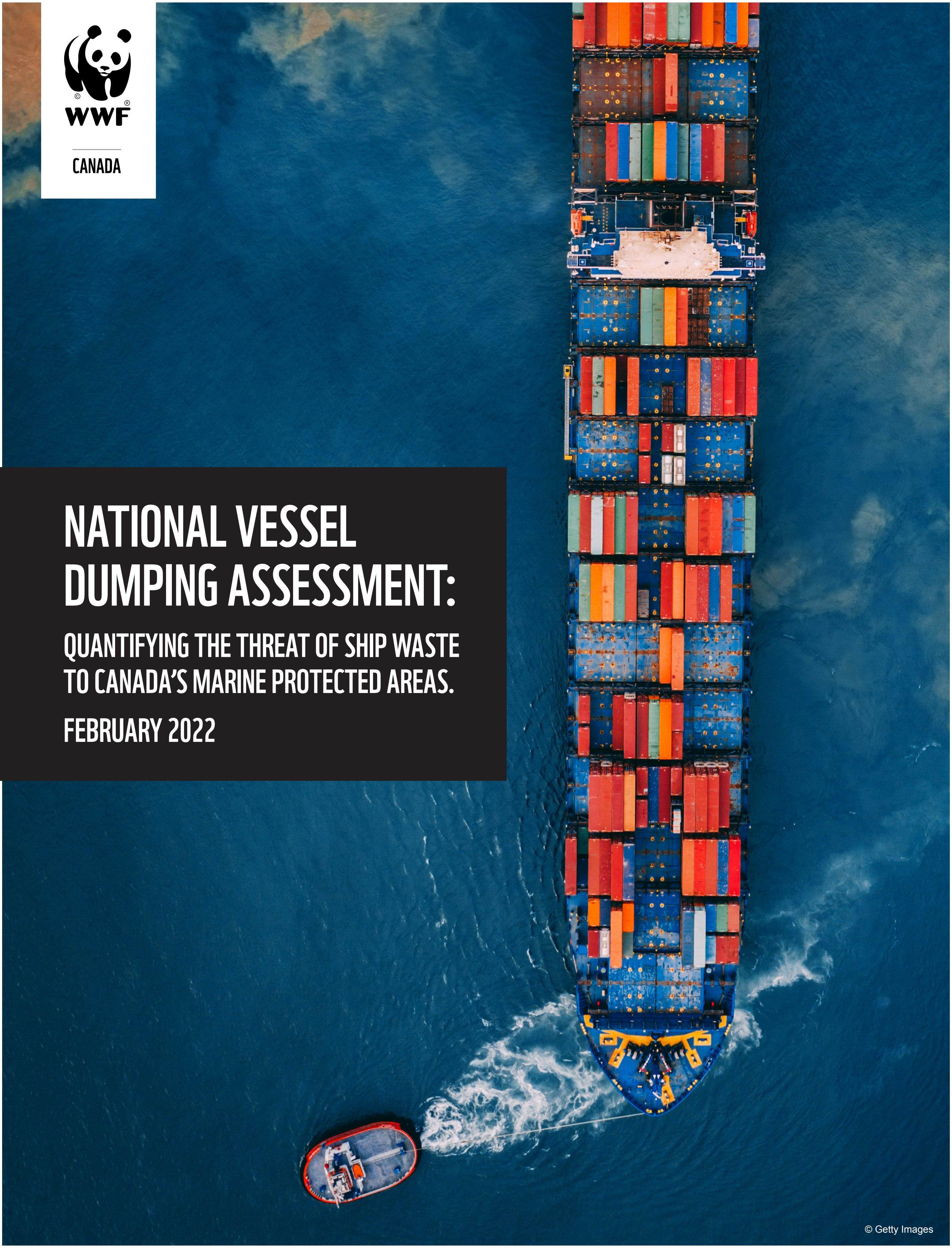
WWF CANADA

NATIONAL VESSEL DUMPING ASSESSMENT:

QUANTIFYING THE THREAT OF SHIP WASTE TO CANADA'S MARINE PROTECTED AREAS.

FEBRUARY 2022



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EXECUTIVE SUMMARY

CANADA HAS PROTECTED MORE THAN 13 PER CENT OF ITS MARINE AND COASTAL AREAS, WITH A COMMITMENT TO REACH 30 PER CENT BY 2030. BUT SHIPS ARE CURRENTLY PRODUCING 147 BILLION LITRES OF HARMFUL WASTE IN CANADIAN WATERS ANNUALLY — NEARLY 10 PER CENT OF WHICH IS DUMPED IN PROTECTED AREAS.

With the world's longest coastline, Canada's three oceans provide important habitat to at-risk species, underpin the livelihoods, sustenance, and culture of coastal and Indigenous communities, and drive national economic activity. But as ship traffic increases, so too does the threat from chronic pollution to our oceans, wildlife, and climate.

The dumping of routine "operational discharges" is still permitted, despite containing acids, carcinogens, pathogens, and toxic substances known to harm marine life and undermine the resiliency of our marine ecosystems. And despite adopting "minimum standards" for new marine protected areas (MPAs) that prohibit dumping, the federal government has not yet defined what types of discharges this ban includes nor how it will be implemented and enforced. And, the ban won't apply to other effective area-based conservation measures (OECMs) or provincially protected areas counting toward Canada's marine conservation targets.

The lack of available information about exactly how much waste ships are producing, and where it's being dumped, has further hampered conservation efforts. WWF-Canada's National Vessel Dumping Assessment gives us a much clearer picture. We now know how much greywater, bilge water, sewage, and scrubber washwater is generated annually by analyzing ship traffic data for 5,546 ships with International Maritime Organization (IMO) numbers active in Canadian waters during 2019.

We found that these **ships produce and can potentially discharge 147 billion litres of harmful waste each year while in Canadian waters** — the equivalent of 59,000 Olympic-sized swimming pools.

This dumping threatens wildlife even in the protected parts of Canada's oceans, with **roughly 10 per cent of ship waste, or 14.7 billion litres, generated in MPAs and OECMs annually.**

High traffic areas like Scott Islands marine National Wildlife Area, off the coast of B.C., stand to be most impacted by dumping; more waste was created, and therefore potentially dumped, in the Scott Islands protected area than any other protected area included in this assessment.

Though there is less shipping traffic in the Arctic than in Canada's busy east and west coasts, the proportion of waste created within Arctic MPAs, like the Tallurutiup Imanga National Marine Conservation Area, is greater than on east and west coast MPAs.

This assessment also calculated how much of each waste stream is produced annually and by what types of ships.

Scrubber washwater was by far the greatest in volume. **Although only one in eight ships is outfitted with a scrubber, the amount of scrubber washwater generated each year is 34 times the volume of all the other waste streams combined, or 97 per cent of total waste.** Most ships with scrubbers use open-loop systems, which means nearly all scrubber washwater is dumped where it is generated. It's unknown how much of the remaining 3 per cent of this waste, which includes sewage, greywater, and bilge water, is dumped at sea, as ships can dispose of it at port reception facilities.

The assessment found that cruise ships produce two-thirds of all scrubber washwater produced in Canadian waters annually. **Despite making up only 2 per cent of the ships in the analysis, cruise ships are the top producers of each of the four waste streams.** The cruise industry also leads the production of wastes within the protected areas included in this study.

The findings of WWF-Canada's National Vessel Dumping Assessment demonstrate both the magnitude of waste generated in Canadian waters and, more specifically, the amount dumped in protected areas that are intended to conserve important habitats and provide refuge for marine wildlife.

The regulations currently in place are inadequate and have gaps that leave wildlife and ecosystems vulnerable. It is imperative that the protections Canada creates effectively conserve our most sensitive marine areas now and into the future.

To meet its long-term goals of building healthy and resilient marine ecosystems, WWF-Canada recommends that the Government of Canada:

- Adopt a comprehensive definition of "dumping" so that minimum standards for MPAs prohibit ships from discharging any operational wastes.
- Extend minimum standards to all areas counting toward Canada's marine conservation targets, not just new federal MPAs.
- Enforce the minimum standards in all existing MPAs and OECMs through the management planning process.
- Ban scrubbers. Not only is scrubber washwater the largest waste stream in our assessment, but scrubbers also encourage continued reliance on heavy fuel oil, which poses a severe environmental risk in the event of a spill.
- Close the Arctic greywater regulatory gap. Greywater treatment and disposal is clearly regulated in southern Canada but not in the Arctic. Explicitly regulating greywater in the Canadian Arctic would add a needed layer of protection inside and outside of Arctic MPAs and OECMs.

As Canada creates networks of MPAs and OECMs, it is important to ensure these sites have the best possible outcomes for wildlife and the people who depend on them. Banning the dumping of substances known to harm wildlife is key to ensuring MPAs are protected in more than name only.


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INTRODUCTION

Canada is an ocean nation. Its 240,000-kilometre coastline is the longest in the world and its seabed accounts for an area nearly two-thirds the size of its land mass. It borders the Atlantic, Arctic, and Pacific oceans and enjoys jurisdiction over North America's only Atlantic gateway to the Arctic. Canada's estuaries, coasts, and oceans drive major economic activity; its maritime sectors contribute approximately $32 billion dollars annually in gross domestic product and supports about 300,000 jobs.[1] Canada is also home to vast marine biodiversity that plays an integral role in defining its history, culture, identity, and economy.

Today, biodiversity is disappearing at an alarming rate.[2] This crisis is fundamentally linked to climate change and environmental degradation driven by chronic pollution from many sources.[3] The loss of marine biodiversity compromises the resiliency of the ecosystems underpinning the health and economic prosperity of Canadians. As an ocean nation, Canada needs to halt biodiversity loss by introducing measures that promote the long-term sustainable use of its oceans and coasts by all ocean users, including the marine shipping industry.

Marine shipping is the backbone of global commerce. Around 90 per cent of goods traded globally are transported by ship—and demand for freight is rising.[4] From 1970 to 2017, global maritime trade increased by an average of 3 per cent annually.[5] Projections suggest that by 2050, passenger transport will increase by 2.3 times and freight transport will increase by 2.6 times.[6] Aside from catastrophic and unintended ship source pollution events, ships produce a variety of polluting wastes whose production is incidental to normal operations, termed "operational wastes."[7] Disposal of operational wastes at sea is generally permissible under both Canadian and international laws, provided it is done in accordance with regulatory requirements. These operational wastes are a source of chronic pollution and contribute to excess stress on marine ecosystems.

1 Fisheries and Oceans Canada. (2021). *Blue Economy Strategy*. Retrieved September 2021, from https://www.dfo-mpo.gc.ca/campaign-campagne/bes-seb/index-eng.html

2 World Wildlife Fund (WWF). (2020). *Living Planet Report 2020—Bending the curve of biodiversity loss*. (R.E.A. Almond, M. Grooten, & T. Petersen, Eds.). https://livingplanet.panda.org/en-us/

3 *Ibid*.

4 Organisation for Economic Co-operation and Development (OECD). (2019). *Ocean shipping and shipbuilding.* OECD. Retrieved September 2021, from https://www.oecd.org/ocean/topics/ocean-shipping/

5 Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP). (2021). *Sea-based sources of marine litter* (K. Gilardi, Ed.; No. 108). http://www.gesamp.org/publications/sea-based-sources-of-marine-litter

6 ITF. (2021). *ITF Transport Outlook 2021.* OECD Publishing, Paris. https://doi.org/10.1787/16826a30-en

7 There are up to 40 waste streams associated with vessel operations, as noted by: Parks, M., Ahmasuk, A., Compagnoni, B., Norris, A., & Rufe, R. (2019). Quantifying and mitigating three major vessel waste streams in the northern Bering Sea. *Marine Policy, 106,* 103530. https://doi.org/10.1016/j.marpol.2019.103530

As ship activity in Canadian waters grows, Canada's challenge is to adapt its regulatory policies to offset the environmental impacts of ship-source pollution. This includes updating anti-pollution legislation to reflect modern scientific guidance and technological advances. Unfortunately, Canada has in some ways fallen behind its neighbours. For example, in 2001, the U.S. State of Alaska set strict requirements for sewage and greywater discharges from large passenger vessels and introduced performance-testing measures to ensure wastewater treatment systems remain in compliance. These changes came after findings indicated sewage treatment plants (also called marine sanitation devices) were ineffective.[8] Since 2003, cruise ships operating in Alaskan waters have been equipped with advanced wastewater treatment systems (AWTS) capable of consistently complying with effluent standards.[9] By comparison, Canada's effluent standards for greywater and sewage are weaker than those required by Alaska. Additionally, Canada does not require the use of AWTS and is yet to approve or certify any greywater treatment system for use in the Arctic.[10]

CANADA'S MARINE CONSERVATION TARGETS

As a signatory to the Convention on Biological Diversity, Canada had committed to protecting at least 10 per cent of its coastal and marine areas by 2020.[11] Working in partnership with coastal communities and provincial, territorial, and Indigenous governments, Canada surpassed this goal. By the end of 2020, nearly 14 per cent of Canada's ocean and coasts were covered by marine protected areas (MPAs) and other effective area-based conservation measures (OECMs).

More recently, Canada, as a member of the Global Ocean Alliance,[12] and the High Ambition Coalition for Nature and People,[13] committed to protect 25 per cent of its oceans and coasts by 2025, and 30 per cent by 2030. This was reflected in the 2021 Ministerial Mandate letter to Minister of Fisheries and

[8] OASIS Environmental, Inc. (2012, December). *Cruise ship wastewater 2009–2012 science advisory panel preliminary report.* Alaska Department of Environmental Conservation. http://www.akleg.gov/basis/get_documents.asp?session=28&docid=237

[9] *Ibid*.

[10] Vard Marine Inc. (2018, May). *Canadian Arctic greywater report: Estimates, forecasts, and treatment technologies* (Report No. 360–000).

[11] Convention on Biological Diversity. (2011). Strategic Plan for Biodiversity 2011–2020, including Aichi Biodiversity Targets. https://www.cbd.int/sp/

[12] Fisheries and Oceans Canada. (2020, July 9). *Canada joins Global Ocean Alliance: Advocates for protecting 30 per cent of the world's ocean by 2030.* Government of Canada. Retrieved October 2021, from https://www.canada.ca/en/fisheries-oceans/news/2020/07/canada-joins-global-ocean-alliance-advocates-for-protecting-30-per-cent-of-the-worlds-ocean-by-2030.html

[13] Environment and Climate Change Canada. (2020, September 28). *Canada joins the High Ambition Coalition for Nature and People.* Government of Canada. Retrieved October 2021, from https://www.canada.ca/en/environment-climate-change/news/2020/09/canada-joins-the-high-ambition-coalition-for-nature-and-people.html

Oceans Joyce Murray.[14] It is anticipated that the Post-2020 Targets, which will be set in early 2022 by the Convention on Biological Diversity, will align with the target of 30 per cent by 2030.

PROTECTED IN NAME ONLY?

Despite Canada's commitments to protect its oceans and coastlines, it remains permissible under Canadian law for ships to dispose of polluting operational wastes in nearly all federal MPAs and OECMs. However, there is hope: Canada is in the final stages of defining and operationalizing a suite of minimum standards for new federal MPAs.[15] Among these minimum standards will be a prohibition on "dumping" in MPAs, a term which Canada is yet to define in the context of its maritime laws. There is a unique window of opportunity at this juncture for Canada to protect its most important ocean areas from ship source pollution by adopting a definition of dumping that includes operational wastes from ships.

PURPOSE OF THIS REPORT

The adoption of robust minimum standards for MPAs and OECMs is critical to ensuring that Canada's network of protected areas can achieve the long-term conservation of nature. The purpose of this report is to inform policy-makers and other stakeholders about the potential amount and distribution of waste generated and discharged each year by ships in Canadian waters, including in federally designated MPAs and OECMs. Specifically, this report features quantitative estimates of four major operational waste streams produced by ships, including sewage, greywater, bilge water, and scrubber washwater. The analysis results include the amount of operational waste generated by ships in Canada's waters annually, as well as the amounts generated in each bioregion and in 122 of the protected and conserved areas that count toward Canada's marine conservation targets. The results also provide a breakdown of the amount of waste produced by different ship types. We note that this analysis did not include all protected and conserved areas, only those designated by federal government departments.

[15] Fisheries and Oceans Canada. (2019, April). *Protection Standards to better conserve our oceans.* Government of Canada. Retrieved October 2021, from https://www.dfo-mpo.gc.ca/oceans/mpa-zpm/standards-normes-eng.html

[14] Trudeau, J. (2021, December 16). *Minister of Fisheries, Oceans and the Canadian Coast Guard Mandate Letter.* Government of Canada. Retrieved December 2021, from https://pm.gc.ca/en/mandate-letters/2021/12/16/minister-fisheries-oceans-and-canadian-coast-guard-mandate-letter

BACKGROUND

FEDERAL MARINE PROTECTED AREAS AND OTHER EFFECTIVE AREA-BASED CONSERVATION MEASURES

MPAs and OECMs can be established in Canadian waters by a wide variety of agencies using a selection of legislative and regulatory tools for numerous reasons. Federal, provincial, territorial, and Indigenous governments, and even non-government organizations have established protected areas within Canada's marine territory; however, the three main agencies with specific mandates to implement and manage MPAs are Fisheries and Oceans Canada (DFO), Parks Canada, and Environment and Climate Change Canada (ECCC). These agencies have complementary but differing responsibilities for advancing protection in the marine environment.

DFO has the responsibility to lead the coordination and implementation of a federal network of MPAs and OECMs, working together with other federal, provincial, territorial, and Indigenous governments. They also have the responsibility to establish MPAs under the *Oceans Act.*[16] *Oceans Act* MPAs are put in place to protect and conserve important fish and marine mammal habitats, endangered marine species, unique features, areas of high biological productivity or biodiversity, or for the conservation and protection of any other marine resource or habitat that is necessary to complete the MPA network. DFO has also designated OECMs under the *Fisheries Act,* known as marine refuges.[17] These sites aim to protect important marine species and their habitats, including unique and significant aggregations of corals and sponges, from the impacts of fishing.

Parks Canada's mandate is to establish protected areas that conserve representative examples of Canada's natural and cultural heritage and provide for the enjoyment and education of the public while maintaining the area to meet the needs of future generations. Some terrestrial National Parks and National Park Reserves created under the *Canada National Parks Act* have marine components to them that count toward Canada's marine conservation targets. In addition, Parks Canada can create wholly aquatic National Marine Conservation Areas (NMCAs) under the *Canada National Marine Conservation Areas Act.*[18] These sites are put in place to maintain healthy marine ecosystems and provide for human use and enjoyment in representative areas of the Atlantic, Arctic, and Pacific oceans, and the Great Lakes.

The third core program under the federal MPA program is marine National Wildlife Areas (mNWAs) established by ECCC.[19] These sites are designated under the *Canada Wildlife Act* to protect and

[16] Fisheries and Oceans Canada. (2021b, July). *About Marine Protected Areas*. Government of Canada. Retrieved October 2021, from https://www.dfo-mpo.gc.ca/oceans/mpa-zpm/info-eng.html

[17] Fisheries and Oceans Canada. (2021c, July). *Marine refuges across Canada*. Government of Canada. Retrieved October 2021, from https://www.dfo-mpo.gc.ca/oceans/oecm-amcepz/refuges/index-eng.html

[18] Parks Canada. (2021, November). *Creating new National Marine Conservation Areas of Canada*. Government of Canada. Retrieved November 2021, from https://www.pc.gc.ca/en/amnc-nmca/cnamnc-cnnmca

[19] Environment and Climate Change Canada. (2021, April). *Current National Wildlife Areas*. Government of Canada. Retrieved October 2021, from https://www.canada.ca/en/environment-climate-change/services/national-wildlife-areas/locationsv.html

conserve marine wildlife, especially migratory birds and species at risk, and their habitats. ECCC also has the authority to establish National Wildlife Areas[20] under the *Canada Wildlife Act* and Migratory Bird Sanctuaries under the *Migratory Birds Convention Act* to protect wildlife and habitats as noted above.

MINIMUM MARINE PROTECTION STANDARDS

As MPAs and OECMs are put in place using a variety of legislative tools, what is and is not permissible has been determined on a case-by-case basis to date. This has led to a wide variety of activities being permitted in federal MPAs and OECMs, including unsustainable oil and gas activities and bottom trawl fisheries. In 2017, based on advocacy from WWF-Canada and others, Canada recognized that it needed consistency and stronger protection across its protected area tools and convened a National Advisory Panel on Marine Protected Area Standards to conduct consultations and provide advice.[21] The Panel identified that a lack of basic standards in MPAs had created uncertainty for rights holders and stakeholders and increased the time and effort required to designate new sites. In April 2019, then-Minister of Fisheries and Oceans Jonathan Wilkinson announced that the Government of Canada would adopt minimum protection standards[22] prohibiting industrial activities including oil and gas exploration and exploitation, mining, dumping, and bottom trawling within all federal MPAs.

