impacts related to the spread of the different invasive species.

The documented impacts for each species were assigned by merging information from different global and regional databases including "Global Invasive Species Database" (GBIF[3] and GISD[4]:); "National Estuarine and Marine Exotic Species Info. System" (NEMESIS[5]); European Network on Invasive Alien Species (NOBANIS[6]). For each species, the associated impact was assigned to three categories: ecological, economical, (human) health and safety, summarised in Table 1 (GESAMP, 2024). Subsequently the species were grouped according to their phylum and the distribution of the reported effects within the different impact categories (in percentages) was calculated. As mentioned above, the data presented in the main body of this report are summarised at phylum level, but single species-related information is available in the Appendix 1 (Table A1). It is important to consider that the information on related impacts was not present for every single species. Therefore, the impact was classified as undefined/uncertain in cases where information was not available across multiple investigated databases.

Table 1: Summary of the main documented types of damages related to the spread and establishment of invasive species. The different categories are based on GESAMP (2024).

Impact category	Documented impact	Description
Ecological (1)	a. Habitat change	Creation of new habitats and/or modification of existing environments and available resources
	b. Alteration of ecological interactions	Changes in food web composition and stability
	c. Spreading vector of pathogens, toxins, and contaminants	Transfer of associated pathogens/toxins or remobilisation of environmental contaminants
Economic (2)	Negative effect on marine industries and human livelihoods	Economic losses to shipping, aquaculture, fisheries, tourism, infrastructure and amenity values
Health and safety (3)	Human exposure to pathogen via direct or indirect (e.g., tropic) pathways	Threats to human health

[3] https://www.gbif.org/dataset
[4] https://www.iucngisd.org
[5] https://invasions.si.edu/nemesis
[6] https://www.nobanis.org

3.2 Results and key considerations

We compiled information for 82 hull-fouling associated marine invasive species, one was removed from the original species dataset from Task 1 as changes in taxonomic assignment merged two species of Annelida (*Janua brasilienses* and *Neodexiospira brasilienses*) into a single species complex. The dominant taxonomic groups (phylum level) included Mollusca (n=25), Arthropoda (n=23), Annelida (16), Bryozoa (n=7) and Cnidaria (n=7). Bryozoa was the phylum with the highest proportion of species for which one or more ecological impacts have been documented (85.7%, n=6), followed by Arthropoda (73.9%, n=17), Cnidaria (71.4%, n=5), Mollusca (52%, n=13) and Annelida (37.5%, n=6) as shown in figure 2.

Alteration of the ecological interaction and habitat changes were the main documented ecological impacts, both being highly represented in bryozoans (86% (n=6) and 57% (n=4), respectively). For arthropods, a lower **number** of species has been reported to modify the existing habitat (22%, n=5), while 74% (n=17) have been reported to contribute to the alteration of the trophic interactions.

Impact as spreading vectors was the least represented ecological impact documented and ranged from 14% (n=1) in Cnidaria to 4% (n=1) in Mollusca. Overall, Annelida is the taxonomic group with the highest percentage of species (63%, n=10) with undefined/uncertain ecological impact.

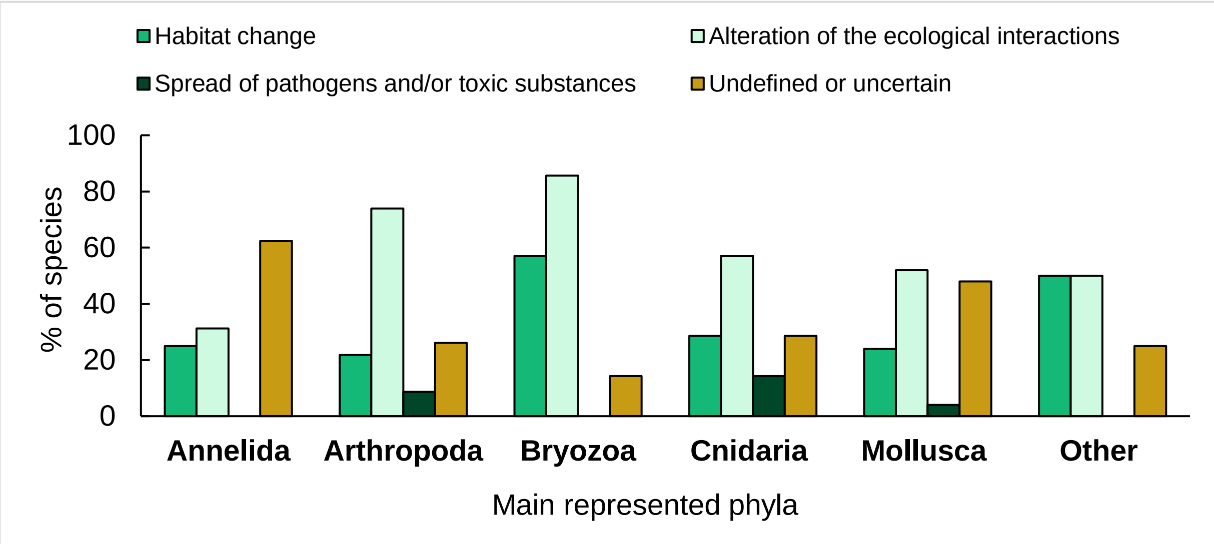

Figure 2: Proportion of invasive species (%) per main phyla causing documented ecological impacts (category 1 in table 1).

Considering the direct human-related impacts, economic impact was the most adverse effect documented across all the species investigated, associated with 71% (n=5) of the bryozoans, 65% (n=15) of the arthropods, 43% (n=3) of the cnidarians, 38% (n=6) of the annelids and 24% (n= 6) of the molluscs. The proportion of species responsible for negatively affecting human health and safety followed the same trend as for the ecological impact, ranging from 14% and 13% for cnidarians and arthropods respectively, and followed by annelids (6%, n=1) and molluscs (4%, n=1).

According to the investigated databases, annelids and molluscs are the taxonomic groups with the least number of species documented for causing human-related impacts, with 50% (n=8) of the annelids and 48% (n=12) of the molluscs presenting undefined or uncertain impacts.

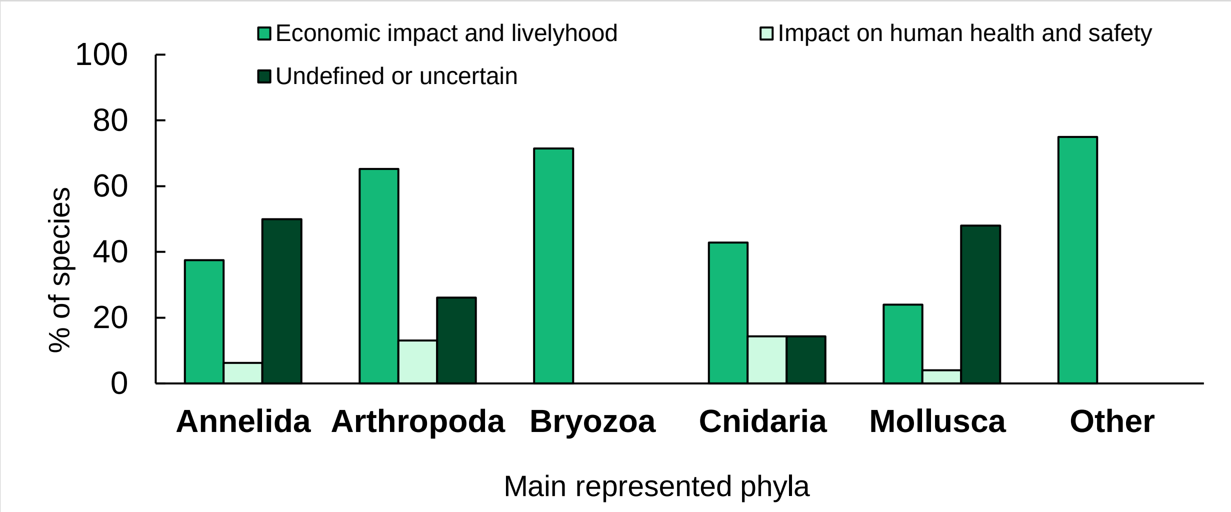

Figure 3: Proportion of species (%) per main phyla causing documented damages on humans through economic impact and impact on human safety and health (category 2 and 3 in Table 1)

It is important to consider that this report is based on a limited study performed in a conservative way, by using available data in existing data repositories on impacts caused by invasive species. For several of the identified species not enough data is currently available to allow determining or defining any damage caused by these species, as also visualised in Figure 2 and Figure 3 above. The absence of any reported impact not necessarily imply that the species does not have any impact related to the three categories used in this report. The distribution of reported adverse effects between the impact categories, within different taxonomic groups were calculated in this work. Although the different species were grouped at phyla level, it should be emphasized that not all species within such a taxonomic group will cause the same impact. The ecological impact is also strongly influenced by local environmental conditions and community interactions; therefore, the same species may not have the (exact) same impact in other geographic areas. Future larger impact assessments caused by the spread of invasive species through fouling of vessels is recommended. The use of a "threat scoring system" using additional categories such as geographic extension/spread, invasive potential and management difficulty as suggested by Molnar et al (2008) should also be considered for more comprehensive assessments. Furthermore, the provision of a monetary value of the impacts caused by invasive species could also be a useful metric to be considered for the development of a more comprehensive threat scoring system for a more in-depth assessment.

A further dedicated assessment of the invasive potential of micro-organisms is advisable. Whether a microorganism is spread due to direct attachment to the hull of a boat or as an associated symbiont of a larger organism does not necessarily affect the impact to its new environment. Although invasions by pathogenic microorganisms are an increasing threat (e.g. Ricciardi et al., 2017), non-indigenous bacteria and viruses are on the other hand underrepresented in invasion ecology studies, which thereby limits the ability to quantify their impacts (Magliozzi et al., 2022). It has been suggested that a key problem in managing pathogen invasions is "*our currently limited ability to detect or identify emerging pathogens, owing to the lack of comprehensive global databases, existence of non-symptomatic reservoir hosts and cryptic pathogen spillovers, and the potentially enormous number of undescribed taxa*" (Ricciardi et al 2017). To improve the collection and sharing of such data, Magliozzi et al. (2022) recently presented a European primary dataset of alien bacteria and viruses, containing data on 446 taxa and their invasion related- factors across terrestrial and aquatic environments. To this end, the ecological impacts of the introduction of organisms in general but microorganisms in special are not well understood, and further investigations into the role of microorganisms as invasive species are needed to allow assessing and minimising transport and spread of such organisms, further preventing new introductions and potential damage.

4 Effectiveness of the MEPC.378(80) measures to avoid the spread of invasive species (Task 3)

4.1 Objective and approach

The objective of Task 3 was to assess whether the measures set out in MEPC.378(80) can be effective in *preventing the further spread of marine invasive species if the guideline is made binding*. For the purposes of this assessment, 'further spread' is defined as *the continued spread of new and existing marine invasive species to and along global coastal environments.* 'Made binding' is defined as *the measures described in the Guidelines becoming mandatory at a large international scale*. In other words, KLD are interested in understanding the ability of mandatory measures to prevent the spread of invasive marine species through *global* (not only Norwegian) marine environments. In our assessment, we do not distinguish between commercial and recreational/private vessels[7] and our considerations around the effect of binding measures are based on their application to both categories.

The Guidelines contain measures that relate to the construction, operation, and maintenance of maritime vessels. There is variation in the 'prescriptiveness' of the Guidelines for how these measures should be carried out and this presents some challenges regarding making them binding. For example, it is relatively straightforward to make binding measures such as item 9.9.4 ('*Reactive cleaning should be performed in an area accepted by the relevant authority for this activity'*). In a binding scenario, reactive cleaning '*must only be'* carried out in an area accepted by the relevant authority for this activity. However, other measures are more ambiguous. For example, item 5.1 of the Guidelines states that during design and construction of ships certain '*items should be taken into consideration'*, including (5.1.1) '*small niches and sheltered areas should be avoided as far as practical*'. If this measure were made binding (i.e., '*items must be taken into consideration*'), compliance can be easily achieved (i.e., by simply considering it, but not acting on it), particularly in the absence of a definition of 'as far as practical'. For simplicity, we have taken a logical and practical approach to the interpretation of ambiguous scenarios but highlight them where necessary.

4.2 Results and key considerations

Likely effectiveness of the measures (if binding) in preventing the further spread of marine invasive species

The Guidelines include 10 'categories' of measures that aim to minimise and manage biofouling throughout a ship's life cycle:

1. Design and construction
2. Antifouling system installation and maintenance
3. Contingency action plans for biofouling management
4. Vessel inspection
5. Hull cleaning and maintenance

[7] The MEPC's definition of 'Ship' includes recreational vessels.

6. Biofouling Management Plan
7. Biofouling Record Book
8. Documentation and dissemination of information relating to biofouling management
9. Training and education around biofouling management
10. Other measures

For convenience, Appendix 2 lists the specific measures put forward by MEPC.378(80) for each of the categories above, along with our interpretation of their mechanism and intended effect regarding biofouling prevention.

In the sections below we briefly discuss the likely efficacy of each category of measures in preventing further spread of marine invasive species if implemented at a global scale. We quantify the 'relative effectiveness' of the various categories using a simplistic rank scale (Low, Moderate, and High[8]) and highlight potential challenges and items for consideration.