The adoption of protection standards consistent with the Panel's recommendations would ensure that Canada's ocean conservation efforts result in lasting and effective protection that makes a real difference on the water. However, as of February 2022, the minimum standards have yet to be fully defined or operationalized.

DO EXISTING LAWS PREVENT SHIPS FROM DUMPING OPERATIONAL WASTES IN MPAS?

Both in Canada and internationally, a wealth of regulation and guidance exists to mitigate the impacts of ship-source pollution. Yet, these existing pieces of legislation do not specifically prohibit ships from discharging operational wastes in Canadian MPAs or OECMs. Instead, each federal MPA has its own regulations that can include prohibited activities and exemptions. To date, very few federally protected areas in Canada include provisions prohibiting operational waste discharges.

[20] Environment and Climate Change Canada. (2017, April). Selection of sites as *National Wildlife Areas*. Government of Canada. Retrieved October 2021, from https://www.canada.ca/en/environment-climate-change/services/national-wildlife-areas/site-selection.html

[21] Fisheries and Oceans Canada. (2019b, April). *National Advisory Panel on Marine Protected Area Standards.* Government of Canada. Retrieved October 2021, from https://www.dfo-mpo.gc.ca/oceans/conservation/advisorypanel-comiteconseil/index-eng.html

[22] Fisheries and Oceans Canada. (2019a, April). *Canada announces new standards for protecting our oceans.* Government of Canada. Retrieved October 2021, from https://www.canada.ca/en/fisheries-oceans/news/2019/04/canada-announces-new-standards-for-protecting-our-oceans.html

Canada regulates ship-source pollution and operational practices through national maritime law and environmental law statutes. International treaty commitments are integrated into national legislation through a combination of direct and referential incorporation. Importantly, international laws that are incorporated into Canadian legislation can include Canadian modifications that strengthen environmental protections. A more comprehensive review of environmental protection legislation as it relates to shipping and MPAs can be found in *Navigating the Law: Reducing Shipping Impacts in Marine Protected Areas*, part of WWF-Canada's Shipping in MPAs Toolkit.[23,24] A brief overview of several key pieces is provided here for context.

INTERNATIONAL LEGISLATION

- *United Nations Convention on the Law of the Sea (UNCLOS)*[25]*: UNCLOS* provides the international legal framework for ocean activities and boundaries and establishes the fundamental duty of states to protect and preserve the marine environment. This entails both a positive obligation to take measures to protect and preserve the marine environment, and a negative obligation to not degrade the marine environment. *UNCLOS* assigns the competence for regulating ship-source pollution to the International Maritime Organization (IMO), a specialized agency of the United Nations.

- *International Convention for the Prevention of Pollution from Ships, 1973/78 (MARPOL)*[26]: The IMO regulates ship-source pollution under *MARPOL*, which consists of six technical annexes with associated guidelines. These include oil (Annex I), noxious liquid substances in bulk (Annex II), harmful substances carried by sea in packaged forms (Annex III), sewage (Annex IV), garbage (Annex V), and air pollution (Annex VI). Notably, *MARPOL* does not currently regulate greywater. *MARPOL* provides additional protections to areas that the IMO has designated as "special areas" and "particularly sensitive sea areas," but these enhanced protections do not extend to Canada's federally designated MPAs and OECMs.

- *International Code for Ships Operating in Polar Waters (Polar Code)*[27]: The *Polar Code* is an extension of *MARPOL* and the *International Convention for the Safety of Life at Sea*. It takes into consideration the unique environmental sensitivities and navigational challenges of the Arctic and Antarctic and introduces more stringent regulations and guidelines accordingly. Although the Polar

[23] West Coast Environmental Law & East Coast Environmental Law. (2020, October). *Navigating the law: reducing shipping impacts in marine protected areas.* https://wwf.ca/wp-content/uploads/2021/02/WWF-MPA-6-Navigating-the-Law-v5.pdf

[24] World Wildlife Fund Canada, West Coast Environmental Law, & East Coast Environmental Law. (2020). *Shipping in Marine Protected Areas toolkit.* WWF.Ca. Retrieved September 2021, from https://wwf.ca/habitat/oceans/shipping-in-marine-protected-areas-toolkit/

[25] United Nations Convention on the Law of the Sea, 10 December 1982, 1833 U.N.T.S. 396 *[UNCLOS]*.

[26] International Convention for the Prevention of Pollution from Ships, 2 November 1973, 1340 U.N.T.S. 184, as amended by the Protocol of 1978 Relating to the International Convention for the Prevention of Pollution from Ships, 17 February 1978, 1340 U.N.T.S. 61 *[MARPOL]*.

[27] International Code for Ships Operating in Polar Waters (Polar Code), IMO Resolution MSD.385(94), 21 November 2014 *[Polar Code]*.

Code provides enhanced protections for polar waters, it does not extend protection to Canada's Arctic MPAs beyond what is prescribed for all Arctic waters. As an extension of *MARPOL*, the *Polar Code* does not regulate greywater.

- *1996 Protocol to the Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 1972 (London Protocol)*[28]: The *London Protocol* is an agreement to control pollution of the sea by dumping. Among other activities, it prohibits the deliberate disposal into the sea of wastes or other matter from vessels. However, the definition of "dumping" provided by the *London Protocol* excludes wastes that are incidental to normal ship operations (i.e., operational wastes).

CANADIAN LEGISLATION

- *Oceans Act*[29]: *The Oceans Act* is a domestication of *UNCLOS*; it sets out Canada's maritime zones, which correspond to varying degrees of jurisdictional powers and sovereign rights. Canada's ability to regulate activities, including shipping, diminishes with distance from the baselines. Baselines are defined as the low-water lines as marked on large scale charts recognized by the coastal state. In instances where the coastline is irregular, straight baselines have been drawn using established reference points. Marine areas landward of the baseline are considered interior waters where Canada enjoys full sovereignty and jurisdictional rights. Maritime zones seaward of the baseline include the territorial sea (0–12 nautical miles [nm] seaward of the baselines), the contiguous zone (12–24 nm seaward of the baselines), and the exclusive economic zone (EEZ) (12–200 nm seaward of the baselines). See Figure 1 for a summary of maritime zones.

- *Canada Shipping Act, 2001 (CSA)*[30]: The *CSA* is Canada's principle maritime statute addressing pollution from ships and provides a means of legislating *MARPOL* into Canadian law. The *CSA* introduces and regulates pollution through the *Vessel Pollution and Dangerous Chemical Regulations (VPDCR)*.[31] Although each of the operational wastes discussed in this report would appear to fit the definition of a "pollutant" as defined by the *CSA*, their disposal at sea is authorized under the *Act*. As a result, pollution control measures introduced by other legislation such as the *Fisheries Act,*[32] the *Migratory Birds Convention Act*,[33] and the *Canadian Environmental Protection Act*,[34] do not prohibit the discharge of wastes that are authorized by the *CSA*.

[28] Convention on the Prevention of Marine Pollution by Dumping of Wastes and Other Matter, 29 December 1972, 1046 U.N.T.S. 120 *[London Convention]*; Protocol to the Convention on the Prevention of Marine Pollution by Dumping Wastes and Other Matter, 7 November 1996, Can T.S. 2006 No 5 *[London Protocol]*.

[29] *Oceans Act,* SC 1996, c 31. Retrieved 29 November 2021, from https://canlii.ca/t/5439k

Canada Shipping Act, 2001, SC 2001, c 26. Retrieved 29 November 2021, from https://canlii.ca/t/5439x

[30] *Vessel Pollution and Dangerous Chemicals Regulations,* SOR/2012-69. Retrieved 29 November 2021, from https://canlii.ca/t/554c2

[32] *Fisheries Act,* RSC 1985, c F-14. Retrieved 29 November 2021, from https://canlii.ca/t/543j4

[33] *Migratory Birds Convention Act,* 1994, SC 1994, c 22. Retrieved 29 November 2021, from https://canlii.ca/t/532r2

[34] *Canadian Environmental Protection Act,* 1999, SC 1999, c 33. Retrieved 19 October 2021, from https://canlii.ca/t/54tsw

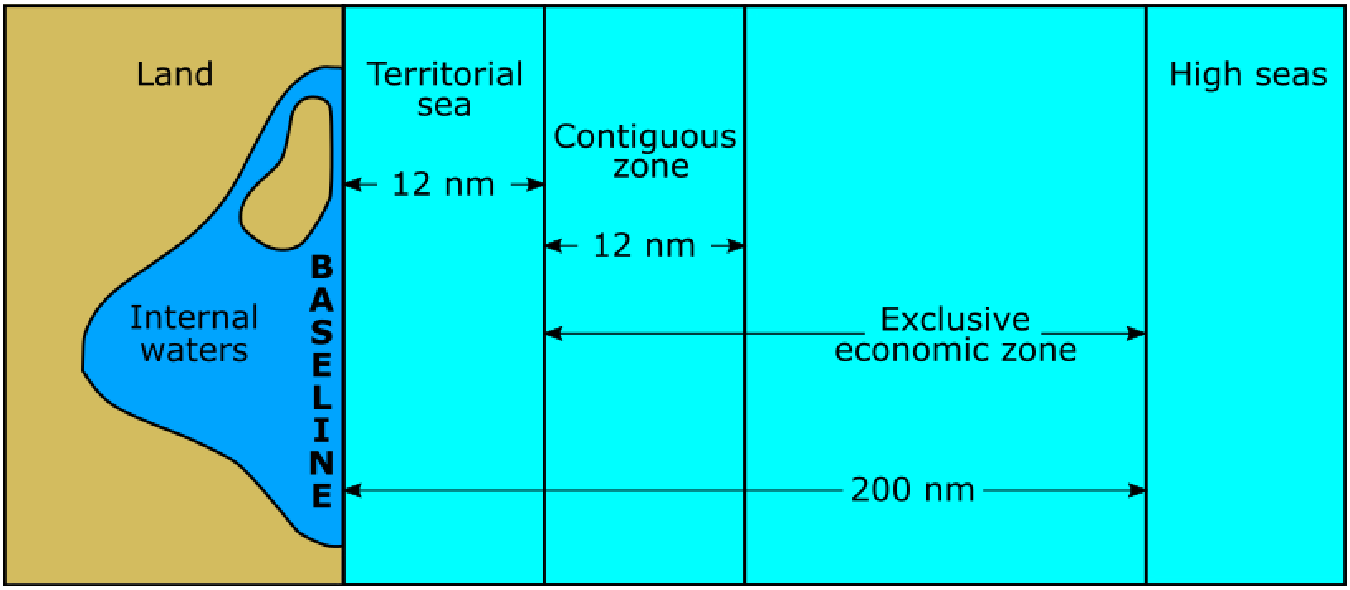


FIGURE 1. Maritime zones as defined by *UNCLOS*, Part V.

- *Arctic Waters Pollution Prevention Act (AWPPA)*[35] : The *AWPPA* addresses pollution prevention from ships in the Canadian Arctic and provides a means of legislating the *Polar Code* into Canadian law. The *AWPPA* introduces and regulates pollution through the *Arctic Shipping Safety and Pollution Prevention Regulations (ASSPPR)*[36]. Although the *AWPPA* establishes the Canadian Arctic as a "zero discharges" area, sewage discharges are permitted under the *Act*. The *AWPPA* is also silent on the subjects of greywater and scrubber washwater, though it prohibits the discharge of oil in any amount.

- *Canadian Environmental Protection Act (CEPA)*[37]: Canada meets its international commitments to the *London Convention* through the the *CEPA*. Like the *London Protocol, CEPA* prohibits ships from disposing of substances at sea but excludes those that are incidental to or derived from normal operations. Unlike the *London Protocol,* which defines these activities under the term "dumping," *CEPA* uses the term "disposal." Thus, it would appear that "dumping" is not yet defined in the Canadian maritime context.

As previously discussed, international treaty commitments introduced into Canadian law can include Canadian modifications that enhance environmental protections. One example of this is the absolute prohibition on discharging oil into Canadian Arctic waters introduced by the *AWPPA*. The *AWPPA* is a domestication of the *Polar Code,* which permits discharges with oil contents up to 5 parts per million. Thus, it stands to reason that Canada could introduce a definition of dumping in the context of MPAs that is more comprehensive than the definition provided by the London Protocol.

[35] *Arctic Waters Pollution Prevention Act,* RSC 1985, c A-12. Retrieved 29 November 2021, from https://canlii.ca/t/543b0

[36] *Arctic Shipping Safety and Pollution Prevention Regulations,* SOR/2017-286. Retrieved 29 November 2021, from https://canlii.ca/t/5333r

[37] *Ibid.*

OPERATIONAL WASTES COVERED BY THIS REPORT

This report estimates the annual production of sewage, greywater, exhaust gas cleaning system ("scrubber") washwater, and bilge water by ships operating in Canadian waters based on 2019 automatic identification system (AIS) data from exactEarth[38] and bespoke attribute data from Clarksons Research Services Ltd.[39] updated for 2021. The sub-sections below provide a description of these four waste streams.

SEWAGE

Sewage, or blackwater, contains human body wastes and wastes from other living animals, drainage from toilets and other receptacles intended to receive or retain human body wastes, drainage from medical premises such as sick bays, drainage from spaces containing living animals, and other drainage or wastes that are mixed with any of the above.[40] Sewage may contain high levels of bacteria, viruses, major and minor nutrients, and organic solids, as well as chlorine or other disinfecting agents, and trace concentrations of other substances including pharmaceutical, personal care products, and plastics.

Ships subject to Canadian jurisdiction and Canadian ships everywhere may discharge sewage either at reception facilities or at sea, provided it is done in accordance with the regulatory requirements set out in the *VPDCR* and the *ASSPPR* (applicable to ships above 60°N). Whether a vessel is required to treat its sewage prior to disposal at sea depends on the passenger capacity and gross tonnage (GT) of the vessel in question as well as how far the vessel is from shore and whether it is in the Arctic, inland waters, or other areas with special restrictions.

Large vessels (400 GT and above, or certified to carry more than 15 passengers), which are the primary focus of this study, are subject to Canada's strictest regulations. Those not operating in inland waters, designated sewage areas, the Banc-des-Américains MPA, or the Arctic may discharge sewage provided it is first passed through an approved sewage treatment plant (STP). Vessels using a comminuting and disinfecting system (CDS) in lieu of an STP may discharge sewage provided the deposit is made at least three nautical miles from shore. Comminuting and disinfecting is a process that involves maceration of solids and the application of a disinfecting agent (typically chlorine) but is generally considered to be inferior to treatment with an STP. Outside the Arctic, ships are not required to treat their sewage if they dispose of it beyond 12 nautical miles from shore. In the Arctic, large vessels are generally required to treat their sewage, although there are exceptions. Ships discharging either untreated or comminuted and disinfected sewage into Arctic waters must also take distance from sea ice features including ice-shelves, fast ice, and areas of ice concentration exceeding 10 per cent into consideration.

[38] https://www.exactearth.com/

[39] https://www.clarksons.com/services/research/

[40] *Vessel Pollution and Dangerous Chemical Regulations,* SOR/2012-69, s 1(1).

Recently, the effectiveness of STP has been put into question by state-sponsored studies submitted to the IMO by the Netherlands, China, and Iran. These studies were conducted independently of one another, and each concludes that STP are characterized by failure to treat sewage to minimum requirements.[41,42,43]

- The Netherlands study found that of 127 samples, 97 per cent failed to meet all minimum requirements.
- The Chinese study found that of 183 samples, 81 per cent failed to meet all minimum requirements.
- The Iranian study found that of 50 samples, 96 per cent failed to meet all minimum requirements.

The high failure rate of STP is largely attributable to a regulatory gap in *MARPOL* Annex IV (the sewage annex), which fails to require STP to undergo performance testing to ensure system lifetime functionality. IMO has since established a correspondence group to begin work on draft amendments to Annex IV to address this pressing issue, but it remains unclear which amendments will be adopted, whether the amendments will succeed in addressing this issue, and when they will finally be implemented.

The widespread failure of STP to effectively treat sewage and the lack of a requirement for ships to treat sewage before discharging it outside the limits of the territorial sea (except for some ships in the Arctic) suggests that much of the sewage discharged into Canada's ocean is either untreated or undertreated. In principle, this means that MPAs and OECMs existing wholly or partially beyond 12 nautical miles from shore have no baseline protections from sewage discharges, and those existing within 12 nautical miles of shore are not well protected.

AWTS are a more effective alternative to STP and are required for cruise ships operating in Alaska. However, Canada does not mandate the use of AWTS in any of its waters. While the authors support the use of AWTS, it is noted that not all existing ships can be retrofitted with AWTS and the cost may be prohibitive for some. Thus, the most practicable option for protecting MPAs and OECMs from the deleterious effects of sewage pollution is to prohibit the discharge of both treated and untreated sewage within their bounds.

[41] IMO MEPC 71. (2017). "MEPC 71/Inf.22." *Updated information and analysis based on tests on the effluent of sewage treatment plants.*

[42] IMO PPR 7. (2020). "PPR 7/16/1." *Considerations on record-keeping and onboard test in surveys to mitigate the environmental impact of sewage discharging.*

[43] IMO PPR 8. (2021). "PPR 8/7/4." *Laboratory analysis on effluent of sewage treatment plant.*

GREYWATER

Greywater is a mixture originating as drainage from sinks, galleys, laundry facilities, baths, and showers, and dishwashers.[44] Greywater originating from cruise ships may also contain pool and spa water. It does not include sewage, though it is commonly mixed with sewage for storage and/or treatment purposes as well as food wastes mixed in from galley operations. Like sewage, greywater may contain high levels of bacteria, viruses, nutrients, and organic solids, as well as cleaning agents and personal care products. In addition, greywater may also contain plastics (e.g., microplastics from laundry facilities, microbeads from personal care products, plastic bags, and packaging originating from galley drainage), pesticides used on board for rodent or insect control, volatile organic compounds originating from the use of solvents, chlorination by-products (e.g., chloroform, bromoform), refrigerants and fire extinguishers (e.g., carbon tetrachloride), glues (e.g., toluene), dry cleaning products (e.g., tetrachloroethylene), those that have formed as the by-product of chlorination (e.g., bromoform, chloroform) or as metabolic products in human waste (e.g., acetone), and semi-volatile organic compounds originating from some health care products (e.g., benzyl alcohol), substances found in plastics (e.g., phthalates), and in paint removers (e.g., phenols).[45] In addition, greywater generally contains trace concentrations of heavy metals (e.g., arsenic, chromium, copper, lead, zinc).[46]

Untreated greywater can be as environmentally damaging as raw domestic sewage.[47] Yet unlike sewage, greywater is not regulated internationally. Canada regulates greywater but not to the same extent that it regulates sewage. Ships subject to Canadian jurisdiction operating outside the Arctic are permitted to discharge greywater into the sea provided it is passed through an STP or is discharged at least 3 nautical miles from shore. As mentioned in the previous section, STP are characterized by high failure rates. Additionally, STP are not specifically designed to handle greywater, which contains a myriad of substances not typically found in sewage. As a result, the effectiveness of the greywater treatment in Canada is suspect.

With regard to the Arctic, the *ASSPPR* are silent about greywater (as is the *Polar Code*). As a result, there is no regulatory guidance on when, where, or how vessels should treat and dispose of greywater when operating above 60°N. Although some ships may have the ability to retain greywater and dispose of it at shore reception facilities, the absence of significant port infrastructure in the Canadian Arctic suggests that most of the greywater produced in Canadian waters above 60°N is dumped into the sea.

[44] *Vessel Pollution and Dangerous Chemical Regulations,* SOR/2012-69, s 131.1(1).

[45] White, E. (2021, March). *Grey Water from Passenger Vessels in Alaska 2000–2019.* https://oceanconservancy.org/wp-content/uploads/2021/03/Grey-water-from-passenger-vessels-in-AK.pdf

[46] *Ibid.*

[47] U.S. Environmental Protection Agency. (2011, November). Graywater discharges from vessels. https://www3.epa.gov/npdes/pubs/vgp_graywater.pdf

BILGE WATER

The bilge is the lowest compartment on a ship. Bilge water is a term used to describe the liquid that collects in this area. Bilge water is generally foul and noxious. It can contain oil, surfactants, seawater, coolants, lubricants from machinery spaces, and drainage from boilers, air conditioners, sludge tanks, and other sources. Bilge water is collected in a holding tank and generally requires treatment through an oil-water separator to meet regulatory standards for discharge into the environment.

Bilge water discharge restrictions centre around oil content. Bilge water can be discharged into the sea provided it does not originate from cargo spaces and the discharge is processed through oil filtering equipment that produces an undiluted effluent with oil content of no more than 15 parts per million. Equipment must include an alarm and discharge-stopping device as soon as the oil content exceeds 15 parts per million. For ships operating in inland waters, the oil concentration limit is reduced to 5 parts per million. Some vessels may adhere to the 5 parts per million oil limit at all times, either for voluntary reasons or due to court orders. The *ASSPPR* provide that the discharge of oil in any quantity into the Arctic marine environment is prohibited, thus it appears that ships are not permitted to discharge bilge water in the Canadian Arctic. Despite this prohibition, ships cannot stop producing bilge water irrespective of their location. Since the Canadian Arctic generally lacks significant port infrastructure capable of receiving large volumes of waste, it is probable that many ships retain bilge water until calling at a port outside the Canadian Arctic, or, alternatively, they may opt to discharge retained bilge water into the sea shortly after travelling below 60°N.

SCRUBBER WASHWATER

Exhaust gas cleaning system (“scrubber”) effluent, also known as “washwater,” is a waste by-product of scrubbers. Scrubbers are designed to reduce the sulfur dioxide content of engine and boiler exhaust prior to stack emission. They have been developed for use on ships to enable continued use of heavy fuel oil (HFO), the most polluting type of marine fuel. HFO is a residual fuel, a tar-like by-product of the crude oil distillation process. HFO replaced coal as the predominant ship fuel in the mid-20th century and has remained popular due to its relatively low cost. Burning HFO produces harmful emissions and has been linked to negative health outcomes in people as well as to negative environmental outcomes such as acid rain.[48] HFO also represents a severe environmental threat when it is spilled and is particularly challenging to clean up.

Scrubbers are permitted by *MARPOL* Annex VI, the key piece of international legislation on air pollution from ships. Since coming into force, Annex VI has progressively reduced the allowable sulfur content of marine fuels—from 4.5 per cent prior to 2012 to 0.5 per cent as of January 1, 2020.[49] In special emission control areas, the sulfur content limit for fuels is 0.1 per cent. To comply with *MARPOL* Annex VI, ships can either use low sulfur marine fuels that meet IMO sulfur standards or

[48] IMO 2020 – cutting sulphur oxide emissions. (n.d.). International Maritime Organization. Retrieved November 2021, from https://www.imo.org/en/MediaCentre/HotTopics/Pages/Sulphur-2020.aspx

[49] IMO 2020 – cleaner shipping for cleaner air. (n.d.). International Maritime Organization. Retrieved November 2021, from https://www.imo.org/en/MediaCentre/PressBriefings/Pages/34-IMO-2020-sulphur-limit-.aspx

they can be fitted with scrubbers that enable them to produce stack emissions that are, in principle, equivalent to those that would be produced by using a low sulfur fuel.[50]

Scrubbers function by introducing exhaust gases to a heavy spray of alkaline washwater (typically seawater) inside a large metal silo. During this process, contaminants—including sulfur and nitrogen oxides, heavy metals, and polycyclic aromatic hydrocarbons (PAHs)—are captured from the exhaust and are retained in the washwater. The resulting washwater, which is toxic, hot, and acidic, is then discharged into the ocean often with little to no filtration.

There are three main types of scrubbers: open-loop systems, closed-loop systems, and hybrid systems. Open-loop systems account for more than 80 per cent of all installations.[51] These systems use seawater, which is continuously drawn in and then discharged in a highly contaminated and acidic state. Closed-loop systems account for less than 3 per cent of all scrubber installations.[52] These systems use freshwater treated with alkaline chemicals, which is recirculated within the system while a small volume of bleed-off water is periodically discharged into the sea. Although bleed-off from closed-loop scrubbers is less produced in smaller volumes than the washwater from open-loop scrubbers, the concentration of PAHs and metals in bleed-off can be substantially greater. Unlike most open-loop systems, closed-loop systems retain sludge from the scrubbing process that must be disposed of at shore reception facilities. Hybrid systems, accounting for about 17 per cent of scrubbers installed on ships, can function in either open-loop or closed-loop mode.

In Canada, the *VPDCR* require that washwater discharge meets the requirements of section 10 of IMO's 2009 Guidelines for Exhaust Gas Cleaning Systems.[53] Under the Guidelines, washwater must comply with limits for pH, PAH concentration, nitrates, turbidity, metals concentration, and temperature. However, these standards do not effectively eliminate the potential for washwater to degrade the aquatic environment. For example, the Guidelines stipulate that the pH of washwater should be no less than 6.5 at a distance of 4 metres from the point of discharge. To achieve this standard, it is possible for washwater to be discharged with a pH as low as 3 and still be compliant with the requirement to achieve a pH of 6.5 at 4 metres distance. To put this in perspective, the average pH of the surface of the ocean globally is about 8.1. A pH 6.5 solution is about 40 times as acidic as surface seawater and a pH 3 solution is more than 100,000 times as acidic as surface seawater.

The IMO Guidelines also fall short in accounting for the actual PAH content of scrubber washwater. The Guidelines prescribe the use of the phenanthrene equivalent for onboard PAH monitoring and measurement of the U.S. Environmental Protection Agency's 16 priority PAHs when the analysis is undertaken by an accredited laboratory. The phenanthrene equivalent method measures the fluorescence of phenanthrene in a washwater sample and uses the resulting value to infer total PAH

[50] *MARPOL* Annex VI.

[51] Clarksons World Fleet Register. https://www.clarksons.net/wfr/#!/login/?returnPath=fleet

[52] *Ibid.*

[53] IMO MEPC 59. (2009). "Resolution MEPC.184(59)." *2009 Guidelines for exhaust gas cleaning systems.*

concentration by way of correlation to a prescribed standard. However, neither approach accounts for alkylated PAHs, which make up the greater part of PAHs in scrubber washwater. Many high molecular weight PAHs are also overlooked. As a result, the PAH content of scrubber washwater may be more than two times greater than is measured.[54] In turn, this means that washwater discharges may regularly exceed the 50 microgram per litre discharge criteria prescribed by the Guidelines.

HEALTH AND ENVIRONMENTAL CONCERNS

Operational wastes contain a variety of substances and organisms that have the potential to harm people and marine life. The sub-sections below include a brief overview of concerns and potential impacts for wildlife and humans.

EUTROPHICATION (NUTRIENT OVERLOADING)

Nutrient availability is a primary control on marine primary productivity (i.e., phytoplankton growth). Phytoplankton are a diverse class of microscopic organisms including diatoms, dinoflagellates, coccolithophores, green algae, and cyanobacteria that inhabit the upper layer of the ocean where sunlight is most abundant. Just like plants on land, phytoplankton use sunlight to convert carbon dioxide and water into glucose and oxygen. In a healthy marine ecosystem, phytoplankton form the base of the marine food web and are consumed by a wide diversity of marine life. On geologic timescales, they also play an important role in sequestering carbon in marine sediments.

In a balanced ecosystem, phytoplankton growth is kept in check by the availability of nutrients, namely nitrogen, phosphorus, and silicon. Under natural conditions, these nutrients are usually almost totally depleted in surface waters due to high biological demand. They are incrementally refreshed through the natural processes of ocean upwelling, weathering, and erosion, and complex biogeochemical cycling.

Ships' discharges that are high in nutrients, including sewage, greywater, and scrubber washwater, can result in a nutrient overload at the surface of the ocean where phytoplankton are most abundant. Since nutrients are often the limiting factor on phytoplankton population growth, this can result in an explosion of phytoplankton growth, also known as a bloom. Coastal areas can be especially susceptible to algal blooms since nutrient levels are often already elevated due to agricultural runoff and municipal sewage drainage.

Out-of-control algal blooms can be deadly.[55] Some phytoplankton, such as those responsible for red tide, produce powerful biotoxins that can kill wildlife, domesticated animals, including pets, and people who eat contaminated seafood or are exposed to contaminated waters. In the aftermath of a bloom, dead phytoplankton sink to the ocean floor and decompose. The process of decomposition depletes oxygen in the water, suffocating wildlife and creating what are termed "dead zones."

[54] IMO MEPC 76. (2021). "MEPC 76/9/4." *Comments on phenanthrene equivalent as contained in the draft 2020 guidelines for exhaust gas cleaning systems.*

[55] For example, Zingone, A., et al. (2021). Toxic marine microalgae and noxious blooms in the Mediterranean Sea: A contribution to the Global HAB Status Report. *Toxic Marine Microalgae and Noxious Blooms in the Mediterranean Sea: A Contribution to the Global HAB Status Report, 102.* https://doi.org/10.1016/j.hal.2020.101843

Harmful algal blooms are a threat to coastal economies. Shellfish bed closures and fish kills can lead to reduced catches for commercial and recreational fisheries, resulting in smaller harvests and more expensive seafood. Closures of recreational waters can harm businesses dependent on tourism. They also threaten the wellbeing of coastal communities that engage in subsistence harvesting, including many of Canada's Indigenous communities. Knock-on effects, including the opportunity cost of poor health, should not be discounted when assessing the impacts of eutrophication by way of harmful algal blooms on people.

OCEAN ACIDIFICATION ACCELERATED BY SHIPS

The oceans are facing an acidification crisis. As ocean acidification and climate change worsen, marine ecosystems globally face an uncertain future. Overcoming these challenges will not only require significant reductions in greenhouse gas (GHG) emissions across all sectors, but the adoption of sustainable operating practices by all ocean users including eliminating polluting ship technologies, like scrubbers, and prohibiting the disposal of acidic wastes in MPAs and OECMs.

Under natural conditions the ocean functions as a carbon sink and plays a key role in the global carbon cycle by absorbing carbon dioxide from the atmosphere and sequestering it in marine sediments. Over millions of years these carbon-rich sediments are subducted under continental plates where the carbon remains until being re-emitted through volcanism.

Humans have disrupted the carbon cycle by re-introducing reservoirs of sequestered carbon back into Earth's atmosphere, primarily by burning fossil fuels. This has led the concentration of carbon dioxide in the atmosphere to rise from pre-industrial values of approximately 280 parts per million to more than 413 parts per million today.[56] The sharp rise in atmospheric carbon dioxide and other GHGs since the Industrial Revolution has given rise to the current climate crisis and has been the primary driver of recent ocean acidification.

The amount of carbon dioxide absorbed by the ocean increases as atmospheric concentrations of carbon dioxide rise. By drawing carbon dioxide from the atmosphere, the ocean has moderated the pace of climate change in the 20th and 21st centuries, but at a cost. Seawater and carbon dioxide combine to form carbonic acid, which lowers the pH of the ocean (i.e., makes the ocean more acidic). Since the Industrial Revolution, the ocean has absorbed about a third of all anthropogenic carbon dioxide emissions and ocean acidity has increased by roughly 30 per cent.

Calcifying organisms—plants and animals whose skeletons, tests, and shells are made of calcite or aragonite—are especially vulnerable to ocean acidification. Under acidifying conditions, these organisms must expend more energy to grow and maintain their skeletons. As a result, they may become more susceptible to disease and predation. Under sufficiently acidic conditions, physiological functions may be impaired to the extent that survival and reproduction are impossible. Some of

[56] National Ocean and Atmospheric Administration. (2021). Global Monitoring Laboratory – Carbon Cycle Greenhouse Gases. Global Monitoring Laboratory. Retrieved November 2021, from https://gml.noaa.gov/ccgg/trends/

the organisms most impacted by ocean acidification are habitat-forming species, including corals. In Canadian waters, cold-water corals play a critical role in providing habitats for a wide range of commercially important species. Studies also suggest that fish with otoliths (carbonate bones within their inner ears) experience decreased ability to detect noise under acidic conditions.[57]

Ships' operational wastes that are disposed of at sea accelerate ocean acidification, adding additional pressure on ecosystems that are already under stress. The effects are felt most acutely in waters with naturally low alkalinity, including most coastal environments as well as the Arctic. Decomposition of organic wastes, like sewage, releases large amounts of carbon dioxide, which combines with seawater to form carbonic acid. This lowers the pH of the seawater (i.e., increases acidity), contributing to ocean acidification. However, in terms of operational wastes, the most egregious offender in terms of acidification potential is scrubber washwater.

Scrubber washwater is highly acidic and accelerates ocean acidification. As mentioned, most scrubbers are open-loop systems (or hybrid systems operated in open-loop mode). These scrubber systems continually draw in seawater and discharge it in a highly acidic state. This occurs as the sulfur, nitrogen, and carbon in the ship's exhaust gas combines with seawater to form strong acids. At the point of discharge, scrubber washwater is commonly 10,000 times more acidic than the surface of the ocean, though in some instances it may be more than 100,000 times more acidic.[58,59,60] This is compounded by the large volumes of scrubber washwater that ships generate. Recent research on the impacts of scrubber-induced ocean acidification indicates that in areas of intense maritime traffic where scrubber water discharge is permitted, annual scrubber-related ocean acidification could

[57] Radford, C. A., Collins, S. P., Munday, P. L., & Parsons, D. (2021). Ocean acidification effects on fish hearing. *Proceedings of the Royal Society B: Biological Sciences, 288*(1946), 20202754. https://doi.org/10.1098/rspb.2020.2754

[58] The power of hydrogen, abbreviated as "pH," is a measure of the relative amount of free hydrogen ions H+ in a solution measured in moles per litre. The pH scale goes from 0 (most acidic) to 14 (most basic). The scale is logarithmic, and each integer represents a 10-fold change in the acidity/basicness of the solution. H+ in mol/L-1 can be calculated using the formula: H+ = 10-pH. The difference between two solutions can be calculated by dividing the H+ of Solution 'A' by the H+ of Solution 'B'.

[59] The surface of the ocean is usually slightly basic, with an average pH of 8.1. (e.g., National Ocean and Atmospheric Administration. (2020, April). *Ocean acidification.* NOAA. Retrieved September 2021, from https://www.noaa.gov/education/resource-collections/ocean-coasts/ocean-acidification)

[60] To comply with IMO guidelines the scrubber washwater plume should be at minimum pH 6.5 at 4 metres from the point of discharge. A pH of 4 at the point of discharge generally corresponds to this value [e.g., Faber, J. (2019, December). *The impacts of EGCS washwater discharges on port water and sediment.* https://cedelft.eu/wp-content/uploads/sites/2/2021/03/CE_Delft_4I091_The_impacts_of_EGCS_washwater_discharges_Def.pdf], though washwater may often be as acidic as pH 3 [e.g., U.S. Environmental Protection Agency. (2011a, November). *Exhaust Gas Scrubber Washwater Effluent* (EPA-800-R-11-006). https://www3.epa.gov/npdes/pubs/vgp_exhaust_gas_scrubber.pdf].

be similar to that induced by carbon dioxide over several years to decades.[61,62,63] This is particularly relevant in semi-enclosed and enclosed seas where hydrodynamic exchange is low.

SCRUBBER-RELATED CLIMATE IMPACTS

Operating a scrubber increases the power demand of a ship, resulting in a 2–3 per cent fuel use increase.[64] As a result, the GHG emissions of a ship using HFO and a scrubber to comply with IMO's global sulfur cap is greater than that of a comparable ship using a low sulfur fuel without a scrubber. Additionally, recent research suggests that ships using IMO-compliant low-sulfur fuels such as marine gasoil produce an average of 40 per cent less particulate matter by mass than ships using HFO and scrubbers.[65] Particulate matter (e.g., black carbon), in addition to being a potential health risk, accelerates melting when it settles on snow or ice. The highly reflective surfaces of snow and ice play an important role in regulating global temperatures by reflecting incoming solar radiation (i.e., sunlight) back into space. The loss of snow and ice decreases the albedo (i.e., reflectivity) of the Earth's surface, resulting in warming temperatures. In turn, warming temperatures may cause more melting and further decreases in albedo. Thus, the use of scrubbers in the Arctic is particularly concerning.

Further, in addition to exacerbating ocean acidification through the deposition of large volumes of highly acidic washwater, increasing ship GHG emissions, and increasing the likelihood of catastrophic oil spills from ships using HFO as fuel, scrubbers directly reduce the capacity of the ocean to act as a carbon sink. Acidification by sulfur oxide reduces uptake of carbon dioxide by the ocean. It has been estimated that for each tonne of sulfur dioxide discharged by scrubber water, the ocean uptake of atmospheric carbon dioxide is reduced by half a tonne, thereby reducing the ability of the ocean to contribute to offsetting global climate change.[66]

[61] Dulière, V., Baetens, K., & Lacroix, G. (2020). Potential impact of wash water effluents from scrubbers on water acidification in the southern North Sea [Final project report]. Royal Belgian Institute of Natural Sciences. Operational Directorate Natural Environment, Ecosystem Modelling. https://doi.org/10.13140/RG.2.2.21935.76968

[62] Stips, A., Bolding, K., Macias, D., Bruggeman, J., & Coughlan, C. (2016). Scoping report on the potential impact of on-board desulphurisation on the water quality in SOx Emission Control Areas. Luxembourg: Publications Office of the EU.

[63] For a review of scrubber impacts, refer to: Hassellöv, I.M., Koski, M., Broeg, K., et al. 2020. ICES Viewpoint background document: Impact from exhaust gas cleaning systems (scrubbers) on the marine environment (Ad hoc). ICES Scientific Reports. 2:86. 40 pp. http://doi.org/10.17895/ices.pub.7487

[64] CE Delft. Scrubbers – An Economic and Ecological Assessment. (2015). Retrieved 9 September 2020 from https://www.cedelft.eu/en/publications/1618/scrubbers-an-economic-and-ecological-assessment

[65] Winnes, H., Fridell, E., & Moldanová, J. (2020). Effects of Marine Exhaust Gas Scrubbers on Gas and Particle Emissions. *Journal of Marine Science and Engineering, 8*(4), 299. https://doi.org/10.3390/jmse8040299

[66] Stips, A., Bolding, K., Macias, D., Bruggeman, J., & Coughlan, C. (2016). Scoping report on the potential impact of on-board desulphurisation on the water quality in SOx Emission Control Areas. Luxembourg: Publications Office of the EU.

OIL, METALS, AND POLYCYCLIC AROMATIC HYRDOCARBONS

The enduring image of oil pollution is a catastrophic spill event resulting in wildlife oiling, acute toxicity, and protracted coastal cleanups. Indeed, oil spills represent a serious threat to marine ecosystems and the wildlife and people whose wellbeing depends on healthy oceans. Oil spills from ships will remain a risk until ships no longer use or transport liquid hydrocarbon fuels. Until this time comes, ships can mitigate risk by transitioning away from the use and carriage of residual fuels (i.e., HFO) that are exceptionally harmful and challenging to clean up when spilled. Unfortunately, the use of HFO has been extended by the trend of ship owners installing scrubbers to comply with IMO's global sulfur cap rather than using less polluting fuels. Rapidly phasing out the use of scrubbers as a means of compliance would reduce the risk associated with marine fuel spills and would have the added benefit of curtailing harmful scrubber washwater discharges.