Category 1: Design and construction

Decades of ship hull surveys and antifouling system maintenance confirmed that the submerged surface area of most ocean-going vessels includes 'niche areas' that are particularly prone to biofouling development. This can be due to their exposure to extensive or insufficient levels of drag, or the challenges associated with applying antifouling coatings to these areas (Davidson et al., 2016). The rationale behind the measures in this category is that if some niche areas can be avoided or structurally adapted during design and construction of vessels the incidence of biofouling hotspots across vessels' hulls can be reduced.

There is some variation in the effectiveness of measures in this category (see list of measures in Table A2.1):

- Most niche areas serve a specific and important operational purpose, examples being rudder hinges, thruster tunnels and recesses, intakes, or rope guards. Redundant niche areas, if they exist, are likely very small in surface area relative to critical niche areas, and their avoidance would likely result in only small reductions in the amount of biofouling on vessels.
- However, effective gains may be able to be made via optimising niche area design. For example, sea chest gratings, weld lines, and other sharp-angled surfaces are known points of antifouling coating (AFC) failure. Use of rounded edges and grating plates should be easy to achieve and could eliminate well-known biofouling hotspots.
- Provision of improved access to inspecting sea chests (e.g., via the use of hinges), and ability to isolate sea chests and other high-risk niche areas for treatment would be a significant benefit and should not present an unsurmountable engineering challenge. Sea chests are hotspots for biofouling and invasive species biomass and diversity on maritime vessels (Coutts and Dodgshun, 2007). Management and treatment of these areas is often limited by access and ability to contain treatment agents. Reducing biofouling accumulation within sea chests and on sea chest gratings would eliminate a major risk area and could be an effective measure for reducing the transport of invasive marine species – provided effective treatment of sea chests is carried out at appropriate intervals.
- Structural features of some vessels require fixed dry-docking block positioning, interfering with the ability of managing dry-docking support strips, a high-risk niche area for biofouling. Design

The MEPC's definition of 'Ship' includes recreational vessels.
measures and does not take into consideration the feasibility of implementation.

considerations that result in the ability to alternate docking block positioning during successive dry-docking events would help mitigate this.

- There are many uncertainties around the rate at which biofouling organisms are released or escape from internal seawater cooling (and other) systems, and their viability and ability to survive (Cahill et al., 2019). As such, mandatory requirements around internal seawater system design would not be based on a solid appreciation of risk.

Overall, the introduction of mandatory measures around ship design and construction, in particular associated with sea chests and other known high-risk niche areas, could have a significant effect on the transport of invasive biofouling species by vessels (high relative effectiveness, **Error! Reference source not found.**). This effect will be incremental if restricted to new builds as many vessels in the existing global fleet will likely remain in service for years or decades. Retrofitting solutions to the existing fleet would accelerate the potential benefits but it is highly questionable whether and to what extent it can be achieved, in particular at a global scale.

Table 2: Relative effectiveness of measures (in the current Guidelines) in reducing the spread of marine invasive species if implemented at a global scale.

Measure category	Relative effectiveness[1]	Considerations regarding making measures binding
1. Design and construction	High	Feasibility of retrofitting existing fleet highly uncertain
2. Antifouling system installation and maintenance		
AFS choice	High	Requires standards that are currently unavailable
AFS installation	High	May not be feasible for all vessel types and sizes
AFS reinstallation and repair	High	May not be feasible for all vessels and facilities
3. Contingency action plans	Moderate	Plans would require evaluation and approval to ensure rigour
4. Inspection	High	Only if combined with mandatory corrective actions where these are needed
5. Cleaning and maintenance	High	For maximum effect would need to include cleaning of niche areas
6. Biofouling Management Plan	High	Underpins implementation of appropriate measures contained in all other categories. However, effective BFMPs require robust guidance and competent assessors/auditors
7. Biofouling Management Book	High	Documents implementation of the BFMP, enables/requires auditing
8. Documentation and dissemination of information	Low	For many nations this information is already available.
9. Training and Education	High	Will ensure quality and operational standards
10. Other measures	Low	Most likely measures already being undertaken to some extent

[1] If implemented globally and not considering feasibility.

Category 2: Antifouling system installation and maintenance

1. Choosing an antifouling system

Optimal performance (biofouling prevention) and longevity of commercial AFS can only be achieved when appropriate systems are installed around the different hull and niche areas of vessels, and when the vessels' operational profiles match the intended and recommended application of the antifouling system (AFS) (DAFF, 2024).

Our considerations regarding the effectiveness of measures in this sub-category (Table A2.2) are as follows:

- Optimised product choice (regarding area of application on vessel, vessel operating profile and environment, available grooming or cleaning technologies, and dry-docking intervals) are important performance factors for AFS that will affect biofouling accumulation[9] and transport. Depending on the nature of niche areas, an individual vessel may require multiple AFS. This may add complexity and cost during application but will provide improved performance. However, for 'mandatory optimised product choice' to be effective as a biofouling and invasive species risk mitigation measure, validated, industry-wide standards for which AFS are appropriate for different scenarios would be required. Such standards are currently non-existent, and auditing of such measures would be difficult.
- Regulatory approvals of antifouling (AF) biocide substances and products account for their potential environmental impact. As such, shipping operators should be able to choose and apply AFC based solely on their efficacy in preventing biofouling for a vessel's envisaged operational and maintenance profiles.
- Consideration of national or regional regulatory requirements regarding coating use may be relevant for situations where hull cleaning or other maintenance may predictably be required in jurisdictions that restrict such activities. This might be relevant for vessels with highly predictable trade routes, such as container ships (Kaluza et al. 2010). Avoidance of associated delays in hull cleaning and maintenance may reduce the transport of biofouling organisms and invasive species by those vessels.

Overall, the introduction of mandatory measures around AFS choice could have a significant effect on the rates at which invasive biofouling species are transported by global vessel movements (high relative effectiveness, Table 2). However, implementation (including enforcement/auditing) would require the availability of validated international standards that are currently unavailable and challenging to develop and implement.

2. Installation of antifouling systems

The Guidelines' measures for this sub-category are outlined in Table A2.3. Our considerations regarding their effect are as follows:

- The performance of AFS is contingent upon proper installation. In the case of AFC this includes appropriate surface preparation (which may include removal of previous coatings), use of appropriate primer and tie coats, and AFC application using recommended tools, and number and thickness of coats (Australian Commonwealth Government 2013).

[9] For the purposes of this assessment, we infer that increased biofouling extent on vessels equates to a higher potential for transferring marine invasive species. This is a simplistic and practical assumption but found to be the case for > 350 vessels surveyed in New Zealand (Inglis et al. 2010).

- While individual anodes create very small niche areas, a large vessel may feature dozens of them and together they may harbour significant fouling biomass and diversity. Anodes and anode fittings are amongst the most frequently fouled areas of vessels, and this could likely be avoided.
- Other small niche areas, such as rope guards are often not coated in AFC and hence often harbour diverse biofouling assemblages. Avoiding or delaying this via coating application is achievable.
- There are some potential challenges, however. For example, sea chests are relatively low-flow environments, and most AFC require some flow to offer long-term effective protection (Piola et al., 2022). While AFC application to sea chests will provide strong benefits for an initial (and potentially considerable) period, the use of chemical or electrical AFS or proactive or reactive treatment of sea chests may be required to ensure protection from biofouling between successive dry-docking events. On smaller vessels, access to thruster tunnels/recesses, or internal areas of pipe openings may be restricted and make AFC application difficult or impossible.

The measures provided in this category of the Guidelines, if made binding, are highly effective at minimising and/or delaying biofouling development and the potential for transport of invasive species in minor and major niche areas of vessels (high relative effectiveness, Table 2). However, particularly for sea chests non-AFC systems are required as coatings alone will not provide effective protection for an entire dry-docking interval. The implementation of some measures may not be feasible for all vessel types and sizes.

3. Reinstalling, reapplying or repairing the antifouling system

The measures listed in this category of the Guidelines (Table A2.4) have the potential to reduce the build-up of biofouling in several high-risk niche areas of vessels, provided the right products are used (see *Choosing an AFS*) and correctly installed (see *Installation of AFS*).

- Requiring coating application and repair to occur in known high-risk niche areas regularly, and in accordance with manufacturers' procedural guidance, is best practice and can considerably reduce the amount of biofouling organisms transported by a vessel.
- Dry-docking block strips are amongst the most heavily fouled niche areas of many vessels and can amount to >10% of their total submerged surface area (Moser et al., 2017). Preventing biofouling development on such strips can considerably reduce biofouling loads and associated transport risk. However, while achievable for many vessels, alternating the position of docking-support blocks is not possible for all vessels or all dry-docks. The position of some vessels' internal structural features such as bulkheads and other reinforcements can dictate where blocks and supports must be placed while a vessel is out of the water.

Similar to AFS installation, also their appropriate repair and reinstallation can be an effective means of minimising and/or delaying biofouling development in vessels' niche areas (high relative effectiveness, Table 2). However, implementation of some measures may not be feasible for all vessel types or maintenance facilities.

Category 3: Contingency action plans

The introduction of mandatory contingency plans for ship's biofouling management, that include measures such as those listed in the Guidelines (Table A2.5), can be an effective way of preventing or limiting biofouling build-up on vessels. However, this requires these plans to be prepared and executed in accordance with a rigorous and demonstrably effective decision-support framework. If this is not the case, vessel operators will likely base decisions around biofouling management – in particular, where they require deviations from planned operational and/or maintenance schedules - on economic factors (e.g. opportunity costs) and favour a course of action that results in minimal financial losses. In addition, the hull/fuel performance monitoring outlined in the Guideline is predominantly relevant to laminar hull areas whose smoothness (highly influenced by biofouling) will affect speed and fuel consumption. This type of performance monitoring will not be able to detect biofouling accumulation in high-risk niche areas, which are not determinants of speed and fuel consumption (Davidson et al., 2016).

Overall, the introduction of mandatory contingency action plans can have a moderate effect on the rates at which invasive biofouling species are transported by global vessel movements (moderate relative effectiveness, Table 2). However, implementation (including enforcement/auditing) would require the availability of global (at least geographically wide-reaching) standards or templates for such plans, and the evaluation and approval of draft plans to ensure rigor.

Category 4: Inspection

Inspections of vessel's submerged areas and internal seawater systems are a highly effective measure for determining the abundance and distribution of biofouling in target area. Our considerations regarding the measures in this category of the Guidelines (Table A2.6), if made binding, are as follows:

- Like all types of surveys, vessel inspections are prone to insufficient sampling effort (not all areas inspected), sampling error (observed biofouling levels do not represent actual biofouling levels), and other sources of bias. Mandatory use of qualified and independent inspectors capable of implementing rigorous surveys is an important measure for minimising the sources of survey error described above. One item not mentioned in the Guidelines is that inspections should be conducted using equipment that is verifiably appropriate for effective detection of biofouling, coating or hull/niche condition. While this can be assumed when using qualified inspectors, it is worth making explicit.
- Mandatory application of inspection intervals that are appropriate for vessels' risk profiles, has the potential to detect biofouling at a relatively early stage of development and limited abundance. It also enables assessment of AFC condition and identification of areas of potential early coating failure, enabling consideration of contingency measures such as repair or monitoring.
- Mandatory inspections triggered by alerts from vessel performance monitoring are an efficient measure for detecting premature biofouling development and/or inappropriate inspection intervals relating to a ship's laminar hull areas. However, performance monitoring (usually of fuel use, cruising speed, and engine power parameters) is unlikely an effective warning system for biofouling in niche areas since most of these (excluding, e.g., propellers) have no effect on hull friction. Reliance on performance monitoring alone is unlikely to be sufficient for preventing transport of invasive marine species.
- Where vessels' submerged surfaces include areas not coated in AFC (e.g., some niche areas such as dry-docking block strips), 18-month inspection intervals (and possibly even 12-month intervals) are likely insufficient for detecting biofouling at a relatively low level of abundance. Uncoated surfaces can accumulate mature biofouling assemblages over considerably shorter periods (Bloecher and Floerl, 2020; Floerl et al., 2005).

- Mandatory preparation and archiving of inspection records are important measures for ensuring the use of robust inspection approaches, and for identifying potential requirements for variations to maintenance schedules.

The mandatory use of biofouling inspections is a highly effective measure for quantifying biofouling extent and the likely 'invasive species risk' posed by vessels. However, for them to serve as a measure for minimising the spread of invasive marine species inspection results *must be tied to appropriate corrective actions where needed* (e.g., in-water cleaning, treatment, or dry-docking). If this is implemented then inspections (with follow-up actions where required) can be a highly effective tool for preventing the spread of marine invasive species (high relative effectiveness, Table 2).

Category 5: Cleaning and maintenance

In-water hull cleaning is an effective measure for biofouling removal but may compromise AFC integrity (performance and service life) and release harmful chemicals and aquatic species into the environment (Tamburri et al., 2021). Comprehensive testing of cleaning systems and processes is necessary to demonstrate and guarantee their effectiveness and minimise associated contamination and biosecurity risks.