Oil spills, however, are not the only source of marine oil pollution. Operational wastes containing small quantities of oil and other polluting substances associated with marine fuels and machine lubricants are routinely discharged into the ocean, including in federal MPAs and OECMs. Marine fuels and machine lubricants contain a variety of harmful substances including PAHs and metal impurities. Scrubber washwater and bilge water are notable sources of PAHs and heavy metals. This danger is highlighted in IMO document MEPC 76/9/1, submitted by the International Council for the Exploration of the Sea (ICES), which states "scrubbers discharge large amounts of metals and PAHs in dissolved, readily bioavailable form. These contaminants may concentrate at ultra-trace levels in the water column and bioaccumulate in plankton, fish and marine mammals, to levels that may impair vital functions and population productivity. Concentrations of these types of contaminants may be hundreds to million times higher in plankton than in the surrounding seawater."[67] Greywater is also a source of potentially harmful dissolved metals. Once released into the environment, metals and PAHs pose a health risk to marine wildlife and human consumers of seafood. Additionally, the bioavailability (i.e., the rate and extent to which a substance is absorbed) of oil and its associated pollutants can be enhanced in the presence of other substances, including surfactants that are commonly discharged in bilge water and greywater.[68]

PAHs are a large class of chemicals characterized by aromatic rings of carbon and hydrogen. They occur naturally in petroleum products and are also formed as by-products of combustion. There are hundreds of parent PAHs and alkyl-derivatives, many of which are known or suspected to have toxic, carcinogenic, and/or mutagenic effects.[69] They are easily adsorbed to particulate organic matter

[67] IMO MEPC 71. (2020). "MEPC 76/1." *Risks to the marine environment posed by scrubber water discharge and recommendations to reduce impacts.*

[68] Tiselius, P., & Magnusson, K. (2017). Toxicity of treated bilge water: The need for revised regulatory control. *Marine Pollution Bulletin, 114*(2), 860–866. https://doi.org/10.1016/j.marpolbul.2016.11.010

[69] Abdel-Shafy, H.I., & Mansour, M.S. (2016). A review on polycyclic aromatic hydrocarbons: Source, environmental impact, effect on human health and remediation. *Egyptian Journal of Petroleum, 25*(1), 107–123. https://doi.org/10.1016/j.ejpe.2015.03.011

as well as anthropogenic particles (e.g., microplastics), and are resistant to degradation. Marine sediments can become enriched with PAHs, putting benthic wildlife at increased risk of exposure. Known consequences of PAHs on benthic and pelagic wildlife include chromosomal mutations in aquatic invertebrates,[70] defects in sea urchin eggs,[71] fish embryo deformities,[72] and carcinogenic effects in flatfish[73] and cetaceans.[74]

Metals, like PAHs, are a diverse group of pollutants. Many metals are toxic to marine wildlife and humans. While some metals, including iron, magnesium, and zinc are essential to vital functions, many others, including mercury, arsenic, and lead, are non-essential and only have adverse effects. Adverse impacts can include impaired organ and reproductive functions, neurodegenerative diseases, genetic defects, and death. Even essential metals can have toxic or sub-lethal effects in sufficiently elevated concentrations. Since metals are not biodegradable, they persist in the environment—in water, sediments, and on the surface of particulate matter—where they can be taken up by plants and animals. Metals that have become sequestered in marine sediments can be remobilized by seafloor disturbances and pH changes. Once consumed by marine life, metals can accumulate and become increasingly concentrated as they pass along the food web in a process known as biomagnification. Predators with long lives, including large fish, marine mammals, and human consumers of seafood, are particularly at risk of accumulating toxic levels of metals. Because of the dangers of toxic metal build-up through the processes of bioaccumulation and biomagnification, disposal of waste containing particulate or dissolved metals, even in low concentrations, should be avoided whenever possible.

PLASTICS

Plastic pollution has been identified as a contaminant of emerging concern by the United Nations Environment Program, and specifically of concern to Arctic ecosystems by the Arctic Council's Arctic Monitoring and Assessment Programme. Marine plastics originate from a variety of sources, including ships, and are found in the sediment and water of every ocean on Earth. Greywater originating from personal quarters, galleys, and laundry facilities contains microplastics and fibres, and occasionally contains larger plastics including food packaging and bags. Since most plastics are not neutrally buoyant, most marine plastics collect either near the surface of the ocean or at the bottom. They are

[70] Government of Canada, Environment Canada, & Health Canada. (1994). *Priority substances list assessment report: polycyclic aromatic hydrocarbons.* https://www.canada.ca/content/dam/hc-sc/migration/hc-sc/ewh-semt/alt_formats/hecs-sesc/pdf/pubs/contaminants/psl1-lsp1/hydrocarb_aromat_polycycl/hydrocarbons-hydrocarbures-eng.pdf

[71] *Ibid.*

[72] Black, J., Birge, W., Westerman, A., et al. (1983). Comparative aquatic toxicology of aromatic hydrocarbons. *Fundamental and Applied Toxicology, 3*(5), 353–358. https://doi.org/10.1016/s0272-0590(83)80004-9

[73] Stein, J., Reichert, W., Nishimoto, M., et al. (1990). Overview of studies on liver carcinogenesis in English sole from Puget Sound; evidence for a xenobiotic chemical etiology II: Biochemical studies. *Science of The Total Environment, 94*(1–2), 51–69. https://doi.org/10.1016/0048-9697(90)90364-z

[74] Martineau, D., Lemberger, K., Dallaire, A., et al. (2002). Cancer in wildlife, a case study: beluga from the St. Lawrence estuary, Québec, Canada. *Environmental Health Perspectives, 110*(3), 285–292. https://doi.org/10.1289/ehp.02110285

ingested by marine wildlife across all trophic levels including zooplankton, bivalves, fish, seabirds, and marine mammals. Ingestion can occur through direct consumption or by being passed from prey to predators. Even in the Canadian Arctic, which has a relatively small industry footprint, wildlife is at risk of ingesting plastics. In 2019, a study of seven belugas in the western Canadian Arctic found microplastics in the gastrointestinal tracts of every whale.[75] In a separate 2019 study, researchers studying microplastics in the eastern Canadian Arctic found that 90 per cent of surface water and zooplankton samples, and 85 per cent of sediment samples, contained microplastics or other anthropogenic particles.[76]

Plastic ingestion represents a potential physical threat as well as a chemical one. Plastics can cause choking, internal punctures, and gastrointestinal blockages. There is also growing concern over the potential impacts of plastic-associated and plastic-derived contaminants. Plastics attract persistent contaminants present in the water including heavy metals, PCBs, PAHs, and pesticides such as DDT and HCB. Plastics are so successful at attracting certain polluting substances that the concentrations found stuck to plastics can be orders of magnitude greater than in surrounding waters. Wildlife and people who consume food sources contaminated with plastics risk exposure to these substances.

BACTERIA AND VIRUSES

Greywater and sewage from ships are a source of bacteria and viruses. Transmission occurs primarily through ingestion of contaminated water and consumption of contaminated seafood. Fecal bacteria in marine environments bind to particle surfaces; in estuarine environments, the concentration of fecal bacteria is often at least one order of magnitude higher in surface sediments than in the water column.[77] As a result, bivalves and other shellfish can be a point of exposure for human consumers. Bacterial pathogens in the marine environment are responsible for a wide range of acute and chronic diseases in humans. These include diarrhea and gastroenteritis, ocular and respiratory infections, hepatitis, and wound infections. Viruses in coastal and estuarine systems that pose serious threats to human health include enteroviruses, adenoviruses, astroviruses, rotaviruses, and the *Caliciviridae* genus, which includes norovirus and calicivirus.[78]

[75] Moore, R., Loseto, L., Noel, M., Etemadifar, A., Brewster, J., MacPhee, S., Bendell, L., & Ross, P. (2020). Microplastics in beluga whales (Delphinapterus leucas) from the Eastern Beaufort Sea. *Marine Pollution Bulletin, 150,* 110723. https://doi.org/10.1016/j.marpolbul.2019.110723

[76] Huntington, A., Corcoran, P.L., Jantunen, L., Thaysen, C., Bernstein, S., Stern, G.A., & Rochman, C.M. (2020). A first assessment of microplastics and other anthropogenic particles in Hudson Bay and the surrounding eastern Canadian Arctic waters of Nunavut. *FACETS, 5*(1), 432–454. https://doi.org/10.1139/facets-2019-0042

[77] Rothenheber, D., & Jones, S. (2018). Enterococcal Concentrations in a Coastal Ecosystem Are a Function of Fecal Source Input, Environmental Conditions, and Environmental Sources. *Applied and Environmental Microbiology, 84*(17). https://doi.org/10.1128/aem.01038-18

[78] Griffin, D.W., Donaldson, K.A., Paul, J.H., & Rose, J.B. (2003). Pathogenic Human Viruses in Coastal Waters. Clinical Microbiology Reviews, 16(1), 129–143. https://doi.org/10.1128/cmr.16.1.129-143.2003

METHODOLOGY

METHODS SUMMARY

This analysis estimates operational waste production by ships within Canadian MPAs and OECMs to assess the potential impact on marine ecosystems. Total greywater, sewage, bilge water and scrubber washwater generated within Canadian waters (up to 200 nm from the coast) was calculated using 2019 AIS data from exactEarth and a bespoke ship attribute dataset provided by Clarksons. Ship traffic from 2019 was used as a pre-COVID-19 baseline. The results were overlaid with MPAs, OECMs, and bioregions identified by Fisheries and Oceans Canada.[79] This section provides a detailed explanation of the methodology used in this study.

Two main datasets were used in this study: (1) AIS data from exactEarth, and (2) a bespoke ship attribute dataset from Clarksons Research.[80] The AIS data provides ship location for each Coordinated Universal Time (UTC) timestamp, along with attributes of individual ships including the unique maritime mobile service identity numbers of their AIS transponders (MMSI), identification numbers issued by the IMO (IMO number), speed over ground (knots) and ship length (m). AIS ship tracks were rerouted to account for travel around land and recalculate vessel speed. The Clarksons bespoke dataset includes ship attributes used to estimate wastewater generation, including vessel type, ship capacity, age, length between perpendiculars (m), length overall, scrubber type, scrubber installation date, operational speed (knots), last drydock date, maximum speed (knots), main engine power (kW), etc. The IMO number of each ship was used to match AIS positional data with ship characteristics in the Clarksons dataset.

[79] Fisheries and Oceans Canada. (2019). *Federal Marine Bioregions* [Dataset]. https://open.canada.ca/data/en/dataset/23eb8b56-dac8-4efc-be7c-b8fa11ba62e9

[80] Clarksons Research Services Ltd. (2021). Clarksons Bespoke Dataset [Dataset].

DATA PROCESSING WORKFLOW

This section provides an overview of the general workflow of data processing. Data manipulation was carried out primarily using python 3.7's pygeos, pandas, and numpy packages. ArcGIS Pro and SAGA GIS were also used for manual data processing and visualization.

- Raw AIS data contained in .csv files were grouped into feather files based on ship MMSI numbers and sorted by date
- Data was resampled to a two-minute temporal interval
- Consecutive stationary AIS points were identified and removed for each ship
- AIS points intersecting land were snapped to the nearest acceptable location up to a maximum distance of 1 nautical mile; points beyond this distance inland were removed
- AIS points were converted to line segments (1 segment for every 2 AIS points)
- Line segments intersecting land were rerouted, with updated time and distance fields
- Line segments were densified to achieve a maximum distance of 0.0125 decimal degrees between vertices
- Line segment vertices were converted back to points and assigned attributes corresponding to the segments from which they originated
- Ship operational phase were assigned
- Ship waste calculations were applied

AIS DATA PREPROCESSING

AIS data were provided by exactEarth[81] for all ships that travelled within the Canadian waters in 2019 (Figure 2). At the highest temporal resolution, the raw data were collected every second for 18,852 individual ships. Approximately 6,000 ships that have associated IMO numbers are included in this study. Each AIS point has the following relevant attributes:

- MMSI number: unique identification number for each AIS transponder
- IMO number: unique identification number for each ship
- Latitude: latitude of AIS point in decimal degrees (dd), at 0.00001 dd resolution
- Longitude: longitude of AIS point in decimal degrees (dd), at 0.00001 dd resolution
- SOG: speed over ground in knots, at 0.1 knot resolution
- Time: UTC timestamp of each AIS point (yyyy-mm-dd hh:mm:ss)
- LOA: overall length of vessel in metres (m)

[81] exactEarth Ltd. (2019). *Enhanced Maritime AIS data* [Dataset].

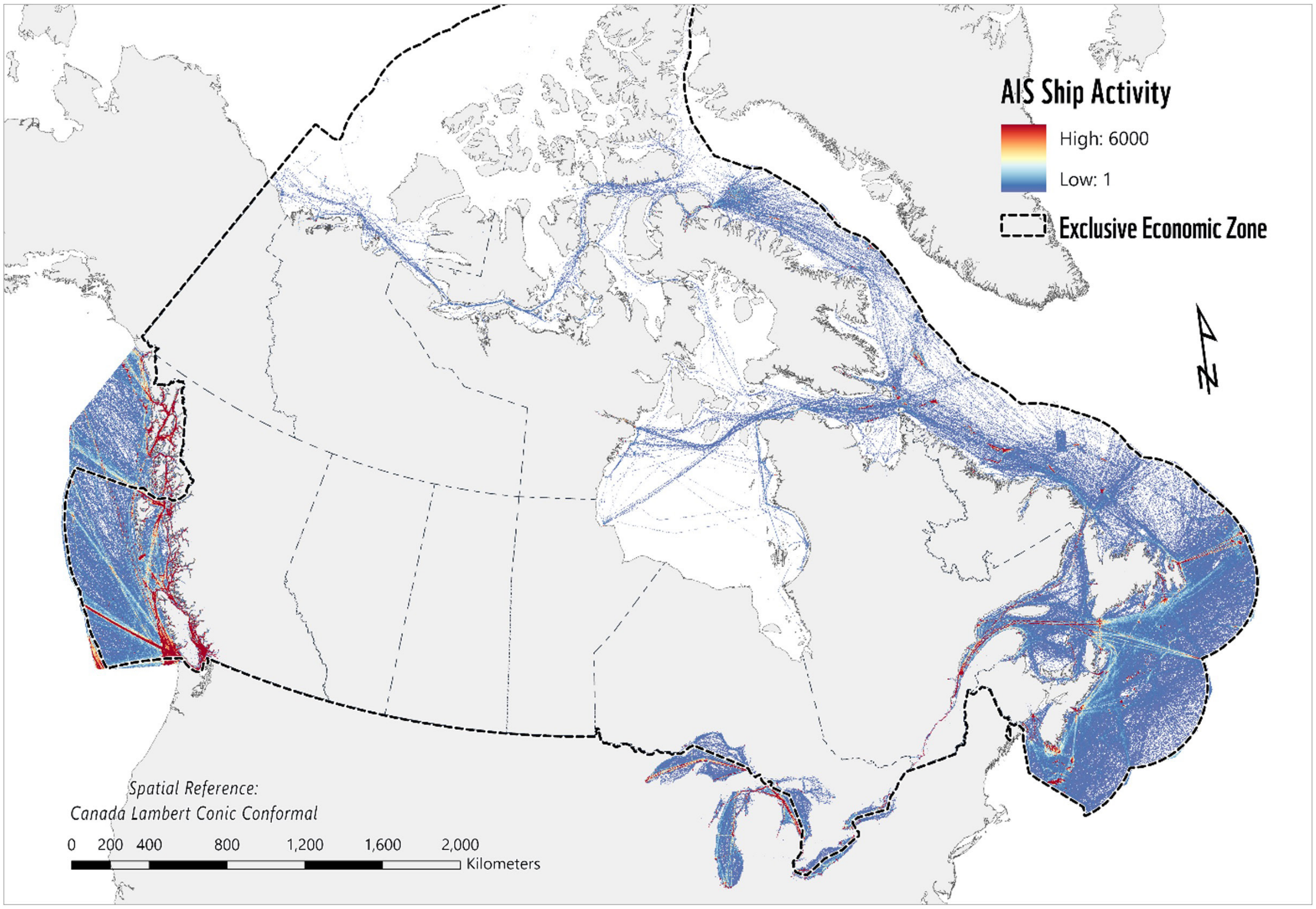


FIGURE 2. Ship activity in Canadian waters represented by the frequency of AIS points per 45 arcsecond grid cell. AIS data provided by exactEarth for the year 2019.

REFORMATTING DATASET

Raw data containing AIS point records was obtained from exactEarth in .csv file format. In order to streamline processing, these files were grouped by MMSI number and sorted by timestamps such that each output file only contained records for a single ship in sequential order. These regrouped files were converted to feather format to enable faster input/output of the data during processing.

DATA FILTERING

Since AIS data can be transmitted at a high frequency (i.e., every few seconds), the AIS points were sampled every 2 minutes to reduce the size of the dataset while retaining an accurate path of ship travel. AIS points beyond the limits of the Canadian EEZ and/or containing invalid coordinates were removed from the analysis, as was any inland ship traffic. To increase computational speed, redundant consecutive points (e.g., stationary or intersecting with land, not including the first and last point in that state) were also removed. Lastly, the stationary state was limited to 48 hours, after which the ship was assumed not to be in operation. Periods at which the ship travelled at a speed less than 3 knots for more than 48 hours were identified and excluded from the analysis.

RECTIFYING SHIP TRACKS

Linear interpolation of AIS data may oversimplify ship tracks, especially if there are large gaps between AIS signals; it also fails to take into consideration maneuvering around islands and coastlines. Therefore, we used a rerouting approach to estimate the path a ship has taken and its speed. For ship tracks between consecutive AIS points that cross over land, the track was rerouted using Dijkstra's algorithm weighted by haversine distance and ship traffic volume. The rerouted ship track takes the shortest path between two points on water, assuming ships can safely navigate over areas with a minimum water depth of 15 metres and favouring paths that have higher ship traffic. This approach was implemented using the Python Package NetworkX 2.6, to generate a weighted ship routing network and query the least-cost path between two AIS points.

First, a grid network containing all possible at-sea ship locations was generated for Canadian waters, with nodes regularly spaced at 45 arcseconds (Figure 3a). Using the General Bathymetric Chart of the Ocean gridded bathymetry dataset resampled to the same resolution, the network was filtered to contain only nodes with a minimum sea depth of 15 metres.[82] The nodes are connected by edges in Queen's case configuration, representing possible ship paths (Figure 3b). Ship paths crossing land were removed, except for segments that overlapped with less than 25 kilometres of the coastline to retain network connectivity. To maintain connected ship paths where water channels are narrow, segments were manually added along coasts of the Alberni-Clayoquot region and Burrard Inlet. Isolated components of the network, most of which are patches containing less than 50 nodes, were removed to ensure a valid path exists between any consecutive AIS points.

The edges were weighted by ship traffic volume with lower costs associated with areas of high ship activity from AIS signals. The edge weights were assigned from a ship traffic weighting matrix. This matrix was derived by calculating the number of AIS points recorded within each 45 arcsecond cell to a maximum of 6,000. These values were then transformed using a multi-scaled standard deviation filter to derive what is known as a multi-scale topographic position index when applied in a geomorphological context.[83] The output was then min-max normalized, multiplied by haversine distance and assigned to edges as the average of the values corresponding to the start and end node of the edge. The result of this process is weights that assign a higher cost to rerouting a ship through areas that see relatively little ship traffic relative to surrounding areas. This causes ships to be rerouted in a more realistic fashion than would be achieved by weighting on distance alone.

[82] General Bathymetric Chart of the Oceans (GEBCO) Compilation Group. (2020). *GEBCO_2020 Grid* [Dataset]. https://doi.org/10.5285/c6612cbe-50b3-0cff-e053-6c86abc09f8f

[83] Guisan, A., Weiss, S.B., & Weiss, A.D. (1999). GLM versus CCA Spatial Modeling of Plant Species Distribution. *Plant Ecology, 143*(1), 107–122. https://doi.org/10.1023/a:1009841519580

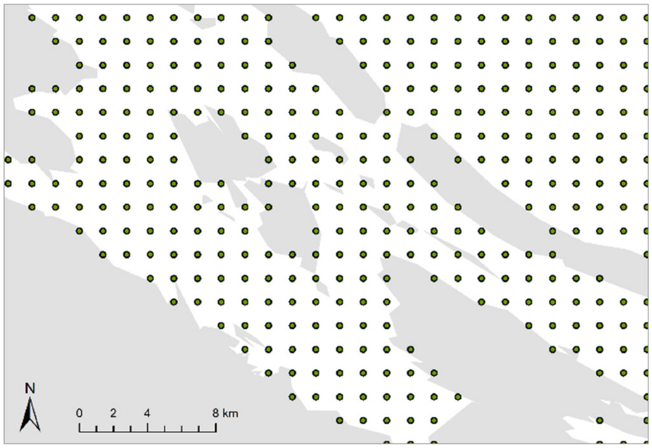


FIGURE 3a. Network of acceptable nodes.

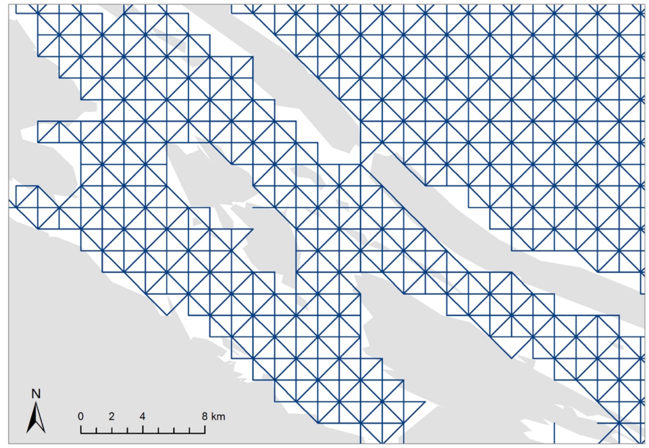


FIGURE 3b. Edges representing possible ship paths.

After generating the weighted network, each pair of consecutive AIS points was converted to a line segment with the same attributes as the starting vertex. Points with a maximum distance of 100 nautical miles (185.2 km) apart were connected to represent each individual ship track. Any AIS points that intersect with land were snapped to the nearest node in the ship routing network using the Ball Tree nearest-neighbour search algorithm, up to a maximum distance of 1 nautical mile. The haversine distance travelled was calculated for each segment from the starting to the end vertex, and speed over ground was derived using the distance travelled and elapsed time between the AIS points:

$$\Delta hd = \sum_{i=1}^{n-1} \left(2r \times \arcsin \sqrt{\sin^2\left(\frac{y_{i+1} - y_i}{2}\right) + \cos(y_i) * \cos(y_{i+1}) \times \sin^2\left(\frac{x_{i+1} - x_i}{2}\right)} \right)$$

Where:

Δhd = *total haversine distance travelled between pairs of AIS points (km)*
n = *number of vertices in ship track*
r = *radius of the earth (6,367 km)*
x_i = *longitude of the i^{th} vertex in the ship track in radians*
y_i = *latitude of the i^{th} vertex in the ship track in radians*

$$SOG = \frac{\Delta hd}{\Delta t} \times c$$

Where:

SOG = *speed over ground (knots)*
Δhd = *total haversine distance travelled between pairs of AIS points (km)*
Δt = *time elapsed between AIS points (h)*
c = *conversion factor for km/h to knots, 0.539957*

Next, ship tracks that intersected with land were identified and rerouted by finding the least-cost path between the two endpoints in the weighted network. These linear segments were replaced with the rerouted segments, and the total haversine distance and speed over ground were recalculated. Unlike linear interpolation, the rectified tracks maneuver around islands and coastlines to estimate a more realistic path for vessels (Figure 4). This prevents underestimating ship speed and wastewater production dependent on engine use. Therefore, we deem that the speed adjustment factor used to account for this estimation by Olmer et al., 2017, is not necessary for rerouted tracks.[84] The speed adjustment factor remains relevant for ship tracks that were not rerouted using this approach. All ship tracks including rerouted paths were saved as feather files for densification and further processing.

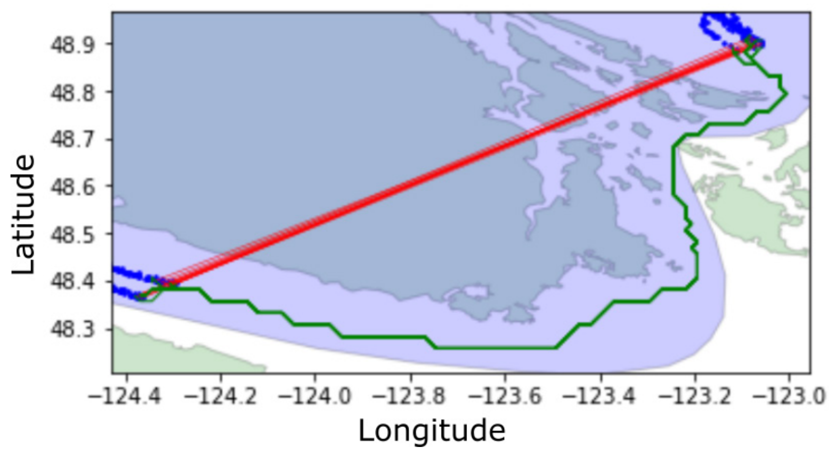


FIGURE 4. Rerouted ship track (green) and original ship track (red) between AIS points (blue) with missing data. The rerouted tracks maneuver around land, accounting for distance, ship traffic, and bathymetry to derive a realistic path.

DENSIFICATION

The spatial resolution of the AIS points is inconsistent across the study area, leading to gaps between AIS points that are larger than the desired resolution for waste production calculations. To ensure continuous coverage, the ship tracks were densified to retain at least one data point per grid cell. Additional vertices were created along the ship tracks with a maximum distance of 0.0125 decimal degrees (45 arcseconds) apart using the Geospatial Data Abstraction Library (GDAL) function 'segmentize.' The new vertices are assumed to have the same speed and non-spatial attributes as the original preceding AIS point. Distance and time elapsed for each segment were recalculated.

[84] Olmer, N., Comer, B., Roy, B., Mao, X.L., Rutherford, D. (2017). Greenhouse gas emissions from global shipping, 2013–2015: Detailed methodology. International Council on Clean Transportation.

PHASE ASSIGNMENT

While in service, ships may be in one of four operational phases: at berth, anchored, maneuvering, or cruising. The operational phase of a ship is necessary to determine auxiliary engine and boiler power demand, which are important factors in estimating scrubber wastewater generation. It will also impact the assumed number of people on board at any given time, which affects greywater and sewage water estimates. To determine the operational phase of a ship, we followed the methodology used in the ICCT report *Greenhouse Gas Emissions from Global Shipping, 2013–2015,*[85] which considers speed over ground and proximity to coast or port. The haversine distance of each AIS point to the closest port in the World Port Index[86] was calculated using the Ball Tree nearest-neighbour search algorithm. To determine whether a ship is 5 nautical miles from the coastline, a 5-nautical mile buffer was created using OpenStreetMap land polygons[87] and intersected with the AIS point. This approach was used instead of finding actual distance due to the complexity of the coastline and high computing power required to query for nearest distances. The ship phase at each AIS position was assigned according to the decision matrix in Table 1.

TABLE 1. Phase assignmet decision matrix adapted from Olmer et al.[88]

		<=1 nautical mile (nm) from port	1–5 nm from port*	<=5 nm from coast	>=5 nm from coast
Speed over ground	<1 knot	Berth	Berth	Anchor	Anchor
	1–3 knots	Anchor	Anchor	Anchor	Anchor
	3–5 knots	Maneuvering	Maneuvering	Maneuvering	Cruising
	>5 knots	Maneuvering	Cruising	Cruising	Cruising

**only applicable to chemical tankers, liquified gas tankers, oil tankers, and other liquid tankers.*

[84] Olmer, N., Comer, B., Roy, B., Mao, X.L., Rutherford, D. (2017). *Greenhouse gas emissions from global shipping, 2013–2015: Detailed methodology.* International Council on Clean Transportation.

[85] *Ibid.*

[86] United Nations Office for the Coordination of Humanitarian Affairs (OCHA). (2019). *World Port Index* [Dataset]. https://data.humdata.org/dataset/world-port-index

[87] OpenStreetMap (OSM). (2021). *Land polygons* [Dataset]. https://osmdata.openstreetmap.de/data/land-polygons.html

[88] Olmer, N., Comer, B., Roy, B., Mao, X.L., Rutherford, D. (2017). *Greenhouse gas emissions from global shipping, 2013–2015: Detailed methodology.* International Council on Clean Transportation.

SHIP ATTRIBUTE DATA PROCESSING

The bespoke dataset provided by Clarksons Research[89] contains ship-specific attributes for 6,230 ships with IMO numbers, which travelled within Canada in 2019. The attributes relevant to this analysis include:

- IMO number: unique identification number of each ship
- Vessel type: classification of ship type, listed in Appendix I
- Ship size: capacity of ship, unit of measure depending on the ship type
- Vessel age: number of years since vessel was built until 2019
- Length between perpendiculars: length between forward and aft perpendiculars measured along the summer load line (m)
- Scrubber type: type of exhaust gas cleaning system installed
- Scrubber installation date
- Operational speed: average speed at which the ship has operated within the last 12 months; considers daily average speed, excluding idle time
- Maximum velocity: speed of the ship at 100 per cent maximum continuous rating, i.e., 100 per cent engine load (knots)
- Main engine power: installed main engine power in kilowatt (kW)

RECLASSIFICATION AND MISSING DATA

The dataset contains 114 different vessel types, which were reclassified into 19 ship classes listed in Appendix I. Of 19 ship types, four ship types representing 157 ships were excluded from the analysis: miscellaneous, naval ships, offshore, and service-other. Refer to Appendix I, Table II, for a list of the ship types that were included and excluded from this analysis. A total of 78 ships were missing installed engine power, a crucial factor in wastewater generation and were also removed from the analysis. Upon matching IMO numbers of attribute data to the AIS data, ships without any recorded activity in Canadian waters were also removed. Greywater, sewage, and bilge water generation were calculated for the 5,546 ships that remained.

Of the 5,546 ships in the analysis, scrubber washwater generation was calculated for the 717 ships that have scrubbers installed or planned for installation through May 10, 2022. This represents 13 per cent of the ships included in the analysis. Although maximum vessel speed for each ship is required for calculating scrubber washwater, this attribute was missing for many ships in the bespoke dataset provided by Clarksons Research. Operational speed was used to derive the maximum velocity per ship, using a ratio that defines the relationship between the operational speed and the maximum

[89] Clarksons Research Services Ltd. (2021). *Clarksons Bespoke Dataset* [Dataset].

speed. This ratio is specific to each ship class and was calculated using known values of operational and maximum speed in the dataset (Table 2). For classes without sufficient records, the average ratio of 0.7 was used.

TABLE 2. Operational-maximum speed ratio by ship type.

SHIP CLASS	OPERATIONAL-MAXIMUM SPEED RATIO
Bulk carrier	0.73
Chemical tanker	0.77
Container	0.56
Cruise	0.49
General cargo	0.70
Liquefied gas tanker	0.70
Oil tanker	0.72
Other liquid tankers	0.70
Roll-on/roll-off cargo (ro-ro)	0.75

ESTIMATING WASTEWATER STREAMS

GREYWATER AND SEWAGE

To estimate the production of greywater and sewage for ships with IMO numbers, we followed the methodology outlined in *Greywater Generation Estimates for the BC Coast* by Vard Marine Inc.[90] The amount of wastewater produced between AIS points was calculated using the following equation:

$$GW \text{ or } SW = g \times POB \times \Delta t / 24$$

Where:

GW	=	*total greywater generation (L)*
SW	=	*total sewage generation (L)*
g	=	*wastewater generation rate (L/person/day), based on ship type*
POB	=	*assumed people on board, based on ship type and capacity*
Δ*t*	=	*time between AIS points (h)*

Wastewater generation rates are based on ship type using values published by the US Environmental Protection Agency and Parks et al., 2019. The assumed number of people on board (*POB*) is based on information provided by Clarksons Research, Jalkanen et al., 2021, and values published by Vard Marine. This information is provided in tables the 3 and 4.

TABLE 3. Wastewater generation rates (*g*).

SEWAGE	34 L/person/day for all ship types
GREYWATER	254 L/person/day for passenger ships (cruise ships, ferries, and yachts) 170 L/person/day for all other ship types

[90] Vard Marine Inc. (2019). Greywater generation estimates for the BC coast. (Report No. 381-000).

TABLE 4. Assumed people on board by ship class. Passenger ships are estimated individually based on passenger capacity and size.

SHIP CLASS	DEFAULT ASSUMED PEOPLE ON BOARD
Bulk carrier	20
Chemical tanker	15
Container	20
Cruise	Determined individually from World Fleet Register[91]
Ferry, passenger only (pax only)	50 per cent of passenger capacity
Ferry, roll-on passenger (ro-pax)	50 per cent of passenger capacity
Fishing	7
General cargo	20
Liquefied gas tanker	20
Oil tanker Other liquid tankers	15 15
Refrigerated bulk	15
Ro-ro	30
Tug/towing	6
Yacht	Estimated individually based on ship size (0.25* length overall)

For the ships missing passenger capacity information, people on board was estimated based on LOA following the approach of Jalkanen et al. (see Table 5).[92]

[91] Clarksons Research Services Ltd. (2021). *World Fleet Register* [Dataset]. https://www.clarksons.net/portal

[92] Jalkanen, J.P., et al. (2021). Modelling of discharges from Baltic Sea shipping. *Ocean Science, 17*(3), 699–728. https://doi.org/10.5194/os-17-699-2021

TABLE 5. Estimating people on board based on ship length (LOA) as done by Jalkanen et al.[93]

SHIP TYPE	PEOPLE ON BOARD (POB)
Ferry ro-pax	$0.03 \times LOA^2 + 3.7 \times LOA$
Cruise	$0.0113 \times LOA^{2.1642}$
Ferry pax only	$10.5 \times LOA$
Yacht	$0.25 \times LOA$
Ro-ro	$0.12 \times LOA$

BILGE WATER

Bilge water is calculated as a function of installed main engine power, following the methodology of Jalkanen et al.[94] Main engine power for each ship is included in the Clarksons dataset. Bilge water generation differs for passenger and non-passenger vessels (see Appendix I, Table I) and uses the following equations:

PASSENGER SHIPS:

$$BW = (0.131284\, p + 373.416) \times \Delta t / 24$$

NON-PASSENGER SHIPS:

$$BW = (0.024696\, p + 154.4874) \times \Delta t / 24$$

Where:

BW = *total bilge water generation (L)*
p = *installed main engine power, by ship (kW)*
Δt = *time between AIS points (h)*

The equations were derived by testing several correlations (vessel size, main engine size, vessel type, etc.) against anonymously reported daily volumes of bilge water. The strongest correlation was found to be with main engine power, providing a reasonable approximation of bilge water production. This simplified approach was used as bilge water volumes vary depending on onboard activities that are difficult to predict at any given time, such as cleaning of engine spaces.

93 *Ibid.*
94 *Ibid.*

SCRUBBER WASHWATER

Scrubber washwater is a function of total energy demand and discharge rate. To estimate generation of scrubber washwater for ships that have scrubbers installed or planned for installation through May 10, 2022, we used the following equation:

$$D = r \times TED \times \Delta t$$

Where:

D = *total washwater generation (t)*
r = *discharge rate (t/MWh)*
TED = *total energy demand per ship (MW)*
Δt = *time between AIS points (h)*

DETERMINING DISCHARGE RATE (r)

Washwater discharge rate depends on scrubber type (see Table 6). The type of scrubbers installed on each ship was provided by the Clarksons bespoke dataset. In instances when the scrubber type was reported as 'to be confirmed', it was assumed to be open-loop since open-loop scrubbers account for the majority of installations.

TABLE 6. Normalized washwater discharge rates (r).

SCRUBBER TYPE	DISCHARGE RATE (T/MWH)
Open-loop	45
Closed-loop	0.1
Hybrid	45

DETERMINING TOTAL ENERGY DEMAND (TED)

Total energy demand, in megawatts, is the sum of the energy demands of the main engine (ME), auxiliary engines (AE), and boilers (BO). AE and BO are a function of ship class, ship capacity or size, and operational phase (i.e., at berth, anchored, maneuvering, or cruising). The main engine demand is equal to the installed engine power multiplied by the main engine load factor (LF), which is expressed as a value between 0 and 1 and describes how hard the main engine is working relative to its potential output.

$$TED = ME + AE + BO$$

$$TED = (p \times LF) + AE + BO$$

DETERMINING AUXILIARY ENGINE AND BOILER OUTPUT (AE, BO)

The auxiliary engine and boiler output values are reported in kilowatts (kW) and depend on main engine power, as well as other ship attributes. Values for AE and BO for each ship according to its class, capacity, and operational phase are reported in the Fourth IMO Greenhouse Gas Study[85] and are included in Appendix II, Table I. The decision matrix found in Table 7 was used for assigning values.

TABLE 7. Decision matrix for assigning auxiliary engine and boiler output values.

MAIN ENGINE POWER (*p*)	AE (kW)	BO (kW)
0–150 kW	0	0
150–500 kW	$0.05 \times p$	Refer to Appendix II
>500 kW	Refer to Appendix II	Refer to Appendix II

Determining main engine load factor (LF)

Main engine power for each ship is provided in the Clarksons bespoke dataset. To calculate the main engine load factor, the following equation from Olmer et al., 2017,[96] was used:

$$LF = \left(\frac{SOG \times SAF}{V_{max}}\right) \times HFF \times W \times DAF$$

Where:

LF = *main engine load factor, by ship*
SOG = *speed over ground, knots*
SAF = *speed adjustment factor*
V_{max} = *maximum vessel speed, knots*
HFF = *hull fouling factor, by ship*
W = *weather adjustment factor, based on ship location*
DAF = *draught adjustment factor, by ship*

[95] International Maritime Organization. (2020). *Fourth IMO Greenhouse Gas Study.* https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Fourth%20IMO%20GHG%20Study%202020%20-%20Full%20report%20and%20annexes.pdf

[96] Olmer, N., Comer, B., Roy, B., Mao, X.L., Rutherford, D. (2017). *Greenhouse gas emissions from global shipping, 2013–2015: Detailed methodology.* International Council on Clean Transportation.

SPEED ADJUSTMENT FACTOR (*SAF*)

The speed adjustment factor is applied to correct for linearly interpolated distances that are often shorter than actual distance travelled, resulting in lower derived speeds. Average speed adjustment factors for cruising and maneuvering phases are provided in Olmer et al., 2017, for 2013–2015 (Table 8), and the average across the three years was used in this study.[97] This yields a speed adjustment factor of 1.097 for cruising and 1.607 for maneuvering. For rerouted ship tracks, the speed adjustment factor is assumed to be 1, as it is only necessary in the case that missing AIS data are estimated using linear interpolation.

TABLE 8. Average speed adjustment factors (SAF), 2013–2015 from Olmer et al.[98]

YEAR	SAF, CRUISING	SAF, MANEUVERING
2013	1.120	1.700
2014	1.110	1.690
2015	1.070	1.430
Average	**1.097**	**1.607**

MAXIMUM SPEED (V_{max})

Maximum vessel speed for each individual ship is provided in the Clarksons bespoke dataset, however, most ships containing scrubbers were missing this value (700 out of 717 ships). For these records, the operational speed of each ship was used to estimate missing values based on the relationship between operational speed and maximum speed. See *Reclassification and missing data* above for details on the derivation of maximum speed. For AIS data with a value for speed over ground higher than the maximum speed of the ship, the speed was adjusted to the limit.

HULL FOULING FACTORS (*HFF*)

The hull fouling factor accounts for hydrodynamic resistance, which increases due to hull fouling as the ship ages. This factor is calculated using the following equation[99]:

$$HFF = 1.02 + \left[0.44 \left\{ \left(\frac{k_2}{L}\right)^{\frac{1}{3}} - \left(\frac{k_1}{L}\right)^{\frac{1}{3}} \right\}\right] \times \frac{1}{0.018 \times L^{-\frac{1}{3}}}$$

Where:

- HFF = *hull fouling factor*
- k_1 = *initial roughness of a new ship*
- k_2 = *final hull roughness depending on ship's age*
- L = *length between perpendiculars (m)*

[97] *Ibid.*

[98] *Ibid.*

[99] *Ibid.*

The initial roughness of a new ship is approximately 120 micrometres (μm), and is estimated to increase by about 30 μm each year (Table 9). This study assumes drydocking every five years. The length between perpendiculars is given in the Clarksons bespoke dataset.

TABLE 9. Average hull roughness based on ship age.

SHIP AGE (YEARS)	AVERAGE HULL ROUGHNESS (MM)
0–1	120
2–5	150
6–10	200
11–15	300
16–20	400
>20	500

WEATHER ADJUSTMENT FACTOR (W)

Weather impacts power demand, as winds and waves countering ship movement will lead to increased power demand. Following the methodology of Olmer et al.,[100] we assume an increase in power demand of 10 per cent for coastal shipping (within 5 nm of the nearest shore) and an increase in power demand of 15 per cent for international shipping (greater than 5 nm away from the nearest shore).

DRAUGHT ADJUSTMENT FACTOR (DAF)

Lastly, hydrodynamic resistance increases as the wetted surface area of a ship increases, which is related to the vessel draught. The draught adjustment factor accounts for varying draught by ship class and year; the average annual draught adjustment factor for ship classes between 2013 and 2015 were taken from Olmer et al.,[101] and the averages of the three years were used, as can be seen in Table 10.

[100] *Ibid.*

[101] *Ibid.*

TABLE 10. Average annual draught adjustment factor (DAF) by ship class.

SHIP CLASS	2013	2014	2015	AVERAGE
Bulk carrier	0.8032	0.8027	0.7982	**0.801367**
Chemical tanker	0.8478	0.8478	0.8483	**0.847967**
General cargo	0.8466	0.8466	0.8448	**0.846**
Liquefied gas tanker	0.8822	0.8822	0.874	**0.879467**
Oil tanker	0.8162	0.8183	0.8226	**0.819033**
Other liquid tankers	0.8856	0.8916	0.8756	**0.884267**
Refrigerated	0.8771	0.8784	0.8777	**0.877733**
Container	0.8761	0.8761	0.8689	**0.8737**
Cruise	0.9866	0.9866	0.9799	**0.984367**
Ferry pax only	0.9322	0.9322	0.9322	**0.9322**
Ferry ro-pax	0.9528	0.9528	0.9459	**0.9505**
Fishing	0.8973	0.8903	0.8903	**0.892633**
Ro-ro	0.9113	0.9113	0.9113	**0.9113**
Service tug	0.9391	0.9391	0.9253	**0.9345**
Yacht	0.9528	0.9528	0.9459	**0.9505**

Finally, if the calculated LF is greater than 1, LF is assumed to be 0.98 as ships do not typically operate above 98 per cent of maximum continuous rating (MCR).