Our considerations regarding the effectiveness of measures in this category (Table A2.7) are as follows:

- Proactive cleaning, also referred to as 'grooming', targets hull surfaces at a stage when biofouling is entirely (or almost entirely) restricted to microfouling (biofilms). Proactive cleaning, undertaken at appropriate intervals (before macrofouling assemblages have developed) and using appropriate methods (that demonstrably do not harm coating surfaces) has the potential to prevent the transport of invasive species by vessels, while also maximising fuel efficiency and reducing greenhouse gas emissions (Swain et al., 2022). However, most commercial grooming systems currently available are designed to clean ships' laminar hull areas but are unable to access niche areas[10]. Unless mandatory proactive cleaning includes the use of methods capable of cleaning niche areas (which presently may be diver-operated and difficult to implement at short intervals), the transport of invasive species by a given vessel will be reduced but not prevented.
- The restriction of proactive cleaning without capture to a fouling rating of 1 (as defined in the Guidelines) minimises the risk of releasing viable gametes or adults of biofouling organisms. It vastly reduces but does not eliminate biosecurity risks since microfouling (biofilms) may contain pathogens such as bacteria and viruses that have the ability to harm natural systems or other marine-based industries such as aquaculture (Georgiades et al., 2021). This is likely more relevant for cleaning operations in coastal environments – if cleaning is undertaken in designated offshore areas[11] any biological material released is unlikely to pose a biosecurity risk (Fletcher et al in press).
- Scheduling and recording of proactive cleaning via Biofouling Management Plan and Biofouling Management Book (see below) enables auditing and the ability to identify situations where variations to cleaning intervals or methods may be required.

[10] Laminar hull surfaces are smooth and planar, while many niche areas are structurally complex and include angles and protrusions.

[11] Recent work from New Zealand suggests that it may be possible to identify offshore areas where any material released is unlikely to be transported to environments where it may pose biological risk.

- A mandatory requirement to restrict cleaning to areas accepted by local authorities (item 9.4.2 in the Guidelines) is redundant. If authorities have regulations around where cleaning is permissible vs not permissible, then these are binding already.
- Reactive cleaning is usually conducted when inspections result in the detection of biofouling above a certain threshold, which generally means that some quantity of macrofouling organisms or assemblages is present. A mandatory requirement for the use of capture and containment systems during reactive cleaning would likely prevent the release (and loss) of the majority of biofouling and AFC material into the surrounding environment, resulting in a vast reduction in biosecurity risk particularly when cleaning is carried out in coastal (e.g., port or harbour) environments[12]. Application of this mandatory requirement at a global scale would have the highly desirable benefit that vessel operators are unable to schedule reactive cleaning to regions where there are no regulatory requirements. This practice of 'dumping one's waste in someone else's back yard' is currently posing considerable environmental and biosecurity challenges for maritime nations in Southeast Asia and Oceania (Floerl, unpublished data).
- Mandatory and effective treatment of internal seawater systems will mitigate the release of viable organisms from these systems. However, given current uncertainties around the amount of biosecurity risk internal seawater systems pose the magnitude of risk mitigation is equally uncertain. Where treatment does occur, release of treatment chemicals in accordance with local regulations is mandatory irrespective of recommendations or binding requirements made by the IMO.
- Release of cleaning waste residues from some land-based maintenance facilities (e.g., dry-docks, haul-outs) can contain viable organisms (Woods et al., 2012). Mandatory treatment and/or containment of cleaning waste will effectively mitigate this risk.

Mandatory requirements around pro-active and reactive hull cleaning concerning cleaning method, cleaning frequency, cleaning location, capture, and proper handling and disposal of cleaning waste, and planning and recording of cleaning operations, can have a strong effect on the spread of invasive biofouling species by maritime vessels (high relative effectiveness, **Error! Reference source not found.**). A growing number of s tudies document the considerable potential of in-water grooming and cleaning as a measure for mitigating vessels' biosecurity risks, and the unintended and opposing effect the use of inappropriate practices can have on AFC performance (Scianni et al., 2023; Swain et al., 2022). That said, requirements to cleaning of laminar hull areas will not reduce the risks posed by niche areas. The development and use of effective and low-risk (biosecurity and contamination) niche area cleaning technologies needs to be encouraged and facilitated for the potential biosecurity benefits of in-water cleaning and grooming to be realised.

Category 6: Biofouling Management Plan

Preparation of effective biofouling management plans (that consider appropriate spatial scales in accordance with vessels expected operational profiles) requires vessels operators to consider a vessel's design, construction, niche areas, AFS (including marine growth prevention systems (MGPS), expected operational schedules and environments, suitability and availability of proactive/reactive cleaning, and 'triggers' for contingency planning (Table A1.8). As such, a well-thought-out biofouling management plan (BFMP) underpins, and facilitates the implementation of all the measures contained in the other categories of the Guidelines (high relative effectiveness Table 2. The only caveat is that any mandatory measures should

[12] Some residual risk is likely to remain. In addition, the geographic availability of effective cleaning-with-capture systems is currently limited.

specify the development of an *effective* BFMP and provide an achievable and repeatable definition for this. This requires the availability of (i) robust guidance resources (e.g., the International Maritime Organization's GloFouling programme has recently run training workshops on BFMPs), and (ii) trained personnel for assessing and/or auditing BFMPs.

Category 7: Biofouling Record Book

The purpose of a biofouling record book (BFRB) is to document and collate evidence and details of the implementation of biofouling management measures set out in the BFMP (Table A2.9). As such it is a tool that enables tracking and auditing of a vessel's biofouling management practices. This is important, as without auditable systems the implementation of binding measures cannot be meaningfully regulated. Over time, accumulation of BFRBs and the information they capture it can also serve as a dataset for querying the effectiveness of biofouling management practices for a given ship type or operational profile, and for the optimisation of these practices. As for the BFMP, the BFRB is an indirect method for mitigation of biofouling and invasive species transport, and its mandatory availability and updating – and auditing - will require vessel operators to implement their ships' BFMPs (high relative effectiveness, **Error! Reference source not found.**).

Category 8: Documentation and dissemination of information

This category of measures (Table A2.10), if made binding, would require IMO Member States to proactively make available information on the location, availability and terms of use associated with biofouling management infrastructure and services such as inspections, in-water cleaning. Similarly, the measures would require shipping companies and agents to familiarise themselves with this information and ensure it is conveyed to inbound vessel operators. Availability and active provision of the information above is desirable and useful. However, for many maritime global regions such information is already available for those that actively seek it. While this measure, if made binding, would make relevant information more easily available, it would have a low overall effect on the spread of invasive species relative to the other categories (low relative effectiveness, Table 2).

Category 9: Training and education

Mandatory training in the *appropriate* use of the biofouling prevention and management measures included in the Guidelines (AFS choice and installation, inspections, in-water cleaning, BFMP and BFRB development and adaptation; Table A2.11) is integral to the effective implementation of these measures (high relative effectiveness, **Error! Reference source not found.**). One real-world example is the recent development of a B iofouling Inspectors Course as a formal tertiary education unit by the government of Western Australia. Introduction of this scheme led to industry and government agencies requiring this certification for anybody undertaking inspections on their behalf to ensure consistency and quality. Another example is represented by the Biofouling Management and In-water Cleaning offered by DNV and available for different counties. The course targets the biofouling management to prevent the spread of invasive aquatic species following both the (MEPC) guidelines and the targeted guidelines at regional level. The Guidelines do not provide information on who would be responsible for the development and provision of training and education, and on minimal knowledge requirements o e obtained via training.

Category 10: Other

Measures in this final category include requirements (i) for ports to ensure a 'smooth flow' of vessels entering and departing, (ii) for regulatory authorities developing biofouling management measures or restrictions to consider the measures included in the MEPC Guidelines, and (iii) for information-sharing among Member States (Table A2.12). It is likely that for profitability (not biofouling) reasons ports already do what they can to achieve item (i), and in our experience most jurisdictions that recently engaged in the development of biofouling related measures have undertaken extensive reviews of similar measures in other regions or at an international (e.g., IMO) level. While useful in principle, it is unlikely that making measures in this category mandatory would have significant effect on preventing the transport of invasive species relative to the other measure categories (low relative effectiveness, Table 2).

Considerations regarding binding vs. voluntary measures

The measures described in MEPC.378(80) have been developed in consultation with biofouling and maritime industry experts. They are intended to provide a holistic approach, across ships' life cycles, to reducing biofouling development on submerged hull surfaces and in internal seawater systems, thereby preventing the transport of marine invasive biofouling species. Some of the categories of measures contained in the Guidelines (Table 2) are interlinked and need to be implemented as a 'package'. For example, appropriate inspection and hull cleaning regimes (measure categories 4 and 5 in Table 2) can be highly effective at minimising biofouling and the transport of invasive species. However, without the development and implementation of effective biofouling management plans and appropriate record-keeping (measure categories 6 and 7), and access to training and capacity-building (category 9) high-quality inspection and cleaning regimes, and auditing ability of these measures are compromised. In our opinion, perhaps with the exception of measures in the *Documentation and Dissemination* (category 8) and *Other* categories (category 10), the adoption of the combined measures described in the Guidelines presents an important and effective avenue for reducing biofouling development and invasive species transport by maritime vessels. The effect this will have on the spread of invasive marine species at a global scale depends on the rate of uptake of the measures.

Based on the results of previous research we consider that to achieve biosecurity benefits at larger geographic (i.e., international or global) scales it is necessary that the measures are implemented by a substantial number of maritime nations. Using an epidemiological modelling framework, Floerl et al. (2016) showed that reducing the propensity for vessels to accumulate biofouling organisms ('vector management') can be an effective tool for reducing the regional spread of a biofouling invader around New Zealand, *given appropriate design of the intervention campaign*. Amongst several intervention designs examined, the one that achieved the greatest reduction in the spread of an invader aimed to achieve behavioural change around critical hull maintenance measures <u>and</u> targeted a large proportion of the national vessel population. This and other studies demonstrate that the greatest environmental benefits will be achieved when measures are: (i) targeted at critical 'transition points' of the so-called risk-release relationship (where achievable changes in behaviour lead to a considerable reduction in environmental risk), and (ii) where there is a high rate of uptake of these measures (Floerl et al., 2016; Wonham et al., 2013).

We consider that the measures in the MEPS Guidelines target the inflection point mentioned above, with respect to biofouling and invasive species transport. However, how can a high rate of uptake be achieved? Social science and economics research clearly demonstrate that knowledge alone does not translate into positive environmental behaviour for most people, particularly when this behaviour comes at an economic cost (Kollmuss and Agyeman, 2002). The measures in the MEPC Guidelines are likely to be associated with both direct and opportunity costs to the maritime industry (Inglis et al., 2012)[13]. As such, we consider the likely effectiveness of the Guidelines to be relatively limited while voluntary. Often, the most effective strategy for achieving significant shifts in *status quo* practices is the introduction of some level of incentive or disincentive (Meyer, 1999; Polonsky et al., 2004). Taylor et al. (2013) found that stakeholders in environmental management *generally considered direct regulation to be necessary in circumstances where high-impact public risks occur*. Arguably, the spread of marine invasive species is a high-impact public risk. The scope for the use of alternative approaches to direct regulation (e.g., self-regulation and voluntary participation) strongly depends on several factors, including the capacity of the targeted sector to self-regulate, the strength of political commitment to regulation, and the exposure of the targeted sector to public and NGO scrutiny. These are critical factors that considerations around the best implementation of the MEPC measures need to address.

Another point to be considered is the environmental cost associated with some measures. Particularly, measure categories 2 and 5 could influence (and be influenced by) the choice of AFS. The list of invasive species compiled for Task 2 of this project includes several taxonomic groups that may include non-target species that are equally or most sensitive to biocides emitted by AFC. Recent studies have predicted the hazards posed by a range of antifouling biocides to different marine species and shown that toxicity can be triggered at concentrations ranging from as low as 0.007 µg/L to as high as > 1000 µg/L, depending on the substance and the taxonomic group. Microalgae and early life-stages of bivalves and crustaceans are usually the most sensitive ecological groups (Martins et al., 2018; Martins et al. 2020). So, while preventing spread of non-indigenous biofouling provides benefits to the environment, the measures adopted should not exacerbate other environmental issues, such as increases in AFC pollution and non-target effects on marine ecological communities.

5 Discussion and conclusions

Shipping is a major contemporary pathway for the introduction and spread of marine invasive species. Managing future biosecurity risks posed by shipping requires the implementation of cost-effective interventions at appropriate scales.

This project identified 82 marine invasive species that are known to have been spread by domestic and international vessel movements and that have established invasive populations outside their natural biogeographic ranges. These species belong to eight phyla (predominantly Annelida, Arthropoda, Bryozoa, Cnidaria, and Mollusca) representing a 'high-risk' subset of the >3,000 marine NIS that have been recorded as fouling organisms on ships' hulls worldwide. Most of the invasive species identified cause multiple types of impacts that are predominantly ecological (38 – 86% of species per phylum) and/or economic in nature (24 – 71% of species per phylum). Only a few species were implicated in threats to human health and safety, which may in part be a consequence of the under-representation of marine micro-organisms in traditional[14] biofouling surveys. For a considerable portion of invasive species, the nature and extent of their impacts have not been quantified or are uncertain. This likely results in an underestimation of the actual impact and highlights the need for targeted and empirical impact studies.

[13] Over time, the environmental benefits achieved may outweigh these costs but a discussion of this is beyond the scope of this assessment.

[14] Focused on macro-organisms and not including the use of molecular tools that can easily identify microbial taxa.

The accuracy of our results is governed by the reliability of the data sources utilised. Over time, revisions and updates to publicly available database records will be required, for example where invasive species expand their spread range, or where their level and/or type of impact changes. While WORMS and WRiMS represent the most comprehensive and robust sources of biogeographic and taxonomic data, they and other sources are in part maintained by scientific experts on a voluntary basis and not all entries are subjected to peer review (GESAMP, 2024; Marchini et al., 2015; Rocha et al., 2013). This, and the apparent lack of records and information for many developing global regions (Carvalho et al., 2023; GESAMP,2024) mean that the true extent of impacts caused by invasive marine NIS around the world likely exceeds the one identified during this project. Furthermore, we consider that the no-representation of microorganisms in our results likely renders their assessment incomplete (given the findings of Georgiades et al. 2021). A more in-depth literature assessment would likely result in the identification of additional microorganisms that are frequently transported via biofouling and have the potential to cause vast economic and health impacts (see also Results and key considerations in Section 3, Task 2).