GENERATING HEAT MAPS

Cumulative heat maps were generated showing the total estimated generation of each wastewater stream based on 2019 ship traffic in Canadian waters, for ships with IMO numbers. This includes greywater, sewage and bilge water for the 5,546 ships in the analysis, and scrubber washwater for the 717 ships that have installed or planned scrubbers up to 2022. Heat maps to show the generation of each wastewater stream were also generated per ship class to enable examination of the distribution of generated wastewater across vessel types.

QUANTIFYING POTENTIAL IMPACT ON ECOLOGICAL AREAS

Each cumulative waste stream raster was overlaid with 12 Canadian marine bioregions[102] excluding the Great Lakes bioregion, and zonal statistics were calculated to estimate the total amount of each wastewater stream generated in each area. The same was done for 129 marine areas in the Canadian Protected and Conserved Areas Database.[103] These include the MPAs created under the *Oceans Act,* NMCAs, marine refuges created under the *Fisheries Act,* mNWAs, and marine portions of NWAs, Migratory Bird Sanctuaries, and National Parks. As the spatial resolution of the waste stream rasters was 0.0125 decimal degrees, 7 of 129 protected areas encompassed a region too small to be rasterized and produce meaningful results in the context of this national scale analysis and were therefore excluded. We note that there are many other MPAs counting toward Canada's marine conservation targets in the database of protected and conserved areas, but we focused on the designations noted above as many of the other sites are small and coastal and would have similar analysis issues as the other MPAs excluded from the analysis. Furthermore, the actual amount of waste may be underestimated for coastal and inland MPAs because the analysis excludes inland ship traffic. Ultimately, 122 MPAs and OECMs that count towards Canada's marine conservation targets were included in the analysis (listed in Appendix III).

[102] Fisheries and Oceans Canada. (2018, March 20). *Map of bioregions*. Government of Canada. Retrieved October 2021, from https://www.dfo-mpo.gc.ca/oceans/maps-cartes/bioregions-eng.html

[103] Environment and Climate Change Canada. (2021a, April). *Canadian Protected and Conserved Areas Database*. Government of Canada. Retrieved September 2021, from https://www.canada.ca/en/environment-climate-change/services/national-wildlife-areas/protected-conserved-areas-database.html

RESULTS

SHIP SUMMARY

This analysis is based on 5,546 ships that were active in Canadian waters in 2019. These ships were identified using 2019 AIS data containing 18,852 unique maritime mobile service identity (MMSI) numbers. MMSI are unique nine-digit number vessel identifiers, therefore, the number of MMSI in the dataset is assumed to be equal to the number of unique vessels that operated in Canadian waters during the 2019 calendar year. Prior to analysis, the AIS dataset was filtered to remove invalid MMSI, as well as MMSI without corresponding AIS data, which reduced the number of MMSI to 14,543. Additional filtering was applied to identify ships with valid IMO numbers, further reducing the total number of ships included in the analysis to 5,546. Bulk carriers account for the majority (42.7 per cent) of the ships included in this analysis, followed by container ships (12.1 per cent), chemical tankers (10.2 per cent), ro-ros (5.8 per cent), general cargo ships (5.8 per cent), tug/towing (5.2 per cent), fishing (4.2 per cent), oil tankers (4.3 per cent), other liquid tankers (3.2 per cent), and cruise ships (2 per cent). All other types of ships account for 4 per cent of the total. See Figure 5 for a breakdown of ships by ship type or refer to Table 11 for a detailed breakdown.

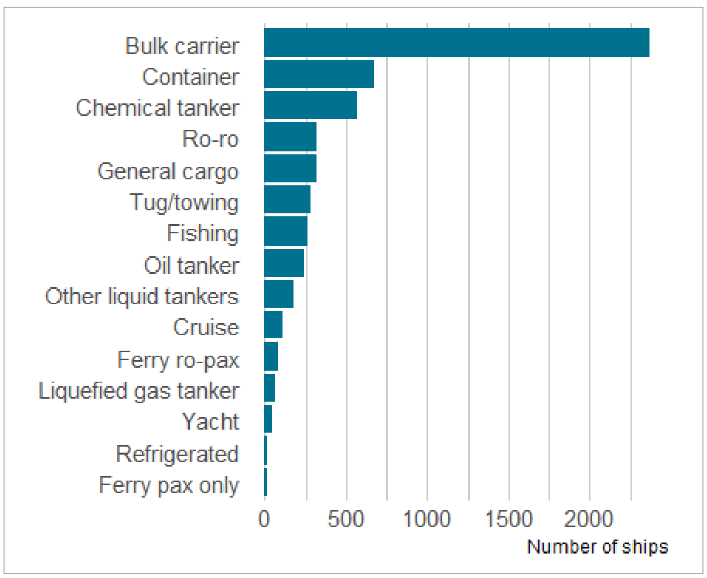
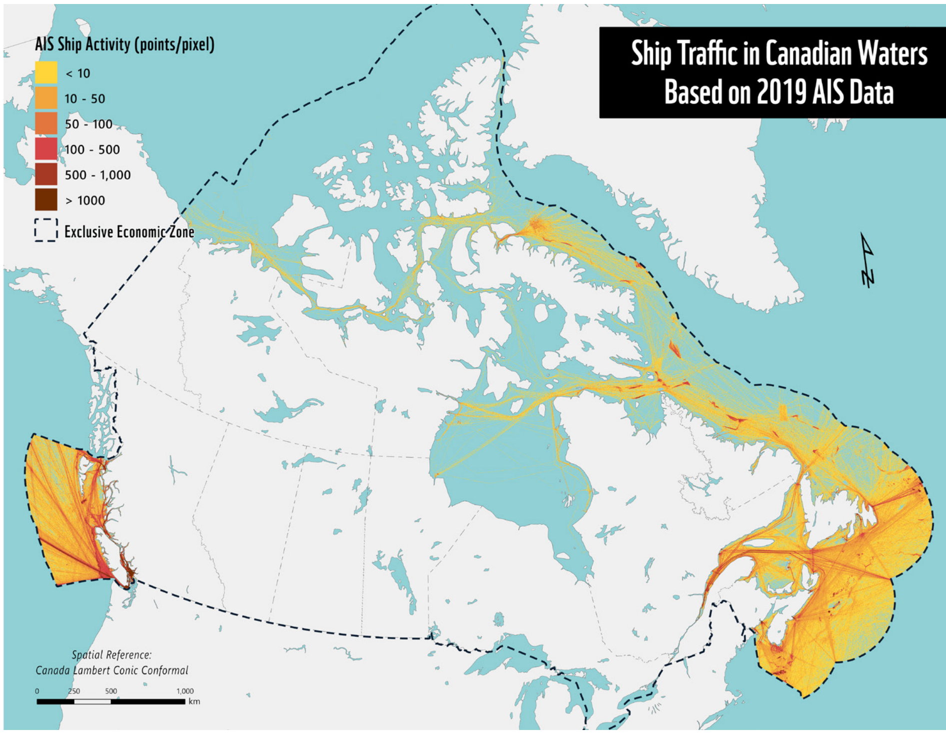


FIGURE 5. A breakdown of the ship types and number of ships included in this analysis.

SHIP ACTIVITY

Ship traffic is heaviest on Canada's East and West Coasts and is primarily driven by merchant traffic to and from Canada's major ports, as well as by passenger traffic, namely cruises and ferries along established routes (see Map 1). In these areas, activity is most densely clustered in the Salish Sea and the St. Lawrence Seaway. Ship traffic is lowest in the western and central Arctic, as well as southern Hudson Bay. The northernmost traffic hub is Milne Inlet, which overlaps the southeastern portion of the Tallurutiup Imanga NMCA. This traffic is dominated by bulk carriers traveling to and from the Mary River iron mine on Baffin Island.



MAP 1. Ship traffic in 2019 inferred from the AIS dataset provided by exactEarth.

To determine which ships are most active in Canadian waters, the total distance sailed and total number of person hours was calculated for each ship (Figure 6). An activity breakdown by ship type is provided in Table 11. The results indicate that, collectively, ships sail 32.3 million kilometres in Canadian waters annually. Merchant ships (i.e., bulk carriers, container ships, ro-ros, cargo ships, chemical, oil, and other liquid tankers, LNG tankers, reefers, and tug/towing vessels) represent nearly 91 per cent of the vessels operating in Canadian waters and account for 74 per cent of the total annual distance sailed. Ranked by ship type, bulk carriers sail the greatest distance in Canadian waters each year (7.2 million km total; averaging 2,700 km per ship per year) followed by container ships (4.4 million km total; averaging 6,600 km per ship per year). Passenger ships and fishing vessels are less numerous than merchant ships and as a result they account for a smaller proportion of the total distance sailed each year. However, when considered on an individual basis, these ships tend to travel greater distances on average than their merchant counterparts. For instance, the most active ships are ro-pax ferries, which sail an average distance of 49,500 kilometres per vessel per year, followed by cruise ships at 15,000 kilometres per vessel per year, tug/towing vessels at 12,100 kilometres per vessel per year, and fishing vessels at 9,700 kilometres per vessel per year.

TABLE 11. Summary of ship activity and scrubber installations, as of May 10, 2022.

SHIP CLASS	NUMBER OF SHIPS (ANALYSIS)	DISTANCE SAILED (KM)	PERSON HOURS	SHIPS WITH SCRUBBERS	PER CENT CHANGE IN SHIPS WITH SCRUBBERS SINCE 2019
Bulk carrier	2369	7,208,299	16,597,160	291	+ 78.5
Chemical tanker	568	2,948,388	4,586,276	74	+ 94.7
Container	670	4,433,661	6,818,495	160	+ 213.7
Cruise	110	1,651,815	309,485,059	58	+ 3.6
Ferry pax only	17	212,994	10,352,273	0	-
Ferry ro-pax	80	3,962,652	170,951,316	0	-
Fishing	264	2,563,584	2,927,438	0	-
General cargo	320	2,010,719	3,529,834	36	+ 38.5
Liquefied gas tanker	65	125,251	195,012	5	+ 66.7
Oil tanker	241	1,135,904	1,658,548	29	+ 93.3
Other liquid tankers	176	604,840	1,048,229	14	+ 40.0
Refrigerated	18	111,449	226,004	0	-
Ro-ro	322	1,726,476	4,212,535	50	+ 92.3
Tug/towing	286	3,467,737	5,667,631	0	-
Yacht	40	106,074	269,127	0	-
Total	**5546**	**32,269,844**	**538,524,936**	**717**	**+ 84.8**

TABLE 12. Summary of the waste produced by each ship type.

SHIP CLASS	GREYWATER (L)	SEWAGE (L)	BILGE WATER (L)	SCRUBBER WASHWATER (T)
Bulk carrier	85,247,685	17,049,537	10,165,488	10,695,847
Chemical tanker	24,516,063	4,903,213	3,265,555	7,747,253
Container	39,498,124	7,899,625	13,435,518	17,051,297
Cruise	2,486,557,271	334,161,847	22,816,294	96,113,167
Ferry pax only	36,733,752	7,346,750	164,436	-
Ferry ro-pax	792,803,237	158,560,647	4,409,993	-
Fishing	22,085,583	2,968,023	8,910,706	-
General cargo	19,886,499	3,977,300	1,722,727	3,072,669
Liquefied gas tanker	1,052,636	210,527	158,016	76,652
Oil tanker	10,751,523	2,150,305	2,555,720	1,585,851
Other liquid tankers	5,881,123	1,176,225	1,002,642	334,862
Refrigerated	1,144,308	228,862	97,248	-
Ro-ro	21,869,112	4,373,822	2,295,314	8,903,620
Tug/towing	22,861,763	4,572,353	6,180,857	-
Yacht	1,519,159	204,156	310,315	-
Total	**3,572,407,838**	**549,783,191**	**77,490,828**	**145,581,216**

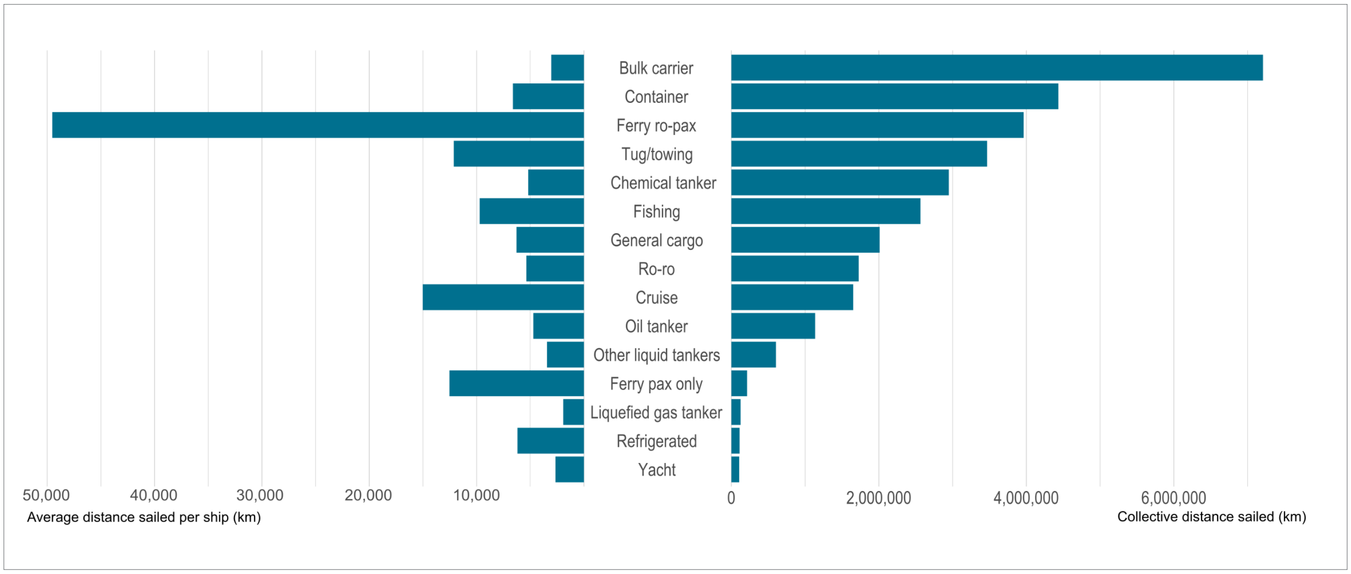


FIGURE 6. A comparison of the collective distance sailed by each ship type versus the average distance sailed per ship. Bulk carriers collectively sailed farther than any other ship type in Canadian waters owing to their large numbers, but individual ferries and cruise ships are much more active than other ships.

Person hours is a measure of the amount of time crew and passengers spend at sea during the calendar year. It is calculated for each ship as the number of operational hours over the course of the year multiplied by the estimated number of people on board. Results indicate that the total number of person hours per year in Canadian waters is 538.5 million. Person hours is positively correlated with distance sailed when the passenger fleet is considered separately from all other ship types due to the generally greater number of people on board passenger ships relative to merchant ships and fishing vessels. Notably, the passenger fleet (i.e., cruise ships, ferries, and yachts) accounts for more than 90 per cent of the total people hours despite representing just 4.5 per cent of ships (Figure 7). These results highlight how a small number of passenger ships is capable of generating the bulk of greywater and sewage in Canadian waters each year. A detailed breakdown of the ships included in this analysis, including ship types, distance sailed, and people hours, is included in Table 11.

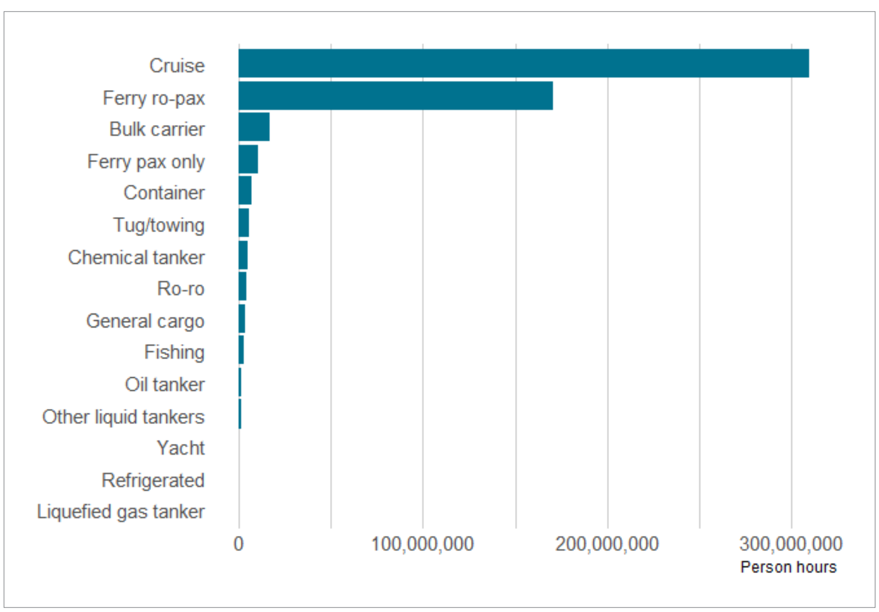


FIGURE 7. Summary of person hours by ship type. Passenger ships represent only 4.5 per cent of ships in Canadian waters but account for more than 90 per cent of the person hours (i.e., the collective amount of time people spend at sea in Canadian waters each year).

SCRUBBERS INSTALLED

Of the ships included in this analysis, 717 (12.9 per cent) are fitted with scrubbers or have scrubbers on order through May 2022. This represents an 84.8 per cent increase in the number of ships with scrubbers operating in Canadian waters relative to 2019.[104] Since 2019, the greatest uptake of scrubbers has been by containerships (+213.7 per cent), chemical tankers (+94.7 per cent), and ro-ros (+93.3 per cent).[105] In comparison, cruise ships, which were among the early adopters of scrubber technology, only increased scrubber installations by 3.6 per cent over the same period.

Of the ships fitted with scrubbers, 81.3 per cent are fitted with open-loop systems, 16.8 per cent are fitted with hybrid systems, and 1.7 per cent are fitted with closed-loop systems.[106] These proportions correspond with global trends in scrubber installations.[107] Most of the ships fitted with scrubbers are bulk carriers (291), followed by container ships (160), and cruise ships (58). Proportionally, cruise ships have invested most heavily in scrubbers (52.7 per cent of the cruise ships in the analysis are fitted with scrubbers), followed by container ships (23.9 per cent), and ro-ros (15.5 per cent). Refer to Table 11 for a breakdown of scrubber installations by ship type.

WASTE GENERATION

Model results indicate that a total of 147 billion litres of waste is generated by ships in Canadian waters each year. This includes 3.6 billion litres of greywater, 549.8 million litres of sewage, 77.5 million litres of bilge water, and 145.6 million tonnes (about 143 billion liters) of scrubber washwater.[108,109] This is equal to approximately 57,200 Olympic swimming pools of scrubber washwater, 1,440 Olympic swimming pools of greywater, 220 Olympic swimming pools of sewage, and 31 Olympic swimming pools of bilge water. Refer to Figure 8 for a side-by-side comparison of the amount of each waste stream, to Figures 9(a-d) for a breakdown of each waste stream by ship type, and to Table 12 for a detailed breakdown of waste production by ship type. Refer to Maps 2–5 for national scale visualizations of the spatial distribution and intensity of waste generation and to Maps 1–12 in Appendix IV for regional scale visualizations.

104 Clarksons Research Services Ltd. (2021). *World Fleet Register* [Dataset]. https://www.clarksons.net/portal

105 *Ibid.*

106 Eighty-six of the ships included in the Clarksons bespoke dataset are fitted with scrubbers whose type is not yet confirmed. For the purposes of this study these ships are assumed to be fitted with open-loop systems since most scrubbers installed globally are open-loop.

107 *Clarksons World Fleet Register.*

108 This is based on an in-situ density of scrubber washwater of 1018.02 kg/m^3. This assumes a salinity of 35 PSU, a temperature of 40°C, and hydrostatic pressure equal to 11.135 decibars.

109 The in-situ density of scrubber washwater was estimated assuming an average temperature of 40°C, based on the 30°C−50°C range reported by: Flagiello et al. (2021). A Novel Approach to Reduce the Environmental Footprint of Maritime Shipping. *Journal of Marine Science and Application, 20*(2), 229–247. https://doi.org/10.1007/s11804-021-00213-2

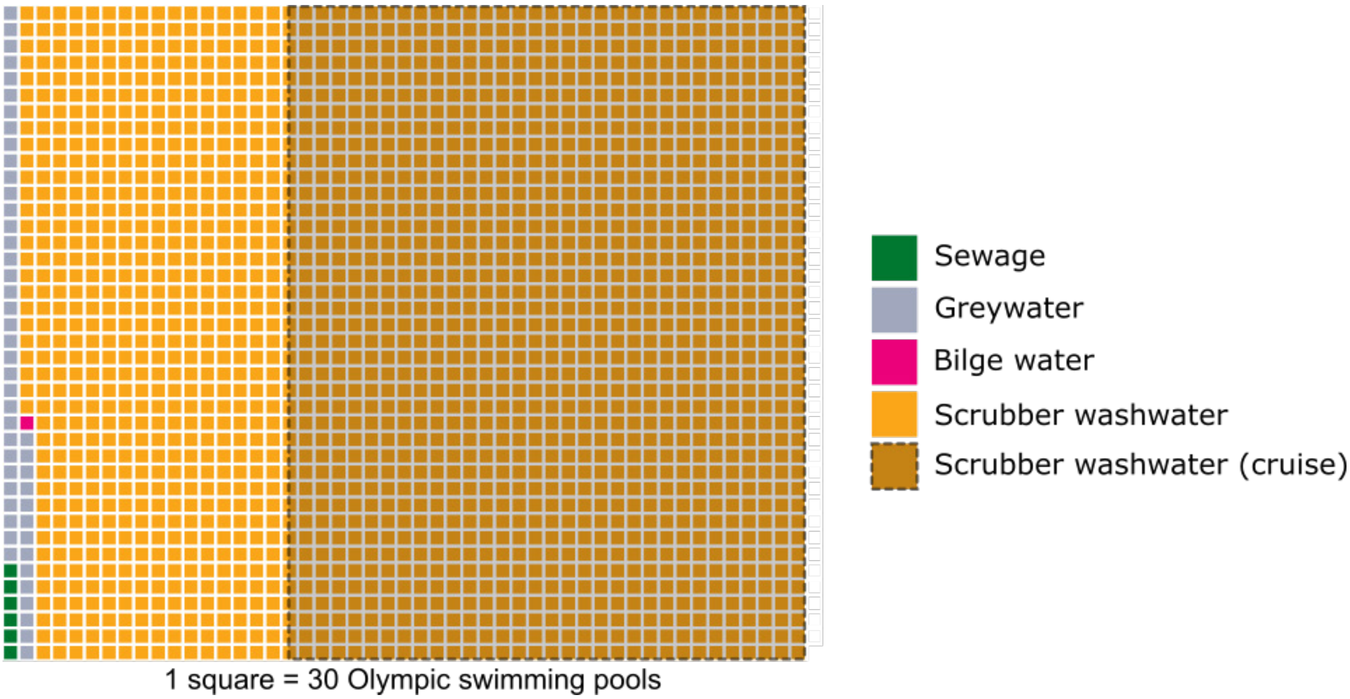


FIGURE 8. The equivalent of about 59,000 Olympic swimming pools of sewage, greywater, bilge water, and scrubber washwater are generated by 5,546 ships in Canadian waters each year.

Scrubber washwater is the most voluminous waste stream by a large margin. Although only about one in eight ships is fitted with a scrubber, the amount of scrubber washwater produced annually is equal to more than 34 times the combined volume of greywater, sewage, and bilge water produced by all ships. Less than 0.003 per cent of the scrubber washwater originates from ships using closed-loop systems with the remaining 99.997 per cent originating from open-loop and hybrid systems.

Cruise ships are the top producer of each of the four waste streams. Despite representing only 2 per cent of ships (*n*=110), cruise ships account for 69.6 per cent of the greywater, 66 per cent of scrubber washwater, 60.8 per cent of sewage, and 29.4 per cent of the bilge water generated in Canadian waters annually. Cruise ship operations are often seasonal, which means that the bulk of discharges from these ships occurs over a period of just a few months each year.

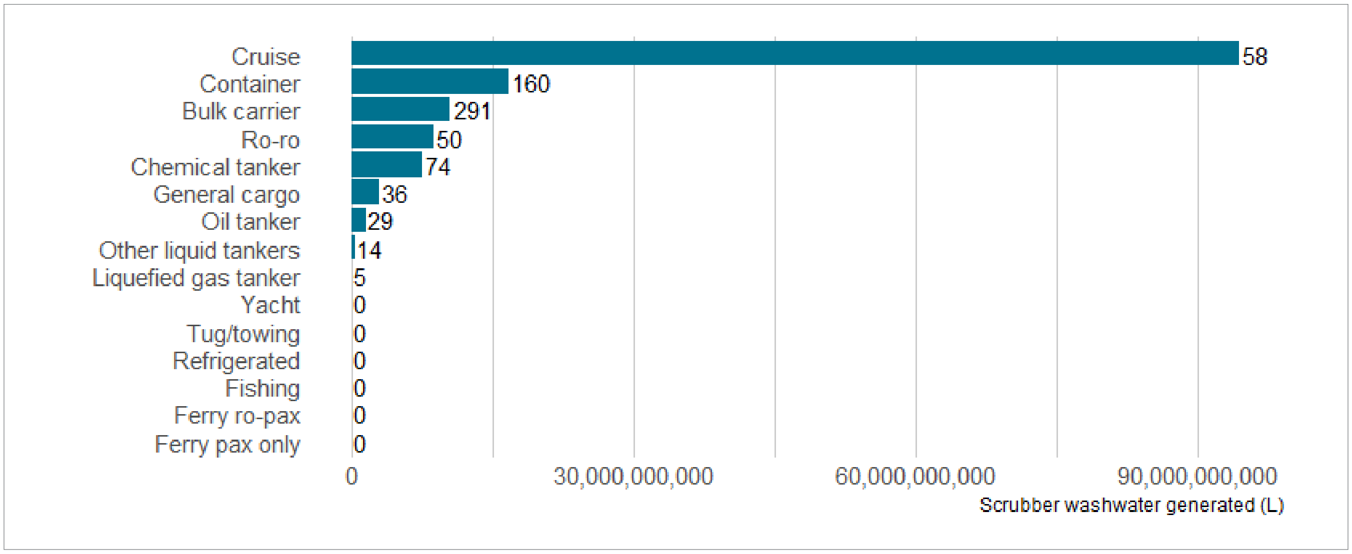


FIGURE 9(a). Annual amount of scrubber washwater generated ranked by ship type. The value to the right of each bar represents the number of ships in each category equipped with a scrubber (e.g., 291 bulk carriers included in the analysis are fitted with scrubbers).

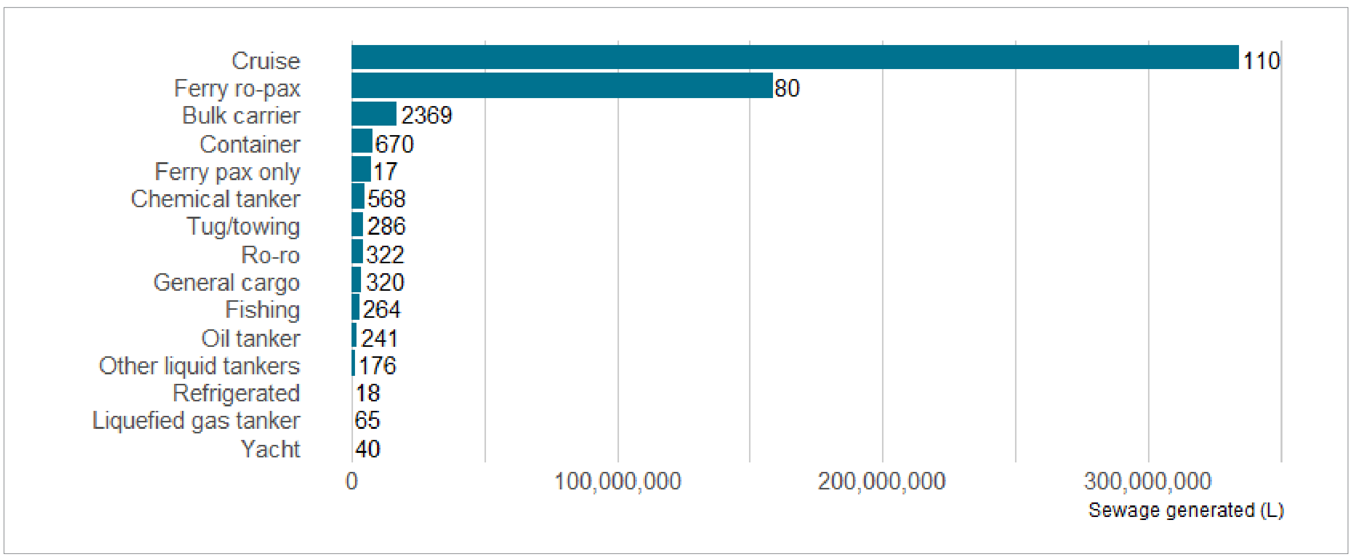


FIGURE 9(b). Annual amount of sewage generated ranked by ship type. The value to the right of each bar represents the number of ships included in that category.

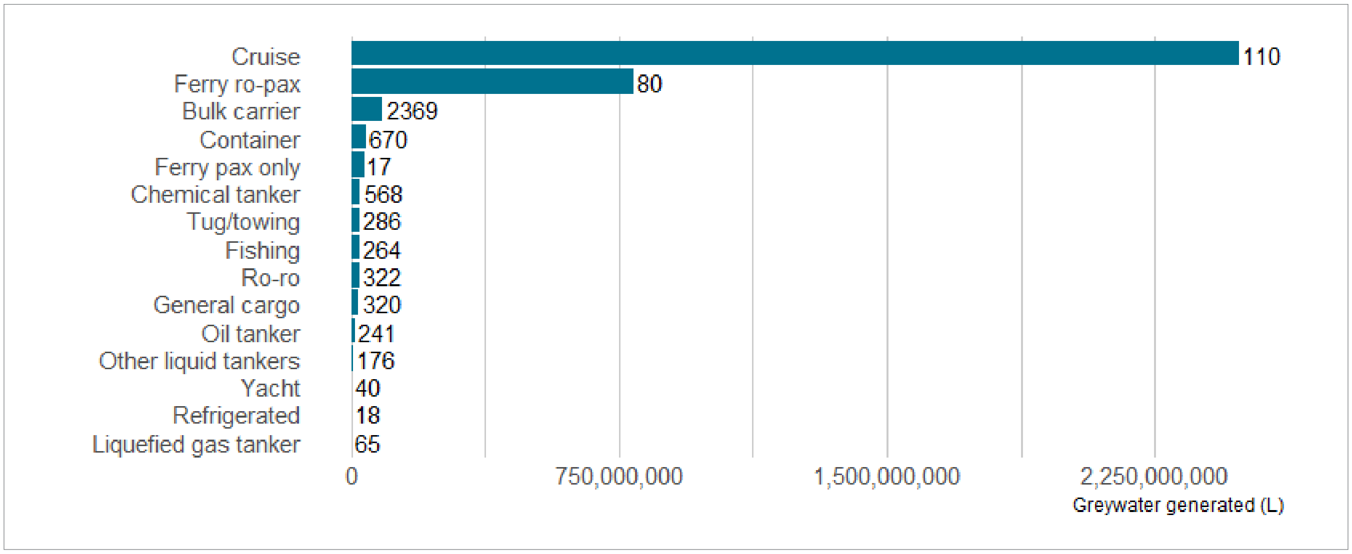


FIGURE 9(c). Annual amount of greywater generated ranked by ship type. The value to the right of each bar represents the number of ships included in that category. Fishing vessels, which can generate large amounts of wastewater as a product of fish cleaning and product preparation, are underrepresented in this study.

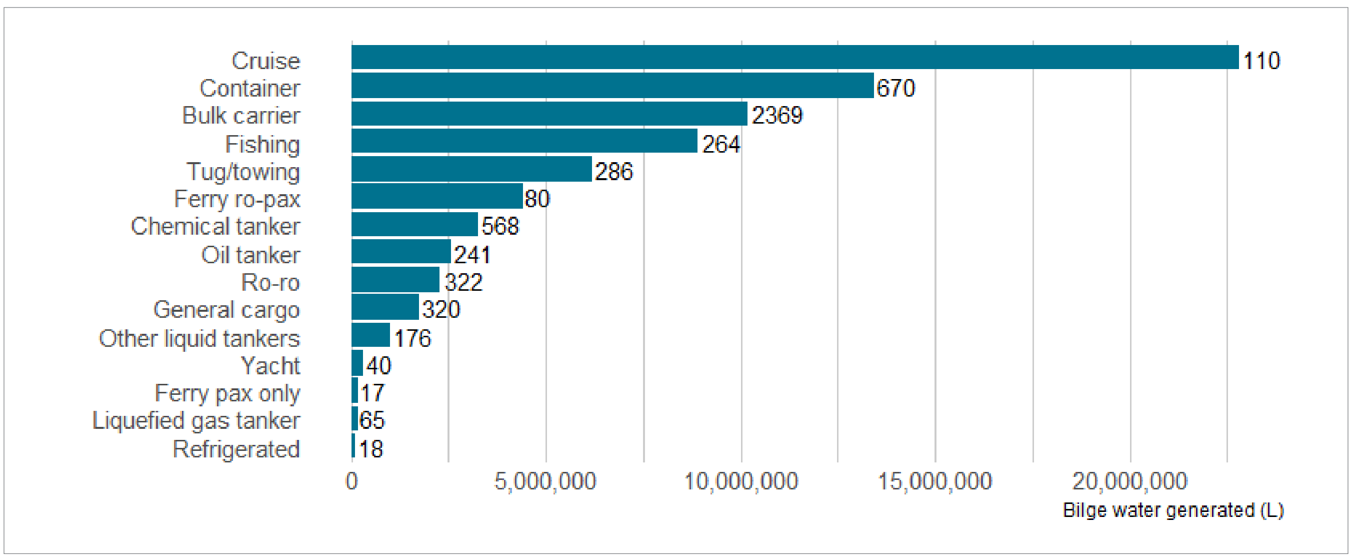
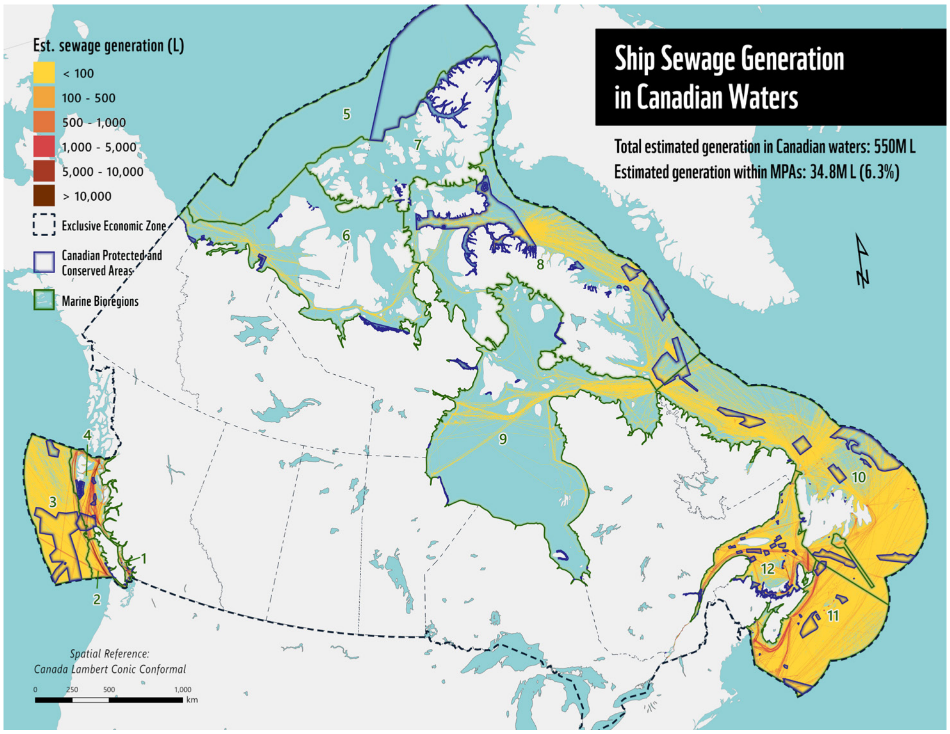
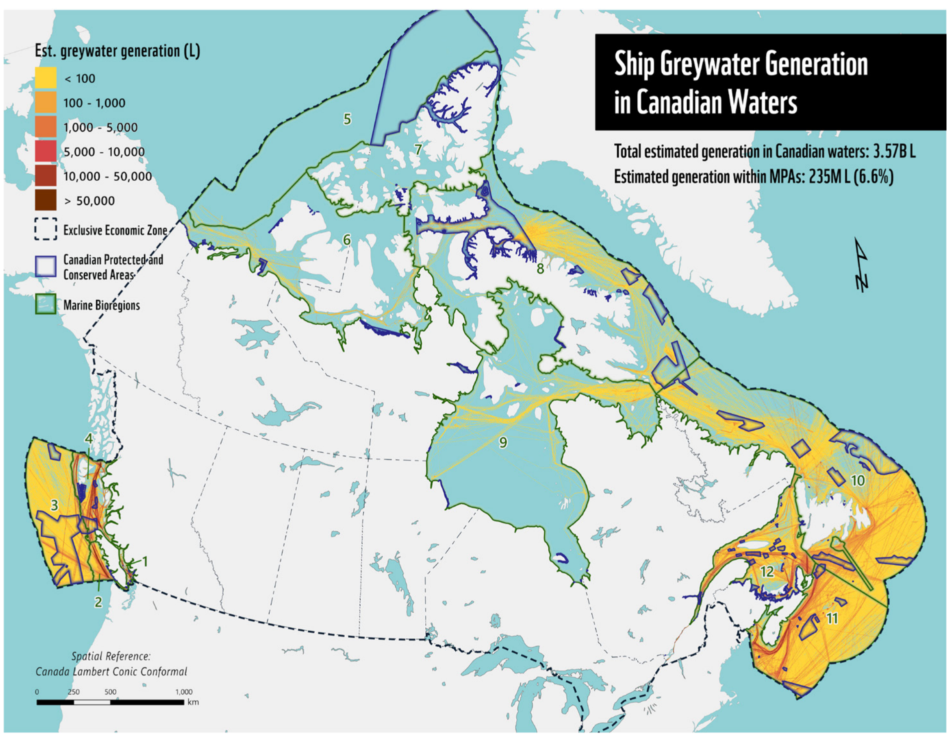


FIGURE 9(d). Annual amount of bilge water generated ranked by ship type. The value to the right of each bar represents the number of ships included in that category.

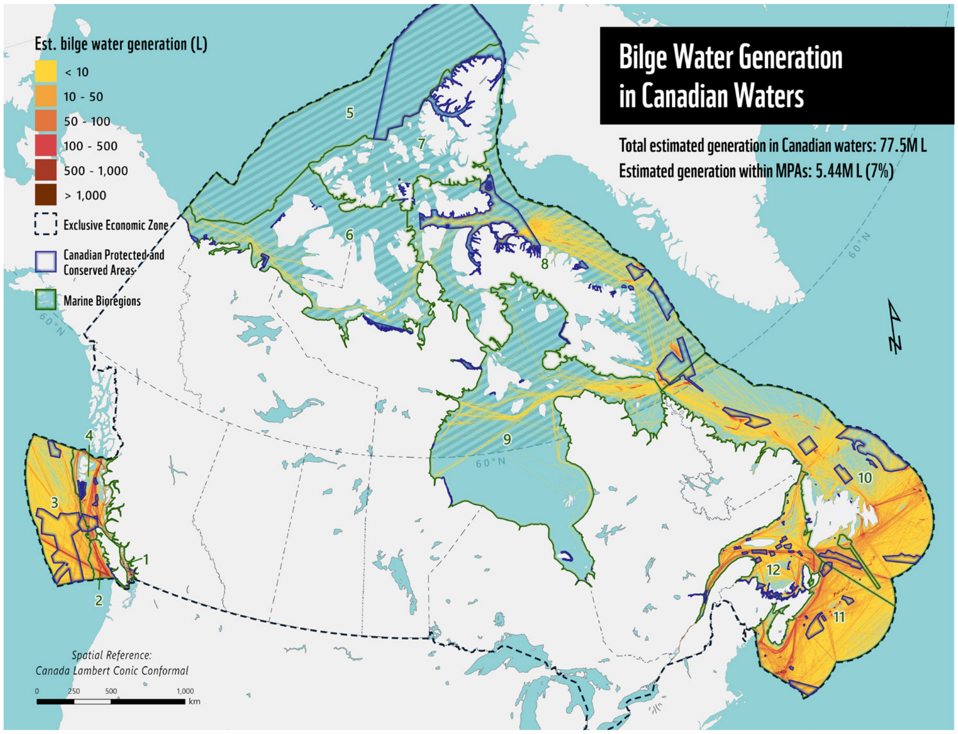
Of the total amount of waste generated by ships each year, 10.1 per cent, or roughly 14.7 billion litres, is generated within 122 of the protected and conserved areas that count toward Canada's marine conservation targets and were included in this analysis. This includes 10.12 per cent of the total scrubber washwater, 6.53 per cent of the greywater, 6.29 per cent of the sewage, and 7.03 per cent of the bilge water. This is equal to approximately 5,786 Olympic swimming pools of scrubber washwater, 93 Olympic swimming pools of greywater, 14 Olympic swimming pools of sewage, and 2 Olympic swimming pools of bilge water.