Task 3 of focused on reviewing the measures suggested in the IMO`s Biofouling Guidelines (MEPC 378(80)) for managing and preventing the further spread of invasive species and assess their effectiveness if these measures were made binding. Our opinion based on this brief assessment is that the measures in the MEPC Guidelines have strong potential for preventing the further global spread of marine invasive species by maritime vessel movements. This potential is unlikely to be reached without some level of regulation implemented by a meaningful proportion of maritime nations. If the measures remain voluntary, we expect a relatively low rate of uptake, mostly restricted to segments of the industry that are well resourced and/or for other reasons are required to maintain clean hulls (e.g., to satisfy biosecurity requirements associated with aquaculture industry operations).

A conceivable option for an empirical assessment of the relationship between uptake and biosecurity risk reduction at a global scale is the development of a spatially explicit maritime transport model. This model could simulate the global movements of an exemplar / case study shipping sector (e.g., cargo and container vessels), and the rates of transport and spread of hypothetical invasive species under different rates of uptake by the shipping network (e.g., 10%, 25%, 50%, 75%, or 100% of maritime nations). Together with increased efforts towards understanding the distribution, impacts, and treatment/management options for invasive populations, this would enable informed decision-making and priority-setting for the future.

Advanced considerations by KLD and/or other relevant agencies around making the measures binding must address: (i) whether and how this could actually be implemented; (ii) what short- or long-term impacts the introduction of binding measures may have on the maritime industry and seaborne trade; and (iii) whether the adoption of the measures will cope with environmental and societal needs. All these items are beyond the scope of this project[15], however the project team (SINTEF Ocean and NIVA) has the capability and data access for undertaking such studies, including a more in-depth assessment concerning the impacts of microorganismal species (Tasks 1 and 2).

[15] These advanced considerations require in-depth consultation with the maritime engineering and shipping sectors, and the inclusion of economic and supply-chain assessments.

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Appendix 1

Table A1.1: List of invasive species with their taxonomic classification, countries were they have been documented as invasive, documented spreading vectors in addition to fouling of vessels, documented ecological effect where a=habitat change, b=changes of the ecological interactions, c=spreading vector for pathogens and/or toxins; documented human related impacts. a=Habitat change; b=Alteration of the ecological interactions; c=Spreading vector of pathogens, toxins and contaminants.

Species	Phylum	Class	Order	Family	Country	Documented spreading vectors	Ecological effect *	Implications and damage on	Resources
Amphibalanus amphitrite	Arthropoda	Thecostraca	Balanomorpha	Balanidae	USA, Belgium, Norway, France UK, AU, Japan, Mexico, Brazil, Portugal, New Zealand, China, Ukraine, Argentina, Greece, Romania, Peru, Venezuela, Portugal, Jamaica, Vanuatu, Trinidad and Tobago	Ships (general)	a, b	Economic loss related to fouling	WoRMS (2024). Amphibalanus amphitrite (Darwin, 1854). Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=421137: https://www.gbif.org/species/4805564; https://invasions.si.edu/nemesis/species_summary/89616#:~:text=Habitat%20Change%2D%20In%20Tampa%20Bay,and%20colonization%20of%20motile%20species
Amphibalanus improvisus	Arthropoda	Thecostraca	Balanomorpha	Balanidae	Belgium, Norway, France, UK, Irland, AU, Japan, Poland, Italy, Turkey, Croatia, Ukraine, Bulgaria, Egypt, Lebanon, Vietnam, Netherlands, Svalbard, Turkmenistan, Azerbaijan	Ballast water, aquaculture, association to organisms	a, b	Economic loss related to fouling; tourism; fisheries	WoRMS (2024). Amphibalanus improvisus (Darwin, 1854). Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=421139; https://www.gbif.org/species/6467647; https://invasions.si.edu/nemesis/species_summary/89622
Anguillicoloides crassus	Nematoda	Chromadorea	Rhabditida	Anguillicolidae	USA, Norway, France, UK, Denmark, Sweden, Austria, Poland, Italy, Czechia, Mexico, Ireland, Russian federation,	Aquaculture, Fishing, pathogen/parasite, ships (general)	b	Aquaculture; fisheries	Nemys eds. (2024). Nemys: World Database of Nematodes. Anguillicoloides crassus (Kuwahara, Niimi & Itagaki, 1974) Moravec & Taraschewski, 1988. Accessed through: World Register

					Germany, Turkey, Portugal, China, Latvia, Lithuania, Egypt, Netherlands, Tunisia, Hungary, Finland				of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=458994; https://www.gbif.org/species/5890148; https://www.nobanis.org/globalassets/speciesinfo/a/anguillicoloides-crassus/anguillicoloides-crassus.pdf
Aplysia dactylomela	Mollusca	Gastropoda	Aplysiida	Aplysiidae	Italy, Turkey, Croatia, Israel, Greece, Cyprus, Lebanon, Malta, Syrian Arab Republic	Ships (general)	nr	nr	MolluscaBase eds. (2024). MolluscaBase. Aplysia dactylomela Rang, 1828. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=138753; https://www.gbif.org/species/5191262; https://www.gbif.org/species/5191262
Arcuatula senhousia	Mollusca	Bivalvia	Mytilida	Mytilidae	Norway, France, UK, SU, Italy, Canada, Mexico, Russian federation, Portugal, New Zeland, Croatia, Israel, China, Slovenia, Romania, Egypt, Tanzania, Tunisia	Ships (general) Fisheries	a,b	nr	MolluscaBase eds. (2024). MolluscaBase. Arcuatula senhousia (W. H. Benson, 1842). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=505946; https://www.gbif.org/species/6531311; https://invasions.si.edu/nemesis/species_summary/79577
Austrominius modestus	Arthropoda	Thecostraca	Balanomorpha	Elminiidae	Belgium, Norway, France, UK, Ireland, Portugal, Netherlands, Svalbard	Aquaculture, hull fouling, ballast water	b	nr	WoRMS (2024). Austrominius modestus (Darwin, 1854). Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=712167; https://www.gbif.org/species/2115769; https://www.gbif.org/species/2115769

Balanus glandula	Arthropoda	Thecostraca	Balanomorpha	Balanidae	Belgium, Japan, South Africa, Argentina	Hull fouling	a, b	nr	WoRMS (2024). Balanus glandula Darwin, 1854. Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=394848; https://www.gbif.org/species/2115706; https://www.gbif.org/species/2115706
Balanus reticulatus	Arthropoda	Thecostraca	Balanomorpha	Balanidae	USA, American Samoa	Ships (general), fouling	nr	nr	WoRMS (2024). Balanus reticulatus Utinomi, 1967. Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=149686; https://www.gbif.org/species/2115697; https://www.gbif.org/species/2115697
Boccardia proboscidea	Annelida	Polychaeta	Spionida	Spionidae	Belgium, Norway, France, AU, South Africa, New Zealand, Argentina	Aquaculture, Fisheries, Ships (general)	nr	nr	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Boccardia proboscidea Hartman, 1940. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=327249; https://www.gbif.org/species/2320810; https://www.gbif.org/species/2320810
Brachidontes pharaonis	Mollusca	Bivalvia	Mytilida	Mytilidae	Norway, France, Italy, Turkey, Croatia, Israel, Greece, Cyprus, Egypt, Lebanon, Malta, Syrian Arab Republic	Ballast water, hull fouling	b	nr	MolluscaBase eds. (2024). MolluscaBase. Brachidontes pharaonis (P. Fischer, 1870). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=140437; https://www.gbif.org/species/4374596; https://www.gbif.org/species/4374596

Branchiomma luctuosum	Annelida	Polychaeta	Sabellida	Sabellidae	Italy, Brazil, Turkey, Portugal, Greece, Cyprus, Lebanon	Hull fouling, natural dispersal	nr	nr	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Branchiomma luctuosum (Grube, 1870). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=130881; https://www.gbif.org/species/5200315; https://www.gbif.org/species/5200315
Bugula neritina	Bryozoa	Gymnolaemata	Cheilostomatida	Bugulidae	USA, Belgium, Norway, France, UK, AU, Sweden, South Africa, Italy, Ecuador, Mexico, Ireland, Brazil, Portugal, New Zealand, Israel, China, Argentina, Chile, Greece, Egypt, Peru, Lebanon American Samoa, Vanuatu, Curacao, Korea	Hull fouling, ships (general), aquaculture, fisheries, ballast water	b	nr	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Branchiomma luctuosum (Grube, 1870). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=130881; https://www.gbif.org/species/4984851; https://www.iucngisd.org/gisd/speciesname/Bugula+neritina
Bugulina stolonifera	Bryozoa	Gymnolaemata	Cheilostomatida	Bugulidae	Belgium, Norway, France, UK, AU, Japan, Turkey, Portugal, New Zealand, China, Argentina, Portugal, Netherland	Hull fouling, ships (general), Aquaculture, debris	b	Economic loss related to fouling; tourism; fisheries	Bock, P. (2024). World List of Bryozoa. Bugula neritina (Linnaeus, 1758). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=111158; https://www.gbif.org/species/8428595; https://invasions.si.edu/nemesis/species_summary/156064
Callinectes sapidus	Arthropoda	Malacostraca	Decapoda	Portunidae	Belgium, Norway, France, Denmark, Italy, Russian Federation, Germany, Turkey, Portugal, Croatia, Israel, Ukraine, Bulgaria, Greece, Cyprus,	Ballast water, ships (general), hull fouling, aquaculture, natural dispersal	b	Fisheries	DecaNet eds. (2024). DecaNet. Callinectes sapidus Rathbun, 1896. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=107379; https://www.gbif.org/species/2225646

					Romania, Egypt, Lebanon, Vietnam, Malaysia, Albania, Syrian Arabic Republic, Bahamas, Thailand, Montenegro				; https://www.nobanis.org/globalassets/speciesinfo/c/callinectes-sapidus/callinectes-sapidus.pdf
Caprella mutica	Arthropoda	Malacostraca	Amphipoda	Caprellidae	USA, Belgium, Norway, France, UK, Denmark, Sweden, South Africa, Canada, Ireland, Germany, New Zealand, Spain, Netherlands, Svalbard, Faroe Islands	Hull fouling, aquaculture, ballast water, debris, ships (general)	b	Economic loss related to fouling; fisheries	Horton, T.; Lowry, J.; De Broyer, C.; Bellan-Santini, D.; Copilas-Ciocianu, D.; Corbari, L.; Costello, M.J.; Daneliya, M.; Dauvin, J.-C.; FiÅ¡er, C.; Gasca, R.; Grabowski, M.; Guerra-GarcÃ-a, J.M.; Hendrycks, E.; Hughes, L.; Jaume, D.; Jazdzewski, K.; Kim, Y.-H.; King, R.; Krapp-Schickel, T.; LeCroy, S.; LÃ¶rz, A.-N.; Mamos, T.; Senna, A.R.; Serejo, C.; Souza-Filho, J.F.; Tandberg, A.H.; Thomas, J.D.; Thurston, M.; Vader, W.; VÃ¤inÃ¶lÃ¤, R.; Valls Domedel, G.; Vonk, R.; White, K.; Zeidler, W. (2024). World Amphipoda Database. Caprella mutica Schurin, 1935. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=146768; https://www.gbif.org/species/5178057 ; https://invasions.si.edu/nemesis/species_summary/-77
Caprella scaura	Arthropoda	Malacostraca	Amphipoda	Caprellidae	USA, France, Italy, Turkey, Portugal, Spain, Chile, Greece, Malta, Morocco	Hull fouling, aquaculture, ballast water, debris, ships (general)	b	nr	Horton, T.; Lowry, J.; De Broyer, C.; Bellan-Santini, D.; Copilas-Ciocianu, D.; Corbari, L.; Costello, M.J.; Daneliya, M.; Dauvin, J.-C.; FiÅ¡er, C.; Gasca, R.; Grabowski, M.; Guerra-GarcÃ-a, J.M.; Hendrycks, E.; Hughes, L.; Jaume, D.; Jazdzewski, K.; Kim, Y.-H.; King, R.; Krapp-Schickel, T.; LeCroy, S.; LÃ¶rz, A.-N.; Mamos, T.; Senna, A.R.; Serejo, C.; Souza-Filho, J.F.; Tandberg, A.H.; Thomas, J.D.; Thurston, M.; Vader, W.; VÃ¤inÃ¶lÃ¤, R.; Valls Domedel, G.; Vonk, R.; White, K.; Zeidler, W. (2024). World Amphipoda Database. Caprella scaura Templeton, 1836. Accessed through: World Register of Marine

									Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=236551; https://www.gbif.org/species/5178082; https://invasions.si.edu/nemesis/species_summary/95430
Cellana rota	Mollusca	Gastropoda		Nacellidae	Israel, Libya, Lebanon	Canals, shipping (general)	b	nr	MolluscaBase eds. (2024). MolluscaBase. Cellana rota (Gmelin, 1791). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=707486; https://www.gbif.org/species/4369982; https://www.gbif.org/species/4369982
Cercopagis (Cercopagis) pengoi	Arthropoda	Branchiopoda	Onychopoda	Cercopagididae	USA, Norway, Sweden, Poland, Canada, Russian federation, Germany, Estonia, Ukraine, Latvia, Lithuania, Finland	Canals , shipping (general), ballast water, hull fouling	b	Health; fisheries; aquaculture	WoRMS (2024). Cercopagis (Cercopagis) pengoi (Ostroumov, 1891). Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=234025; https://www.gbif.org/species/2234642; https://www.nobanis.org/globalassets/speciesinfo/c/cercopagis-pengoi/cercopagis-pengoi.pdf
Cerithium scabridum	Mollusca	Gastropoda	Caenogastropoda (incertae sedis)	Cerithiidae	Italy, Turkey, Israel, Greece, Cyprus, Egypt, Lebanon, Malta, Syrian Arab Republic, Tunisia	Ballast water, Canals, shipping (geeneral)	nr	nr	MolluscaBase eds. (2024). MolluscaBase. Cerithium scabridum R. A. Philippi, 1848. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=139065; https://www.gbif.org/species/4362895; https://www.gbif.org/species/4362895
Chama asperella	Mollusca	Bivalvia	Venerida	Chamidae	USA, Turkey, Israel, Greece, Cyprus, Lebanon	Ballast water, natural dispersal, hull fouling ships (general)	nr	nr	MolluscaBase eds. (2024). MolluscaBase. Chama asperella Lamarck, 1819. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=208488; https://www.gbif.org/species/4372055; https://www.gbif.org/species/4372055

Chama aspersa	Mollusca	Bivalvia	Venerida	Chamidae	Turkey, Israel	Natural dispersal, hull fouling, Shipping (general)	nr	nr	MolluscaBase eds. (2024). MolluscaBase. Chama aspersa Reeve, 1846, sensu Spry, 1964. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=208485; https://www.gbif.org/species/4372054; https://www.gbif.org/species/4372054
Chama pacifica	Mollusca	Bivalvia	Venerida	Chamidae	USA, Norway, Turkey, Israel, Greece, Cyprus, Egypt, Lebanon, American Samoa Syrian Arab Republic	Canals, Shipping (general)	nr	nr	MolluscaBase eds. (2024). MolluscaBase. Chama pacifica Broderip, 1835. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=139120; https://www.gbif.org/species/4372070; https://www.gbif.org/species/4372070
Charybdis (Charybdis) hellerii	Arthropoda	Malacostraca	Decapoda	Portunidae	USA, India, Brazil, Turkey, Israel, Greece, Cyprus, Cuba, Egypt, Indonesia, Lebanon, Venezuela, Syrian Arab Republic, United Arab Emirates, Saint Martin, Belize	Ballast water, Canals, shipping (geeneral)	b	Fisheries	DecaNet eds. (2024). DecaNet. Charybdis (Charybdis) hellerii (A. Milne-Edwards, 1867). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=107382; https://www.gbif.org/species/2225632; https://www.iucngisd.org/gisd/speciesname/Charybdis+hellerii
Conomurex persicus	Mollusca	Gastropoda	Littorinimorpha	Strombidae	Turkey, Israel, Greece, Cyprus, Libya, Lebanon Syrian Arab Republic	Ballast water, shipping (general)	nr	nr	MolluscaBase eds. (2024). MolluscaBase. Conomurex persicus (Swainson, 1821). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=565371; https://www.gbif.org/species/6489949; https://www.gbif.org/species/6489949
Coscinodiscus wailesii	Bacillariophyta	Bacillariophyceae	Coscinodiscales	Coscinodiscaceae	USA, Belgium, France, UK, Denmark, Sweden, Mexico, Ireland, Russian Federation, Germany, Argentina	Ballast water, aquaculture, shipping (general)	a	nr	Kociolek, J.P.; Blanco, S.; Coste, M.; Ector, L.; Liu, Y.; Karthick, B.; Kulikovskiy, M.; Lundholm, N.; Ludwig, T.; Potapova, M.; Rimet, F.; Sabbe, K.; Sala, S.; Sar, E.; Taylor, J.; Van de Vijver,

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Crepidula fornicata	Mollusca	Gastropoda	Littorinimorpha	Calyptraeidae	Belgium, Norway, France, UK, Denmark, Sweden, Italy, Ireland, Germany, Spain, Greece, Netherlands, Malta	Hull fouling, aquaculture, debris, fisheries	a,b	Fisheries; aquacolture	MolluscaBase eds. (2024). MolluscaBase. Crepidula fornicata (Linnaeus, 1758). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=138963; https://www.gbif.org/species/5192789 ; https://www.iucngisd.org/gisd/speciesname/Crepidula+fornicata
Cyclope neritea	Mollusca	Gastropoda	Neogastropoda	Nassariidae	Spain	Aquaculture, Fisheries, Shipping (general)	nr	nr	MolluscaBase eds. (2024). MolluscaBase. Cyclope neritea (Linnaeus, 1758). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=140487; https://www.gbif.org/species/4368237 ; https://www.gbif.org/species/4368237
Diadumene lineata	Cnidaria	Hexacorallia	Actiniaria	Diadumenida e	Belgium, Norway, France, UK, Denmark, Italy, Ireland, New Zealand, Ukraine, Bulgaria, Romania, Netherlands	Aquaculture, hull fouling ballast wate, ships (general), fisheries, natural dispersal, fisheries	nr	nr	RodrÃ-guez, E.; Fautin, D; Daly, M. (2024). World List of Actiniaria. Diadumene lineata (Verrill, 1869). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=395099; https://www.gbif.org/species/4283395 ; https://invasions.si.edu/nemesis/species_summary/52757
Dyspanopeus sayi	Arthropoda	Malacostraca	Decapoda	Panopeidae	France, UK, Italy, Spain	Ships (general)	nr	nr	DecaNet eds. (2024). DecaNet. Dyspanopeus sayi (Smith, 1869). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.

									php?p=taxdetails&id=107412; https://www.gbif.org/species/2227670 ; https://www.gbif.org/species/2227670
Eriocheir sinensis	Arthropoda	Malacostraca	Decapoda	Varunidae	USA, Belgium, Norway, France, UK, Denmark, Sweden, Poland, Italy, Czechia, Canada, Ireland, Russian Federation, Germany, Portugal, Estonia, Spain, Ukraine, Latvia, Slovakia, Romania, Lithuania, Netherlands, Moldova, Iran, Serbia, Hungary, Iraq, Finland	Ships (general), ballast water, aquaculture, hull fouling, natural dispersion, individual release	a, b, c	nr	DecaNet eds. (2024). DecaNet. Eriocheir sinensis H. Milne Edwards, 1853. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=107451; https://www.gbif.org/species/2225776 ; https://www.iucngisd.org/gisd/speciesname/Eriocheir+sinensis
Eurytemora americana	Arthropoda	Copepoda	Calanoida	Temoridae	Belgium, France, Argentina, Venezuela, Dominican Republic, Svalbard	Ballast water, ships (general)		nr	Walter, T.C.; Boxshall, G. (2024). World of Copepods Database. Eurytemora americana Williams, 1906. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=104873; https://www.gbif.org/species/2114326 ; https://www.gbif.org/species/2114326
Ficopomatus enigmaticus	Annelida	Polychaeta	Sabellida	Serpulidae	USA, Belgium, Norway, France, UK, Denmark, Japan, South Africa, Italy, Ireland, Germany, Turkey, Portugal, New Zealand, Croatia, Israel, Spain, Slovenia, Ukraine, Argentina, Bulgaria, Greece, Romania, Egypt, Georgia, Portugal, Tunisia, Netherland, Uruguay, Turkmenistan, Kores, Azerbaijan	Ballast water, Hull fouling, ships (general), aquaculture	a, b	Economic loss related to fouling; human livelyhoods	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Ficopomatus enigmaticus (Fauvel, 1923). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=130988; https://www.gbif.org/species/2327735 ; https://invasions.si.edu/nemesis/species_summary/68350
Fulvia fragilis	Mollusca	Bivalvia	Cardiida	Cardiidae	Italy, Turkey, Israel, Greece, Cyprus, Egypt, Libya, Lebanon, Malta, Tunisia	Ballast water, canals	nr	nr	MolluscaBase eds. (2024). MolluscaBase. Fulvia fragilis (ForsskÃ¥l, 1775). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=605733;

									https://www.gbif.org/species/5729175 ; https://www.gbif.org/species/5729175
Gammarus tigrinus	Arthropoda	Malacostraca	Amphipoda	Gammaridae	Belgium, Norway, France, UK, Sweden, Poland, Ireland, Russian Federation, Germany, Estonia, Lithuania, Switzerland, Netherlands, Finland, Luxemburg	Ballast water, Canals, shipping (general)	b	nr	Horton, T.; Lowry, J.; De Broyer, C.; Bellan-Santini, D.; Copilas-Ciocianu, D.; Corbari, L.; Costello, M.J.; Daneliya, M.; Dauvin, J.-C.; FiÅ¡er, C.; Gasca, R.; Grabowski, M.; Guerra-GarcÃ-a, J.M.; Hendrycks, E.; Hughes, L.; Jaume, D.; Jazdzewski, K.; Kim, Y.-H.; King, R.; Krapp-Schickel, T.; LeCroy, S.; LÃ¶rz, A.-N.; Mamos, T.; Senna, A.R.; Serejo, C.; Souza-Filho, J.F.; Tandberg, A.H.; Thomas, J.D.; Thurston, M.; Vader, W.; VÃ¤inÃ¶lÃ¤, R.; Valls Domedel, G.; Vonk, R.; White, K.; Zeidler, W. (2024). World Amphipoda Database. Gammarus tigrinus Sexton, 1939. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=102296; https://www.gbif.org/species/2219863 ; https://invasions.si.edu/nemesis/species_summary/93781
Garveia franciscana	Cnidaria	Hydrozoa	Anthoathecata	Bougainvilliidae	France, Italy, Germany, Brazil, Ukraine, Bulgaria, Romania, Egypt, USA, Venezuela	Ballast water, shipping (general)	a, b	Economic loss related to fouling	Schuchert, P. (2024). World Hydrozoa Database. Garveia franciscana (Torrey, 1902). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=117340; https://www.gbif.org/species/2266521 ; https://invasions.si.edu/nemesis/species_summary/48820
Gelliodes fibrosa	Porifera	Demospongiae	Haplosclerida	Niphatidae	USA	hull fouling	nr	Economic loss related to fouling	de Voogd, N.J.; Alvarez, B.; Boury-Esnault, N.; CÃ¡rdenas, P.; DÃ-az, M.-C.; Dohrmann, M.; Downey, R.; Goodwin, C.; Hajdu, E.; Hooper, J.N.A.; Kelly, M.; Klautau, M.; Lim, S.C.; Manconi, R.; Morrow, C.; Pinheiro, U.; Pisera, A.B.; RÃ-os, P.; RÃ¼tzler, K.; SchÃ¶nberg, C.; Turner, T.; Vacelet, J.; van Soest, R.W.M.; Xavier, J. (2024).

									World Porifera Database. Gelliodes fibrosa (Wilson, 1925). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=184501; https://www.gbif.org/species/2245492 ; https://www.gbif.org/species/2245492
Gonionemus vertens	Cnidaria	Hydrozoa	Limnomedusae	Niphatidae	USA, Belgium, Norway, France, UK, Denmark, Sweden, Italy, Portugal	Ballast water, hull fouling, fisheries, aquaculture, ships (general), debris,	c	Tourism; recreational activities	Schuchert, P. (2024). World Hydrozoa Database. Gonionemus vertens A. Agassiz, 1862. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=117768; https://www.gbif.org/species/2266754 ; https://invasions.si.edu/nemesis/species_summary/50740
Hemigrapsus sanguineus	Arthropoda	Malacostraca	Decapoda	Varunidae	USA, Belgium, Norway, France, UK, AU, Denmark, Canada, Germany, Croatia, Romania, Indonesia, Tunisia, Netherlands	Ships (general), ballast water, aquaculture, hull fouling, recreational equipment,	b	Fisheries; aquacolture	DecaNet eds. (2024). DecaNet. Hemigrapsus sanguineus (De Haan, 1835). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=158417; https://www.gbif.org/species/2225772 ; https://www.iucngisd.org/gisd/speciesname/Hemigrapsus+sanguineus
Hemigrapsus takanoi	Arthropoda	Malacostraca	Decapoda	Varunidae	Belgium, Norway, France, UK, Denmark, Germany, Netherlands, Svalbard	Ballast water, ships (general), aquaculture, solid ballast,	b	nr	DecaNet eds. (2024). DecaNet. Hemigrapsus takanoi Asakura & Watanabe, 2005. Accessed through: World Register of Marine Species at: https://marinespecies.org/aphia.php?p=taxdetails&id=389288; https://www.gbif.org/species/4382841 ; https://www.gbif.org/species/4382841
Hydroides dianthus	Annelida	Polychaeta	Sabellida	Serpulidae	Norway, France, UK, AU, Japan, Italy, Turkey, Ukraine, Argentina, Cyprus,, Egypt, Curacao	Fisheries, Ships (general)	nr	nr	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Hydroides dianthus (Verrill, 1873). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131000;

									https://www.gbif.org/species/2328293 ; https://www.gbif.org/species/2328293
Hydroides dirampha	Annelida	Polychaeta	Sabellida	Serpulidae	USA, AU, Egypt, Lebanon	Ships (general)		Economic loss related to fouling	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Hydroides dirampha MÃ¶rch, 1863. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131001; https://www.gbif.org/species/2328201 ; https://www.gbif.org/species/2328201
Hydroides elegans	Annelida	Polychaeta	Sabellida	Serpulidae	USA, Norway, France, UK, AU, Japan, South Africa, Italy, Mexico, Brasil, Turkey, Portugal, New Zeland, Israel, China, Argentina, Greece, Cyprus, Egypt, Lebanon, Portugal, Malta, Curacao	hull fouling, ships (general), ballast water,	a, b	Economic loss related to fouling; fisheries	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Hydroides elegans (Haswell, 1883) [nomen protectum]. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131002; https://www.gbif.org/species/2328302 ; https://invasions.si.edu/nemesis/species_summary/68295
Hydroides heterocerus	Annelida	Polychaeta	Sabellida	Serpulidae	Turkey, Israel, Cyprus, Lebanon	nr	nr	nr	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Hydroides heterocerus (Grube, 1868). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131005; https://www.gbif.org/species/8400812 ; https://www.gbif.org/species/8400812
Hydroides homoceros	Annelida	Polychaeta	Sabellida	Serpulidae	Turkey, Israel, Cyprus	nr	nr	nr	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Hydroides homoceros Pixell, 1913. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=238212; https://www.gbif.org/species/2328291 ; https://www.gbif.org/species/2328291

Hydroides minax	Annelida	Polychaeta	Sabellida	Serpulidae	Turkey, Israel, lebanon	nr	nr	nr	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Hydroides minax (Grube, 1878). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131007; https://www.gbif.org/species/2328346; https://www.gbif.org/species/2328346
Limnoperna securis	Mollusca	Bivalvia	Mytilida	Mytilidae	Croatia, Spain	hull fouling , ballast waters	b	nr	MolluscaBase eds. (2024). MolluscaBase. Limnoperna securis (Lamarck, 1819). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=506084; https://www.gbif.org/species/6531560; https://www.gbif.org/species/6531560
Littorina saxatilis	Mollusca	Gastropoda	Littorinimorpha	Littorinidae	South Africa, Italy	nr	nr	nr	MolluscaBase eds. (2024). MolluscaBase. Littorina saxatilis (Olivi, 1792). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=140264; https://www.gbif.org/species/8116657; https://www.iucngisd.org/gisd/speciesname/Littorina+saxatilis
Lyrodus pedicellatus	Mollusca	Bivalvia	Mytilida	Teredinidae	USA, South Africa, Argentina	shipping (general)	a, b	Economic loss related to fouling	MolluscaBase eds. (2024). MolluscaBase. Lyrodus pedicellatus (Quatrefages, 1849). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=141600; https://www.gbif.org/species/2288831; https://invasions.si.edu/nemesis/species_summary/81878
Maeotias marginata	Cnidaria	Hydrozoa	Limnomedusae	Olindiidae	USA, Canada, Portugal, Estonia	shipping (general), canals	b		Schuchert, P. (2024). World Hydrozoa Database. Maeotias marginata (Modeer, 1791). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=234026;

									https://www.gbif.org/species/2266741 ; https://invasions.si.edu/nemesis/species_summary/-36
Marenzelleria viridis	Annelida	Polychaeta	Spionida	Spionidae	Belgium, Norway, France	ships (general), ballast water, natural dispersal,	a, b, c	Health	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Marenzelleria viridis (Verrill, 1873). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131135; https://www.gbif.org/species/2321012 ; https://invasions.si.edu/nemesis/species_summary/-684
Marginella glabella	Mollusca	Gastropoda	Neogastropoda	Marginellidae	Spain	nr	b		MolluscaBase eds. (2024). MolluscaBase. Marginella glabella (Linnaeus, 1758). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=140322; https://www.gbif.org/species/5727495 ; https://www.gbif.org/species/5727495
Megabalanus coccopoma	Arthropoda	Thecostraca	Balanomorpha	Balanidae	USA, Belgium, Norway, France, AU, Japan, Poland, Brazil, New Zealand, Oman	hull fouling, ballast water	b	Economic loss related to fouling; aquaculture; fisheries	WoRMS (2024). Megabalanus coccopoma (Darwin, 1854). Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=149682; https://www.gbif.org/species/5166489 ; https://invasions.si.edu/nemesis/species_summary/656268
Membraniporopsis tubigera	Bryozoa	Gymnolaemata	Cheilostomatida	Sinoflustridae	USA, AU, New Zealand, Uruguay	hull fouling	nr	Tourism and recreational activities; fisheries	Bock, P. (2024). World List of Bryozoa. Membraniporopsis tubigera (Osburn, 1940). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=472363; https://www.gbif.org/species/7009942 ; https://invasions.si.edu/nemesis/species_summary/-546
Mercenaria mercenaria	Mollusca	Bivalvia	Venerida	Veneridae	Belgium, Norway, France, UK, Japan, Italy,	ships (general), aquaculture,	a, b		MolluscaBase eds. (2024). MolluscaBase. Mercenaria mercenaria

					Portugal, Spain, China, Netherland	pathogen/parasite, fisheries			(Linnaeus, 1758). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=141919; https://www.gbif.org/species/2287668; https://invasions.si.edu/nemesis/species_summary/-57
Mya arenaria	Mollusca	Bivalvia	Myida	Myidae	Belgium, France, , UK, AU, Denmark, Sweden, Poland, Italy, Russian Federation, Turkey, Portugal, Estonia, Ukraine, Latvia, Bulgaria, Greece, Romania, Lithuania, USA, Georgia, Iceland, Netherlands	hull fouling, ballast waters, aquaculture	a, b		MolluscaBase eds. (2024). MolluscaBase. Mya arenaria Linnaeus, 1758. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=140430; https://www.gbif.org/species/7791733; https://www.iucngisd.org/gisd/speciesname/Mya+arenaria
Mytilopsis adamsi	Mollusca	Bivalvia	Myida	Dreissenidae	Mexico	hull fouling, ballast waters	nr		MolluscaBase eds. (2024). MolluscaBase. Mytilopsis adamsi J. P. E. Morrison, 1946. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=505330; https://www.gbif.org/species/6525791; https://www.gbif.org/species/6525791
Mytilopsis sallei	Mollusca	Bivalvia	Myida	Dreissenidae	Norway, Japan, India, Israel; China, Singapore, Egypt, Micronesia, Fiji, Philippines, Venezuela, Malaysia, Senegal, gabon	ships (general)	b	Economic loss related to fouling; livelyhoods	MolluscaBase eds. (2024). MolluscaBase. Mytilopsis sallei (RÃ©cluz, 1849). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=397147; https://www.gbif.org/species/5189109; https://www.iucngisd.org/gisd/speciesname/Mytilopsis+sallei
Neodexiospira brasiliensis	Annelida	Polychaeta	Sabellida	Serpulidae	France, UK, South Africa, Netherlands	nr	a	Fisheries	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Neodexiospira brasiliensis (Grube, 1872). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131209; https://www.gbif.org/species/2327326

									; https://invasions.si.edu/nemesis/species_summary/-44
Ocinebrellus inornatus	Mollusca	Gastropoda	Neogastropoda	Muricidae	USA, Norway, France, Denmark, Canada, Portugal	aquaculture, fisheries,	b		MolluscaBase eds. (2024). MolluscaBase. Ocinebrellus inornatus (RÃ©cluz, 1851). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=578702; https://www.gbif.org/species/4601972 ; https://invasions.si.edu/nemesis/species_summary/73246
Oculina patagonica	Cnidaria	Hexacorallia	Scleractinia	Oculinidae	Norway, France, Italy, Turkey, Israel, Spain, Greece, Algeria, Lebanon, Tunisia	ships (general)	nr		WoRMS (2024). Oculina patagonica de Angelis D'Ossat, 1908. Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=135210; https://www.gbif.org/species/5184825 ; https://www.gbif.org/species/5184825
Onuphis eremita oculata	Annelida	Polychaeta	Eunicida	Onuphidae	Turkey	nr	nr		Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Onuphis eremita oculata Hartman, 1951. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=335573; https://www.gbif.org/species/6154005 ; https://www.gbif.org/species/6154005
Palaemon macrodactylus	Arthropoda	Malacostraca	Decapoda	Palaemonidae	USA, Belgium, Norway, France, UK, AU, Poland, Italy, Germany, Portugal, Spain, China, Argentina, Bulgaria, Romania	ballast water, aquaculture, natural dispersal, ships (general)	b		DecaNet eds. (2024). DecaNet. Palaemon macrodactylus Rathbun, 1902. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=181372; https://www.gbif.org/species/2224970 ; https://invasions.si.edu/nemesis/species_summary/96450
Perna viridis	Mollusca	Bivalvia	Mytilida	Mytilidae	USA, Norway, Japan, South Africa, Ukraine, Micronesia, Fiji, Venezuela, Jamaica, Trinidad and Tobago	ballast water, aquaculture, hull fouling	a, b, c		MolluscaBase eds. (2024). MolluscaBase. Perna viridis (Linnaeus, 1758). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.

									php?p=taxdetails&id=367822; https://www.gbif.org/species/5729682 ; https://www.iucngisd.org/gisd/speciesname/Perna+viridis
Phyllorhiza punctata	Cnidaria	Scyphozoa	Rhizostomeae	Mastigiidae	USA, Italy	ballast water, aquaculture, natural dispersal, hull fouling, ships (general)	a, b		Collins, A.G.; Morandini, A.C. (2024). World List of Scyphozoa. Phyllorhiza punctata von Lendenfeld, 1884. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=135298; https://www.gbif.org/species/2264530 ; https://www.iucngisd.org/gisd/speciesname/Phyllorhiza+punctata
Pinctada imbricata radiata	Mollusca	Bivalvia	Ostreida	Margaritidae	France, Portugal, Croatia, Greece, Cyprus, Libya, Malta, Syrian Arab Republic	canals, fisheries, shipping (general)	nr		MolluscaBase eds. (2024). MolluscaBase. Pinctada imbricata radiata (Leach, 1814). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=564660; https://www.gbif.org/species/6532399 ; https://www.gbif.org/species/6532399
Platorchestia platensis	Arthropoda	Malacostraca	Amphipoda	Talitridae	Denmark, Sweden, South Africa, Poland, Argentina, Netherlands	shipping (general)	nr		Horton, T.; Lowry, J.; De Broyer, C.; Bellan-Santini, D.; Copilas-Ciocianu, D.; Corbari, L.; Costello, M.J.; Daneliya, M.; Dauvin, J.-C.; FiÅ¡er, C.; Gasca, R.; Grabowski, M.; Guerra-GarcÃ-a, J.M.; Hendrycks, E.; Hughes, L.; Jaume, D.; Jazdzewski, K.; Kim, Y.-H.; King, R.; Krapp-Schickel, T.; LeCroy, S.; LÃ¶rz, A.-N.; Mamos, T.; Senna, A.R.; Serejo, C.; Souza-Filho, J.F.; Tandberg, A.H.; Thomas, J.D.; Thurston, M.; Vader, W.; VÃ¤inÃ¶lÃ¤, R.; Valls Domedel, G.; Vonk, R.; White, K.; Zeidler, W. (2024). World Amphipoda Database. Platorchestia platensis (KrÃ¸yer, 1845). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.

									php?p=taxdetails&id=103217; https://www.gbif.org/species/2218560 ; https://www.gbif.org/species/2218560
Polydora cornuta	Annelida	Polychaeta	Spionida	Spionidae	Mexico, Brazil, Turkey, New Zeland, Ukraine, Argentina, Bulgaria, greece, Romania	Aquaculture, hull fouling ballast wate, ships (general), fisheries, natural dispersal, fisheries	b	Aquacolture	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Polydora cornuta Bosc, 1802. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131143; https://www.gbif.org/species/5197747 ; https://invasions.si.edu/nemesis/species_summary/204501
Portunus (Portunus) segnis	Arthropoda	Malacostraca	Decapoda	Portunidae	Norway, Turkey, Greece, Cyprus, Egypt, Libya, Lebanon, Malta, Syrian Arab Republic	Shipping (general)	nr		DecaNet eds. (2024). DecaNet. Portunus (Portunus) segnis (ForskÃ¥l, 1775). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=442813; https://www.gbif.org/species/5863622 ; https://www.gbif.org/species/5863622
Rapana venosa	Mollusca	Gastropoda	Neogastropoda	Muricidae	USA, Belgium, Norway, France, UK, Italy, Russian Federation, Turkey, Israel, China, Slovenia, Ukraine, Argentina, Bulgaria, Greece, Romania, Georgia, Netherlands, Uruguay	shipping (general), natural dispersal, fisheries, aquaculture,	b	Aquacolture; fisheries	MolluscaBase eds. (2024). MolluscaBase. Rapana venosa (Valenciennes, 1846). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=140416; https://www.gbif.org/species/4363583 ; https://www.iucngisd.org/gisd/speciesname/Rapana+venosa
Rhithropanopeus harrisii	Arthropoda	Malacostraca	Decapoda	Panopeidae	Belgium, Norway, France, UK, Denmark, Japan, Poland, Italy, Russian federation, Germany, Brazil, Portugal, Estonia, Spain, Ukraine, Bulgaria, Romania, Lithuania, Venezuela, Netherlands, Moldova, Panama,	ballast water, aquaculture, hull fouling, sold ballast, fisheries, shipping (general), natural dispersal	a, b, c	Economic loss related to fouling; livelyhoods; fisheries	DecaNet eds. (2024). DecaNet. Rhithropanopeus harrisii (Gould, 1841). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=107414; https://www.gbif.org/species/2227663 ; https://www.iucngisd.org/gisd/speciesname/Rhithropanopeus+harrisii

					Tunisia, Finland, Turkmenistan, Kazakhstan, Azerbaijan				
Sabella spallanzanii	Annelida	Polychaeta	Sabellida	Sabellidae	AU, New eland, Portugal	ballast water, hull fouling	a, b	Fisheries; aquaculture; livelyhoods	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Sabella spallanzanii (Gmelin, 1791). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=130969; https://www.gbif.org/species/2328603 ; https://www.iucngisd.org/gisd/speciesname/Sabella+spallanzanii
Spartina alterniflora	Tracheophyta	Magnoliopsida	Poales	Poaceae	France, UK, AU, Denmark, Japan, South Africa, India, Brazil, New Zealand, Spain, China	solid ballast	a, b	Livelyhoods	WoRMS (2024). Spartina alterniflora Loisel.. Accessed at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=234072; https://www.gbif.org/species/5290035 ; https://www.iucngisd.org/gisd/speciesname/Spartina+alterniflora
Spirorbis marioni	Annelida	Polychaeta	Sabellida	Serpulidae	France, Italy, Turkey, Portugal, Greece, Cyprus, Lebanon; Syrian Arab Republic	shipping (general)	b	Economic loss related to fouling	Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Spirorbis marioni Caullery & Mesnil, 1897. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131229; https://www.gbif.org/species/5199417 ; https://www.gbif.org/species/5199417
Synidotea laevidorsalis	Arthropoda	Malacostraca	Isopoda	Idoteidae	USA, France, Argentina	hull fouling, ballast water, shipping (general)	nr		Boyko, C.B.; Bruce, N.L.; Hadfield, K.A.; Merrin, K.L.; Ota, Y.; Poore, G.C.B.; Taiti, S. (Eds) (2024). World Marine, Freshwater and Terrestrial Isopod Crustaceans database. Synidotea laevidorsalis (Miers, 1881). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=148669; https://www.gbif.org/species/2204780 ;

									https://invasions.si.edu/nemesis/species_summary/546963
Terebella ehrenbergi	Annelida	Polychaeta	Terebellida	Terebellidae	nr	nr	nr		Read, G.; Fauchald, K. (Ed.) (2024). World Polychaeta Database. Terebella ehrenbergi Grube, 1869. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=131541; https://www.gbif.org/species/7695036 ; https://www.gbif.org/species/7695036
Theora (Endopleura) lubrica	Mollusca	Bivalvia	Cardiida	Semelidae	USA, Norway, Australia, Italy, New Zealand, Israel, Spain	solid ballast, ships (general)	nr (colonises polluted habitats where natural organisms they do not grow)		MolluscaBase eds. (2024). MolluscaBase. Theora (Endopleura) lubrica Gould, 1861. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=772058; https://www.gbif.org/species/5189038 ; https://invasions.si.edu/nemesis/species_summary/81322
Tricellaria inopinata	Bryozoa	Gymnolaemata	Cheilostomatida	Candidae	Belgium, Norway, France, UK, Italy, Ireland, Germany, Portugal, New Zealand, Greece	debris, fisheries, recreational equipment, aquaculture, hull fouling	a, b	Economic loss related to fouling	Bock, P. (2024). World List of Bryozoa. Tricellaria inopinata d'Hondt & Occhipinti Ambrogi, 1985. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=111254; https://www.gbif.org/species/4985072 ; https://invasions.si.edu/nemesis/species_summary/-572
Tubastraea coccinea	Cnidaria	Hexacorallia	Scleractinia	Dendrophylliidae	USA, India, Mexico, Brazil, China, Ecuador, Cuba, Egypt, Marshall Islands, Mauritius, Venezuela, Dominican Republic, Vietnam, Samoa, Jamaica, Tanzania, Anguilla, Bahamas, Mozambique, Sri Lanka, Curacao, Dominica, Myanmar, Belize, Saudi Arabia,	hull fouling, natural dispersal,	b		Hoeksema, B. W.; Cairns, S. (2024). World List of Scleractinia. Tubastraea coccinea Lesson, 1830. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=291251; https://www.gbif.org/species/2259549 https://www.iucngisd.org/gisd/speciesname/Tubastraea+coccinea

					Bonaire, Aruba, Cabo Verde, Cayman, Kuwait, Djibouti				
Victorella pavida	Bryozoa	Gymnolaemata	Ctenostomatida	Victorellidae	USA, Belgium, UK, Sweden, Poland, Mexico, Germany	ships (general), hull fouling, aquaculture,	a, b	Economic loss related to fouling	Bock, P. (2024). World List of Bryozoa. Victorella pavida Saville-Kent, 1870. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=111673; https://www.gbif.org/species/4985433 ; https://invasions.si.edu/nemesis/species_summary/155524
Watersipora arcuata	Bryozoa	Gymnolaemata	Cheilostomatida	Watersiporidae	USA, AU, Italy, Mexico, New Zeland, Malta	hull fouling	a, b	Economic loss related to fouling	Bock, P. (2024). World List of Bryozoa. Watersipora arcuata Banta, 1969. Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=395087; https://www.gbif.org/species/1005671 ; https://invasions.si.edu/nemesis/species_summary/-250
Watersipora subtorquata	Bryozoa	Gymnolaemata	Cheilostomatida	Watersiporidae	USA, France, AU, South Africa, Ireland, Portugal, China, Ecuador, Lebanon, Venezuela, American Samoa, Vaniatu, Cabo Verde	ships (general), hull fouling, fisheries,	a, b		Bock, P. (2024). World List of Bryozoa. Watersipora subtorquata (d'Orbigny, 1852). Accessed through: World Register of Marine Species at: https://www.marinespecies.org/aphia.php?p=taxdetails&id=111592; https://www.gbif.org/species/1005677 https://www.iucngisd.org/gisd/speciesname/Watersipora+subtorquata

Appendix 2 – Measures set out in the Guidelines

In the sections below, we use a tabular format to outline the measures[16] included in each of the Guidelines' main categories of ship construction, operation, and maintenance (left column ('Specific guidance provided') of summary tables). We provide comments regarding intent and effect of each measure (right column 'Rationale and effect' of summary tables), followed by a brief assessment of whether and how the measures, if made mandatory, would assist in preventing the spread of invasive species.

Category 1: Design and construction

Table A2.1

Item	Specific guidance provided	Rationale and (implied) intended effect
1	In the design, construction, or modification of a ship, the following items should be taken into consideration:	
	i. Small niches and sheltered areas should be avoided as far as practical.	Niche areas harbour the majority of biofouling diversity and biomass on a ship. Minimisation of niche areas is useful as it reduces biofouling load. However, most niche areas have operational functions and cannot be avoided.
	ii. Rounding/bevelling of corners, [sea chest] gratings, and protrusions to promote more effective coverage of AFC[17]; hinging of [sea chest] gratings.	Minimisation of AFC degradation and delamination due to sharp corners and angles reduces biofouling extent. Hinged sea chest gratings would enable diver access for inspection and in-water cleaning; currently often compromised by permanent (welded) gratings.
	iii. Provide capacity to block off sea chests and areas such as moon pools and floodable docks.	Ability to isolate these areas would enable or improve effectiveness of proactive or reactive treatment. Currently often compromised via inability to contain treatments and maintain target concentrations or temperatures.
	iv. Internal seawater cooling systems should be designed with a minimum number of bends and flanges, and of appropriate material to minimize biofouling and be compatible with MGPS. Dead ends should be avoided.	Little is known about the release/escape of viable biofouling organisms[18] from internal seawater systems. Limited ability to use 'materials that minimise biofouling' – such materials are yet to be developed.

[16] For brevity the text describing the various measures was condensed relative to the original text (in the Guidelines), as needed.
[17] Antifouling coatings.
[18] For the purposes of this assessment, *biofouling organisms* include reproductive stages/propagules (larvae, spores) and juvenile or adult individuals or colonies.

Category 2: Antifouling system installation and maintenance

Choosing an antifouling system

Table A2.2

Item	Specific guidance provided	Rationale and (implied) intended effect
1	It is recommended to install AFS[19] in all submerged surfaces on a ship where biofouling may attach. Factors to consider for choosing an AFS include:	
	i. Ship design and construction. Targeted installation of AFS may be employed for different areas of the ship. AFS for the hull may include specific AFC, paint and/or surface treatment. Installation of any proactive cleaning measures should be in accordance with the recommendations from the AFC provider and should not damage the AFC. For niche areas, the selected AFS should be optimized for conditions of the niche area.	Depending on their exposure to laminar flow and associated drag, some niche areas require different coating types or other systems for optimised protection than the regular hull. This measure may achieve better protection for biofouling for some areas.
	ii. Active ingredients of AFC. Environmental impact assessment of the selected AFC with respect to the release of harmful substances should be considered.	Active ingredients (biocides) of AFC drive coating performance (i.e., biofouling prevention).
	iii. Operating profile. Patterns of activity and operating routes may influence the effectiveness of the AFS.	Different AFC and other AFS types are available and recommended for vessels depending on frequency of travel, speed, voyage durations, and depending on whether primary operation occurs in coastal vs. offshore environments. Appropriate coating and other system choice in relation to operating profile is important for antifouling performance and coating longevity.
	iv. Operating environments.	See (iii) above.
	v. Cleaning method. The choice of AFC should be compatible with the cleaning technologies available to ensure both minimum biofouling growth as well as reducing the risk of damage to the AFC and the potential release of harmful waste substances to the environment.	Using cleaning methods not suited for a given coating may damage and degrade the coating, compromise its future performance and result in release of harmful substances.
	vi. Maintenance. AFC lifespan and lifetime of MGPS (e.g. anodes) should exceed the period between dry-dockings.	Where this is not the case, biofouling build-up is likely elevated following lifespan exceedance.
	vii. Legal requirements. Any national or regional regulatory requirements should be considered in the selection of AFS.	Regulatory requirements may rule out the use of some coatings or cleaning methods, with consequences for biofouling development and ability for management.

[19] Antifouling system (may include coatings, anodes, UV or electro-chemical systems and others.

Table A2.3

Item	Specific guidance provided		Rationale and (implied) intended effect
1	AFS installation should be done according to manufacturer's guidance		Incorrect installation may result in reduced effectiveness
2	Niche areas are particularly susceptible to biofouling growth. Recommended measures for installation of an AFS in niche areas include:		
	i.	Sea chests. Internal surfaces and inlet gratings of sea chests should be protected by an AFS that is suitable for the flow conditions of the area over the gratings and through the sea chest.	Sea chests are amongst the most heavily fouled niche areas on vessels and MGPS installed within seas chests are not always effective. AFS installation within sea chests will delay biofouling build-up.
	ii.	Bow and stern thrusters. Free-flooding spaces which may exist around the thruster tunnel require special attention. The housings/recesses and retractable fittings such as stabilizers and thruster bodies should have an AFC of adequate thickness for optimal effectiveness.	AFC are often not applied to difficult-to-reach niche areas such as these. Ensuring they are coated appropriately will reduce biofouling build-up.
	iii.	Rudder hinges and stabilizer fins should be moved through their full range of motion during the coating process to ensure that all surfaces are correctly coated to the specification of the AFC. Rudders, rudder fittings and the hull areas around them should also be adequately coated to withstand the increased wear rates experienced in these areas.	Complete coverage of niche areas with AFC will reduce biofouling development.
	iv.	Propellers and shafts are generally not coated but polished. Fouling release coatings or other suitable coatings may be applied where possible and appropriate to maintain efficiency.	Fouling-release (FR) coatings do not prevent biofouling but interfere with its ability to firmly attach. Use of FR coatings on propellors and shafts will achieve sloughing of biofouling when a vessel is in motion.
	v.	Stern tube seal assemblies and the internal surfaces of rope guards. Exposed sections of stern tube seal assemblies and the internal surfaces of rope guards should be carefully painted with AFC appropriate to the degree of water movement over and around these surfaces.	As per (ii) and (iii) above.
	vi.	Cathodic protection anodes. Biofouling can be minimized if anodes are flush-fitted to the hull or gaps between hull and anode are avoided. Where this is not achievable the hull surface under the anode and the anode strap should be coated with a suitable AFC. Recesses of bolts in the anode surface should be caulked.	Avoidance of micro-niches associated with anodes will reduce biofouling accumulation.
	vii.	Pitot tubes. Where retractable pitot tubes are fitted, the housing should be internally coated with an AFC suitable for static conditions.	As per (ii), (iii), and (vi) above.

	viii. Pipe openings and accessible internal areas should be protected by an AFS as far as practicable. Any anti-corrosive or primer coating used should be appropriate for the specific pipe material and area requirements. Care should be taken in surface preparation and coating application to ensure good adhesion and coating thickness.	As per (ii), (iii), (vi), and (vii) above.

Reinstalling, reapplying or repairing the antifouling system

Table A2.4

Item	Specific guidance provided	Rationale and (implied) intended effect
1	Reinstalling, reapplying or repairing the AFS should be in accordance with manufacturer's guidance to facilitate good adhesion and durability.	Appropriate procedures will maximise AFS performance, integrity, and longevity.
2	Positions of dry-docking blocks and supports should be varied at each dry-docking to ensure that areas under blocks are painted with an AFC, at least at alternate dry-dockings. Where this is not possible, these areas should be managed by other means, e.g. the application of specialized coatings.	Dry-docking block 'strips' are amongst the most heavily fouled areas of vessels because they often lack AFC coverage. Alternating block positions in dry-dock is a useful tool for reducing biofouling extent.
3	When reinstalling, reapplying, or repairing AFS in niche areas:	
	i. The area around bow, stern and any other thrusters prone to coating damage should be routinely maintained.	AFC coated areas subject to excessive, or insufficient flow may suffer from premature coating failure. Routinely addressing this can reduce biofouling accumulation and transport over time.
	ii. Recesses within rudder hinges and behind stabilizer fins need to be carefully and effectively cleaned and recoated.	See (i) above.
	iii. Gratings located in sea chests may require a major-refurbishment type of surface preparation at each dry-docking to ensure coating durability.	See (i) above.

Category 3: Contingency action plans

Table A2.5

Item	Specific guidance provided	Rationale and (implied) intended effect
1	A ship-specific contingency action plan based on specific triggers from monitoring of biofouling parameters (e.g., fuel consumption) should be described in the Biofouling Management Plan. A contingency action plan could include the following aspects:	The rationale here is that an agreed plan for managing biofouling will enable mitigation actions to be taken if biofouling development (and impacts) occur earlier or at a higher level.
	i. Proactive actions can be implemented to lower the risk of biofouling accumulation if a higher biofouling risk may be predicted owing to planned operational changes.	Such proactive actions might include unscheduled grooming or cleaning operations.
	ii. Corrective actions to operating profile, maintenance or other repair plans, if the monitoring identifies an early indication of elevated risk.	Guidance for the implementation of corrective actions as part of the contingency action plans.
	iii. Inspection may be necessary to determine biofouling accumulation if the monitoring of biofouling parameters identifies an indication of prolonged elevated risk.	Inspections are efficient ways to check biofouling status and performance of AFS.
2	Depending on the relevant biofouling risk parameters, the contingency action plan should trigger a reaction to be conducted in line with the Biofouling Management Plan.	Responding to 'triggers' in biofouling parameters will reduce risk of extensive biofouling development and associated potential spread of invasive species.

Category 4: Inspection

Table A2.6

Item	Specific guidance provided	Rationale and (implied) intended effect
1	Inspections should be carried out:	
	i. By organizations, crew or personnel competent to undertake inspections following these guidelines and competent to use relevant inspection methods or equipment to determine the level of biofouling and the condition of the AFS.	Inspections carried out by unqualified personnel may result in inaccurate biofouling assessments, with consequences for the implementation of appropriate management measures.
	ii. for the purpose of fixed schedule inspections, by inspection organizations or personnel able to provide impartial inspection.	Independent inspections are least likely to be biased or affected by operational schedules or commercial obligations.
	iii. for the purpose of inspections as part of contingency actions, by organizations, crew or personnel competent for such inspections.	Any inspection must only be conducted by operators who are adequately trained in assessing biofouling conditions.
2	Frequency of inspection dates during the in-service period of the ship should be based on the ship-specific biofouling risk profile, including inspection as a contingency action, and specified in the BFMP. The BFMP should also specify management actions to be taken when biofouling is identified during inspections.	Conduction of inspections at intervals appropriate to a ship's risk profile, and in the presence of appropriate response measures, is an effective way of preventing excessive biofouling development and transport.

Item	Specific guidance provided	Rationale and (implied) intended effect
3	For ships not undertaking performance monitoring, the first inspection date should be within 12 months of application, reapplication, installation or renewal of AFS to confirm their effective operation.	
4	Where monitoring indicates that the AFS is not performing effectively (e.g. increased fuel consumption), an inspection should be carried out to confirm the condition of the AFS and level of biofouling as soon as practical or possible, in line with the BFMP and contingency action plan.	See item 2 above.
5	Subsequent inspections should occur at least every 12 to 18 months and may need to increase to confirm the continued effectiveness of ageing or damaged AFS. In-water inspections should seek to coincide with existing subsea operations. If no AFS are installed in areas of a ship and no other measures are undertaken (e.g. in-water cleaning) inspections should occur more frequently (<12 months) to manage the risk of biofouling accumulation.	Permanently submerged areas or structures not coated in AFC will develop biofouling considerably sooner than 12 months following immersion. Regular/frequent inspections need to be tied to response measures for them to be effective – as described in item 6 below.
6	In-water inspections should assess biofouling across the entirety of a ship's hull and niche areas. If high levels of biofouling are identified during an inspection and there are reasons to suspect issues with the AFS's effectiveness, actions should be taken to manage the biofouling and subsequent inspections should occur more frequently until dry-docking and recoating of AFC.	Consistent use of appropriate inspection methods ensures that extensive biofouling development in any submerged areas of vessels are reliably detected.
7	In-water inspections should determine the level of biofouling of the hull and of all niche areas, and the condition of the AFS. The inspection areas should be subdivided into appropriate sections as listed in the appendix to the Guidelines. The fouling rating for each area on the ship should be the highest rating identified in the inspected areas (fouling ratings are defined in Table 1 of the Guidelines).	Consistent use of appropriate inspection methods ensures that extensive biofouling development in any submerged areas of vessels are reliably detected.
8	An inspection report should be prepared, and a copy should be available on board and listed/linked in the Biofouling Record Book (BFRB).	Record-keeping enables informed decision-making about hull and internal seawater system maintenance, and the identification of meaningful adaptations to operational or maintenance schedules in response to the results of successive inspections.

Category 5: Cleaning and maintenance

Table A2.7

Item	Specific guidance provided	Rationale and (implied) intended effect
1	**Proactive cleaning** is the periodic removal of microfouling on ships' hull and niche areas or other submerged surfaces as relevant prior to macrofouling growth and can be conducted with or without capture. Proactive cleaning *without capture* should:	
	i. not be conducted on biofouling with rating ≥2 in line with table 1.	This measure minimises the release of viable macrofouling organisms that may be able to survive in the receiving environment.
	ii. be performed in an area accepted by the relevant authority for this activity. Regulations regarding the discharge of biofouling and waste substances into the marine environment and the location of sensitive areas (such as Marine Protected Areas) may be relevant	This measure is intended to avoid violation of local or regional regulations or other authoritative requirements.
	iii. inspection may be necessary to determine biofouling accumulation if the monitoring of biofouling parameters identifies an indication of prolonged elevated risk.	Inspection may assist with adaption of cleaning frequency to prevent macrofouling development.
	iv. Procedures for proactive cleaning and frequency should be described in the BFMP. All proactive cleaning, and any determination of biofouling level prior to the cleaning, should be entered in the BFRB	Good record-keeping will over time help evaluate the appropriateness of biofouling management plans for a given vessel and enable adaption and optimisation of such plans.
2	**Reactive cleaning** systems physically remove micro- and macrofouling from the hull and niche areas. Reactive cleaning should:	
	i. be conducted using a reactive cleaning system that is compatible with the AFC in order to minimize damage of the AFC	Damage to AFC can release contaminants and vastly reduce AFC service life
	ii. be conducted with the aim of achieving a fouling rating ≤1 for the cleaned area in line with table 1	Not achieving a rating of 1 or less in target areas means the cleaning system is not effective.
	iii. strive for effective collection and safe disposal of all biofouling material and waste substances	Prevent release of contaminants (AFC fragments) and viable organisms (biofouling material) into the surrounding environment.
	iv. be performed in an area accepted by the relevant authority for this activity	Some jurisdictions have restrictions on in-water cleaning activities.
3	Biofouling management in niche areas should include:	
	i. maintenance of any MGPS installed to ensure they operate effectively to prevent accumulation of biofouling in relevant niche areas	Recent research indicated that MGPS often do not perform adequately, but that this is often a consequence of insufficient maintenance and inspection.
	ii. regular polishing (with capture of debris) of uncoated propellers to maintain operational efficiency and minimize macrofouling accumulation	Propellers (and other niches) not coasted with AFC are prone to rapid biofouling development.

Item	Specific guidance provided	Rationale and (implied) intended effect
	iii. appropriate treatment of internal seawater cooling systems and discharge of any treated water in accordance with applicable regulations	Prevent biofouling development in internal seawater systems, and contamination arising from discharge of water from treated systems (internal seawater treatment often involves the use of descaling and other aggressive agents)
	iv. minimizing the use of any soap, cleaner or detergent used on surfaces and ensuring they are toxic- and phosphate-free, biodegradable and non-hazardous to the marine environment.	General environmental considerations, no significance for biofouling prevention.
4	Operators undertaking in-water reactive cleaning should be aware of any regulations or requirements regarding the discharge of cleaning waste and the location of sensitive areas.	See 1.ii and 2.iii
5	Ship recycling facilities should adopt measures (consistent with applicable national and local laws and regulations) and a plan to ensure that biofouling organisms or waste substances are not released into the local aquatic environment	See 1.ii and 2.iii

Category 6: Biofouling Management Plan

Table A2.8

Item	Specific guidance provided	Rationale and (implied) intended effect
1	It is recommended that every ship have a ship-specific BFMP under the responsibility of shipowners, ship operators and shipmasters. A BFMP may require information from ship designers, shipbuilders, shipowners, AFC and MGPS manufacturers, recognized organizations and suppliers	Requires consideration of a vessel's design, construction, niche areas, AFS (incl. MGPS), expected operational schedules and environments, and resultant needs for proactive and reactive biofouling management needs and contingency measures. Outlines actions in case 'triggers' of biofouling risk are detected. A well thought-out BFMP is a useful baseline for effective biofouling prevention and management.
2	An effective BFMP should contribute to the aim of maintaining a recommended fouling rating ≤1, as described in chapter 8 of the Guidelines.	Achieving a fouling rating of ≤1 would mean no macrofouling is present on a vessel.
3	The ship-specific BFMP should include, but not necessarily be limited to, the items listed on pages 18-19 of the Guidelines.	Setting a standard for BFMP development, to avoid inconsistencies and reduced effectiveness of some plans.

4	The effectiveness of the management actions in place should be reviewed following inspections and cleaning. The BFMP should be updated if the management actions in place are ineffective or deficient. Efficacy of the following items should be evaluated: (i) ability to minimize biofouling by use of proactive cleaning methods, (ii) biofouling inspections schedule, (iii) ability to minimize biofouling by MGPS, (iv) AFS performance, (v) outcome of reactive biofouling management procedures (efficacy of biofouling removal and access to niche areas).	Review and adaptation of BFMP enables optimisation and avoidance of unnoticed and/or unmanaged development of biofouling.

Category 7: Biofouling Record Book

Table A2.9

Item	Specific guidance provided	Rationale and (implied) intended effect
1	All biofouling management activities should be recorded in a BFRB, including the items on page 20 of the Guidelines.	The BFRB is used to collate evidence and details of biofouling management measures set out in the BFMP.

Category 8: Documentation and dissemination of information

Table A2.10

Item	Specific guidance provided	Rationale and (implied) intended effect
1	States are encouraged to provide information on the location and the terms of use of proactive cleaning, inspection, reactive cleaning services and facilities to comply with these Guidelines. States requiring inspection or cleaning prior to arrival in their territory should inform the Organization. Member States or other relevant stakeholders are encouraged to communicate the outcome of testing of cleaning systems and applicable test standards to relevant stakeholders via https://bwema.org.	Availability of information regarding inspections, in-water cleaning, and other aspects enable vessels' operators to plan operations set out in their BFMP and avoid delays or lapses in critical procedures (which may interfere with biofouling prevention).
2	States are encouraged to provide technical and research information to the Organization, including any studies on the impact and control of invasive aquatic species in ships' biofouling, information on local biofouling pressure, databases on regional biofouling management options, tools for the choice of AFS, and on the efficacy and practicality of in-water cleaning technologies, risk assessment tools and inspection reporting tools.	Information sharing enhances technology and policy development, and enables internationally operating vessels to schedule biofouling management measures in accordance with availability and other criteria.
3	State authorities should provide ships with timely, clear and concise information on biofouling management measures and cleaning requirements that are being applied to shipping and ensure these are widely distributed. Shipowners and operators should endeavour to become familiar with all requirements related to biofouling.	See item 2.

4	Organizations or shipping agents representing shipowners and operators should be familiar with the requirements of State authorities with respect to biofouling cleaning and management procedures, including information that will be needed to obtain entry clearance. Verification and detailed information concerning State requirements should be obtained by the ship prior to arrival.	See item 2.
5	To monitor the effectiveness of these Guidelines as part of the evaluation process, States are encouraged to provide the Organization with records describing reasons why ships could not apply these Guidelines, e.g. design, construction or operation of a ship, particularly from the viewpoint of ships' safety, or lack of information concerning the Guidelines.	See items 1 and 2.

Category 9: Training and education

Table A2.11

Item	Specific guidance provided	Rationale and (implied) intended effect
1	Training for ships' masters and crew, in-water cleaning or maintenance facility operators and those surveying or inspecting ships as appropriate should include instructions on the application of biofouling cleaning and management procedures, based upon the information contained in these Guidelines. Instruction should also be provided on: (i) maintenance of appropriate records and logs, (ii) impacts of invasive aquatic species from ships' biofouling, (iii) benefits to the ship of managing biofouling, (iv) relevant health and safety procedures and issues.	All biofouling management measures and record keeping for a vessel are undertaken appropriately and effectively.

Category 10: Other measures

Table A2.12

Item	Specific guidance provided	Rationale and (implied) intended effect
1	States and port authorities should aim to ensure a smooth flow of ships going in and out of their ports to avoid ships waiting offshore, so that AFS can operate as effectively as possible.	Reduced lay-up and waiting periods in and outside port facilities reduce biofouling development.
2	States should consider these Guidelines when developing other measures and/or restrictions for managing ships' biofouling	A consistent approach to biofouling management guidelines, regulations, and restrictions if preferable to wide geographic variation and reduces confusion.
3	Where other measures are being applied, States should notify the Organization of the specific requirements, with supporting documentation, for dissemination to other States and non-governmental agencies where appropriate	Information-sharing reduced confusion and involuntary non-compliance.