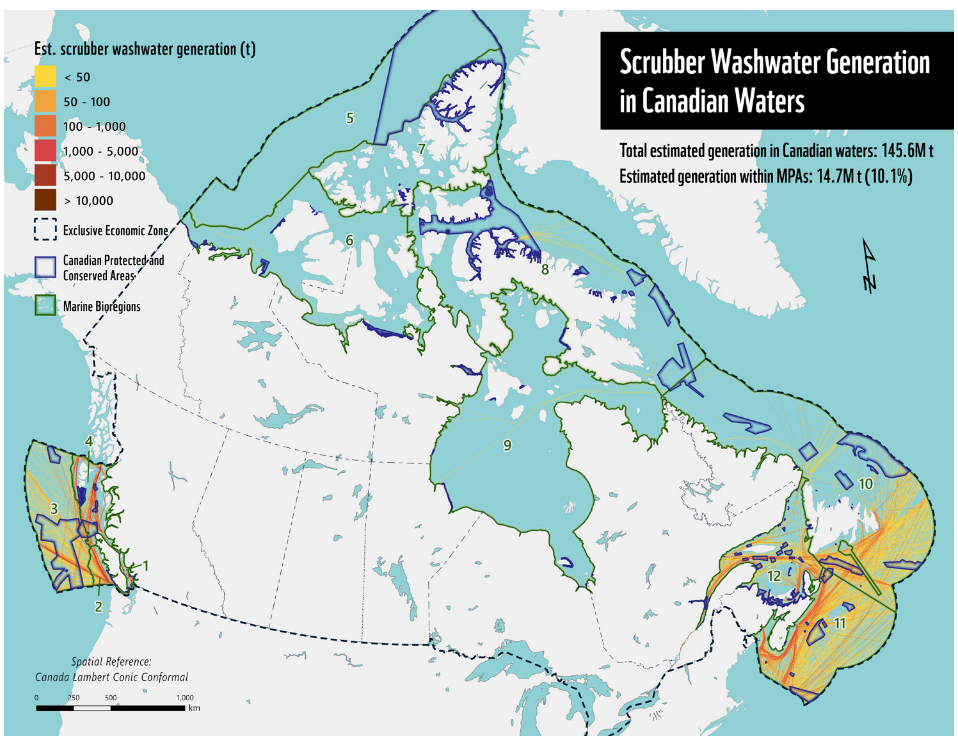
MAP 2. Annual greywater generation in Canada based on 2019 ship traffic.



MAP 3. Annual sewage generation in Canada based on 2019 ship traffic.



MAP 4. Annual bilge water generation in Canada based on 2019 ship traffic. Discharging bilge into Arctic waters is prohibited, therefore, bilge generated in this region will be disposed of at port reception facilities or discharged at sea outside of the Arctic.



MAP 5. Annual scrubber washwater generation in Canada based on 2019 ship traffic. The majority of scrubber washwater is produced by open-loop scrubbers and hybrid scrubbers operating in open-loop mode. All open-loop scrubber washwater is discharged into the sea.

MPAs and OECMs in high traffic areas are the most affected. In terms of total waste generation, Scott Islands Marine National Wildlife Area is the most impacted MPA, followed by the Saguenay-St. Lawrence Marine Park, the Offshore Pacific Seamounts and Vents Closure, the Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs MPA, and the Corsair and Georges Canyons Conservation Area, as seen in Figure 10. A detailed summary of waste generated in 122 MPAs and OECMs is presented in Appendix III, Table I.

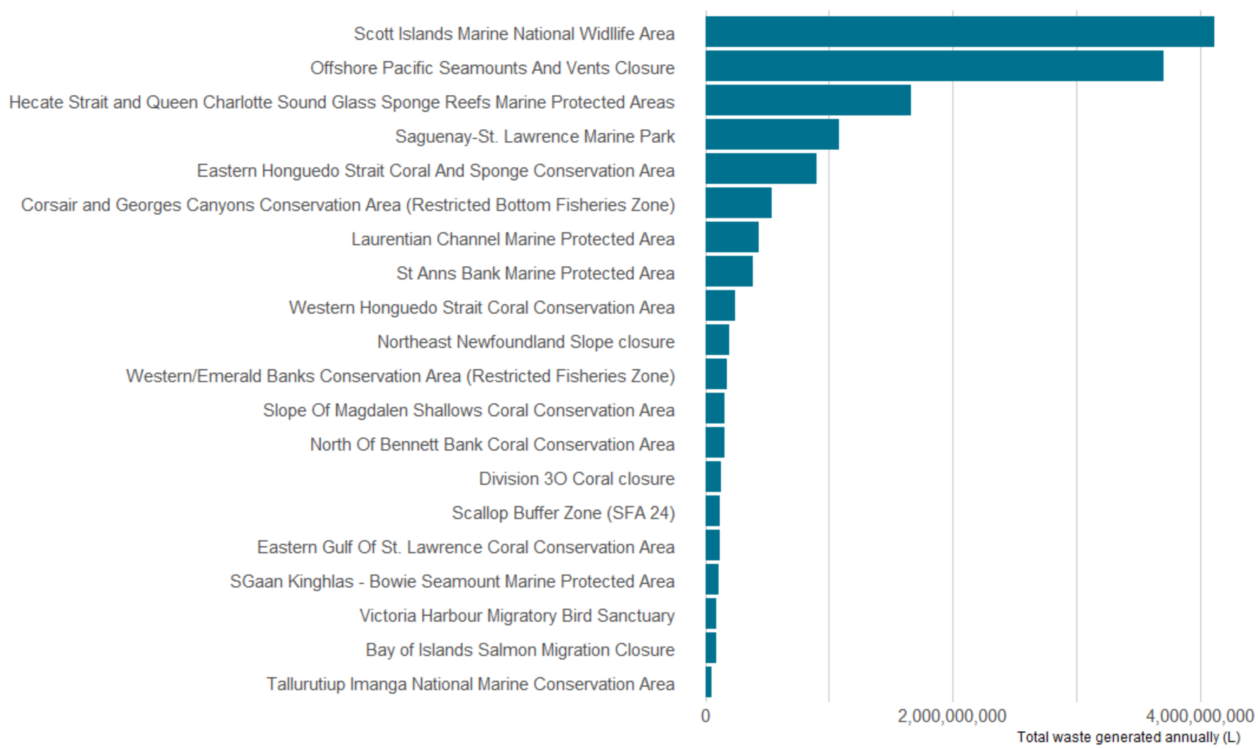


FIGURE 10. Ranked top 20 MPAs and OECMs for annual waste generation. By volume, scrubber washwater is the dominant waste stream produced on the East, West, and Arctic Coasts.

The amount of each operational waste stream generated in MPAs and OECMs on Canada's East, West, North, and Central coasts is presented in Figure 11. Overall, the greatest amounts of waste are generated off Canada's West Coast, followed closely by the East Coast. Comparatively little waste is generated off the Arctic and Central coasts (i.e., Hudson Bay below 60°N) owing to the limited ship traffic in these regions. However, of the waste that is generated in Arctic waters, sewage and greywater are disproportionately generated in Arctic marine protected areas. Each year, 28 per cent of the greywater and 26.9 per cent of the sewage generated in the Arctic is generated within MPAs and OECMs. By comparison, less than 5 per cent of the sewage and greywater generated off the West coast is generated in protected and conserved areas.

Cruise ships lead the production of all waste streams in MPAs and OECMs. They are responsible for 32 per cent of the bilge water, 59 per cent of the scrubber washwater, 70 per cent of the sewage and 78 per cent of the greywater generated within the protected areas included in this study. Refer to

Appendix III, Table II, for an overview of regional waste production and waste production in MPAs and OECMs sorted by ship type. A breakdown of waste generation in each DFO bioregion is provided in Table 13. The top three most impacted bioregions are the Northern Shelf (28 per cent of all waste), the Scotian Shelf (18 per cent of all waste), and the Southern Shelf (16 per cent of all waste).

TABLE 13. Summary of waste generated in each Fisheries and Oceans Canada bioregion. Discrepancies in the total waste generation calculated by bioregion compared to total EEZ calculations may be attributed to spatial misalignment of coastlines in the Federal Marine Bioregions dataset. The most recent version of the dataset as of September 2021 was used for this analysis.

WASTE STREAM GENERATION	GREYWATER(L)	SEWAGE (L)	BILGE WATER (L)	SCRUBBER WASHWATER (T), INCL. 2020-22
Total	3,572,407,838	549,783,191	77,490,828	145,581,216
BY BIOREGION				
Arctic Archipelago	227,689	30,599	5,095	-
Arctic Basin	137,737	19,202	4,381	3,421
Eastern Arctic	22,182,865	3,297,610	1,677,369	258,996
Gulf of Saint Law-rence	424,203,933	71,391,411	9,869,969	17,820,315
Hudson Bay Complex	4,308,105	766,464	641,092	107,864
Newfoundland-Labrador Shelves	110,990,458	18,072,540	9,681,245	10,497,849
Northern Shelf	1,055,866,730	146,072,957	12,995,057	42,008,854
Offshore Pacific	92,753,155	13,680,875	4,927,336	12,967,312
Saint-Pierre et Miquelon	34,748,296	5,406,557	3,136,443	4,879,851
Scotian Shelf	472,368,720	68,249,678	11,486,490	26,280,387
Southern Shelf	441,581,052	60,868,329	9,508,716	23,790,560
Strait of Georgia	728,004,975	130,515,648	9,768,051	8,483,990
Western Arctic	7,233,372	995,330	167,364	45,745
Total	**3,394,607,086**	**519,367,199**	**73,868,608**	**147,145,143**

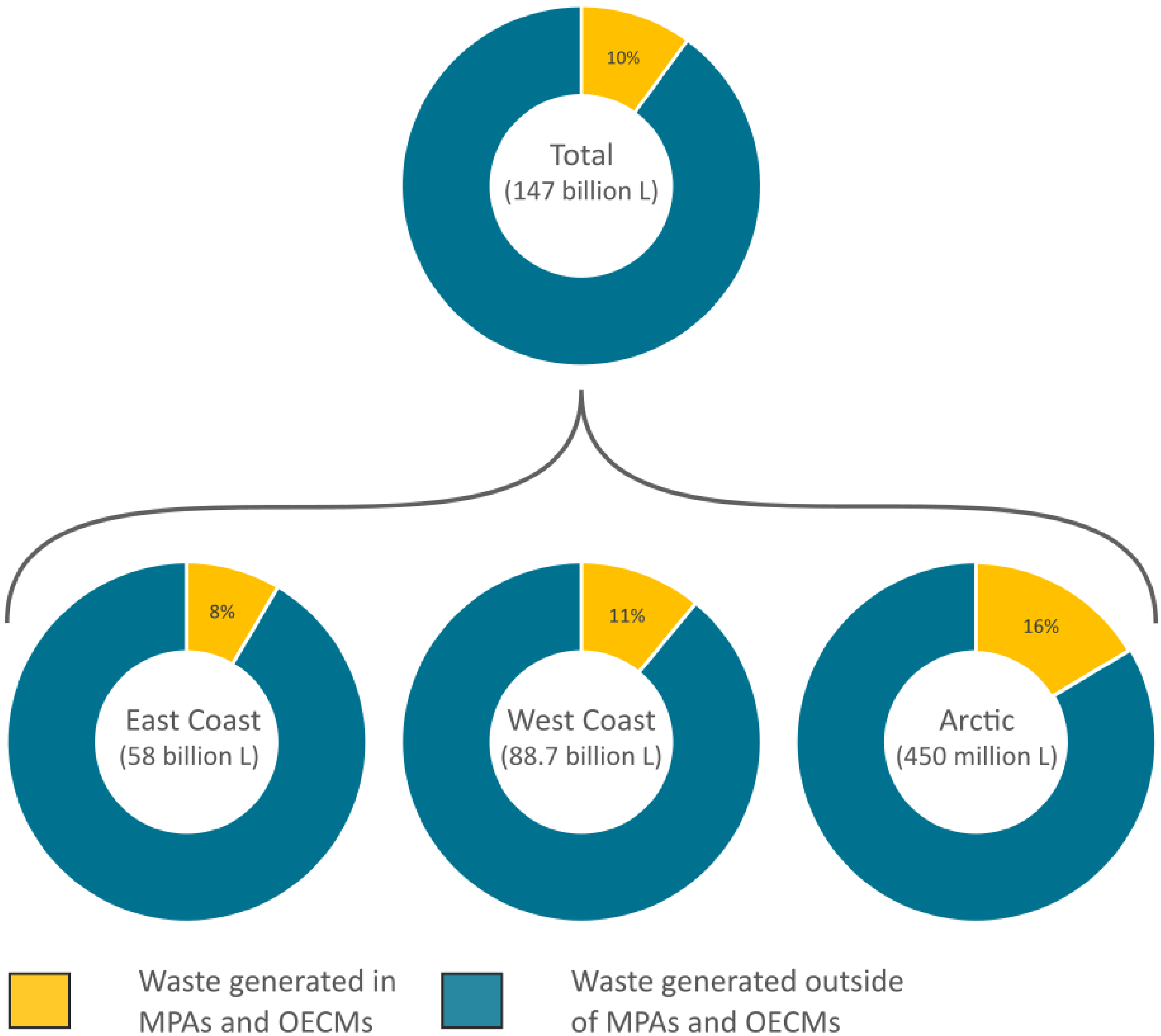


FIGURE 11. Summary of waste produced on each coast and the proportion produced in MPAs and OECMs.

OVERVIEW

Large amounts of operational wastes are generated and discharged by ships in Canadian waters each year. These wastes can negatively impact marine wildlife and degrade the quality of the marine environment, which in turn threatens the wellbeing of Canadians who rely on healthy oceans as a source of food, income, or for community or cultural values. Despite the growing threat of ship-source pollution and the role it plays in perpetuating the biodiversity crisis, the amount of waste generated by ships in Canadian waters, including in federally designated protected areas (i.e., MPAs and OECMs) has remained unknown until now. As Canada prepares to introduce minimum standards for new MPAs, there is an opportunity to usher in a new era of sustainable shipping by prohibiting ships from discharging operational wastes in designated protected areas. This study was undertaken to highlight the amount and kinds of waste that will continue to be discharged in Canada's MPAs and OECMs in the absence of further regulatory action.

CONSERVATION CHALLENGES

This study finds that a combined 147 billion litres of sewage, greywater, bilge water, and scrubber washwater are produced by ships in Canadian waters each year. Unsurprisingly, the spatial distribution of where waste is generated closely approximates the distribution of ship activity. Of the total annual amount of waste generated, about 60.3 per cent is on the West Coast, 39.3 per cent the East Coast, 0.3 per cent in the Arctic, and 0.01 per cent in southern Hudson Bay. More than 10 per cent of the total waste generated in Canadian waters is generated in MPAs and OECMs. Overall, MPAs and OECMs on the West Coast receive 6.6 per cent of the total amount of waste generated in Canadian waters on an annual basis, East Coast MPAs and OECMs receive 3.3 per cent, and Arctic MPAs and OECMs receive 0.05 per cent (excluding bilge water).

The substantial amount of waste generated in the most impacted MPAs and OECMs raises the question of whether these sites can effectively achieve their intended conservation objectives if new restrictions on the disposal of operational wastes are not introduced. For example, the Western Honguedo Strait Coral Conservation Area, located in the Gulf of St. Lawrence, is designated to protect cold-water corals including three sea pen species. These slow growing, calcifying animals form structures that provide diverse habitats for many other species, but can be impacted by more acidic waters. Despite this, the Western Honguedo Strait Coral Conservation Area is the fifth most impacted protected area included in the study in terms of litres of waste produced per square kilometre, receiving an estimated 239 million litres of acidic scrubber washwater annually.

Another example of ship discharges potentially conflicting with MPA conservation objectives is in the Saguenay-St. Lawrence Marine Park, where more than 1 billion litres of operational waste is generated and potentially discharged by ships each year. The Park is home to over 2,000 species, including those designated under the *Species at Risk Act* such as the blue whale, the Atlantic cod, and the endangered St. Lawrence beluga whale. Historically, the St. Lawrence beluga have suffered abnormally high cancer rates as the result of exposure to pollution produced by local aluminum smelters.[110] PAHs, which have been identified as a primary contributing factor to the heightened morbidity and mortality observed in the St. Lawrence beluga population, are also found in abundance in scrubber washwater, bilge water, and other wastes regularly discharged by ships.

Today, the St. Lawrence beluga population is still in decline and contaminants remain a top threat to species recovery.[111] While a key measure identified in the action plan to help recover the St. Lawrence beluga is to reduce toxic chemical compound discharges, recovery actions have yet to effectively reduce threats from contaminants.[112] Prohibiting vessels from disposing operational wastes in MPAs and OECMs in the Gulf of St. Lawrence and elsewhere would reduce the contaminant load that belugas and other animals are exposed to and would reduce the local impacts of acidification from scrubber washwater in areas set aside for the conservation of calcifying organisms such as sea pens, corals, and bivalves.

The results also indicate that although the total amount of waste produced in the Arctic less than what is produced on Canada's busy east and west coasts, the proportion of waste produced in Arctic MPAs is greater. More than 16 per cent of waste generated in the Arctic is in designated protected areas. This value excludes bilge water, which is prohibited from being discharged into the Canadian Arctic due to its trace oil content. In comparison, 8 per cent of the waste generated on the East Coast and 11 per cent of waste generated on the West Coast occurs in designated protected areas.

Today, the Arctic is changing at a record pace. It is warming at three times the average global rate, causing sea ice—the foundation of Arctic life—to melt, changing the face and reality of the region. As the ice-free season in the Canadian Arctic grows, new opportunities for development and economic growth will be supported by an expanding Arctic shipping industry. The findings of this study indicate that current shipping routes favour passage through Arctic protected areas. As a result, increasing Arctic shipping—be it due to a longer ice-free season that accommodates additional voyages each year, an increased number of ships transiting the Arctic, or both—could drive a rapid increase in the amount of waste generated in Arctic MPAs and OECMs. This trend is already observable near the Mary River Mine on Baffin Island (Milne Inlet), which has become a significant traffic hub in recent years, with shipping routes passing through the southeastern portion of the Tallurutiup Imanga National Marine Conservation Area.

110 Martineau, D., Lemberger, K., Dallaire, A., et al. (2002b). Cancer in wildlife, a case study: beluga from the St. Lawrence estuary, Québec, Canada. *Environmental Health Perspectives, 110*(3), 285–292. https://doi.org/10.1289/ehp.02110285

111 Fisheries and Oceans Canada. (2012). Recovery Strategy for the beluga (Delphinapterus leucas) St. Lawrence Estuary population in Canada. Species at Risk Act (SARA) Recovery Strategy Series. Fisheries and Oceans Canada, Ottawa. 88 pp + X pp. https://www.canada.ca/en/environment-climate-change/services/species-risk-public-registry/recovery-strategies/beluga-whale-st-lawrence-estuary-population.html

112 Fisheries and Oceans Canada. (2016). St. Lawrence Beluga: A science-based review of recovery actions for three at-risk whale populations. https://www.dfo-mpo.gc.ca/species-especes/publications/mammals-mammiferes/whalereview-revuebaleine/review-revue/beluga/index-eng.html#621

Another notable finding of this study is the amount of scrubber washwater generated in Canadian waters annually. Scrubber washwater accounts for 97 per cent of the total volume of all waste streams modeled in this study despite only 13 per cent of the ships being fitted with scrubbers. Two-thirds of the scrubber washwater produced in Canadian waters each year is produced by cruise ships fitted with scrubbers, which account for just 1 per cent of the ships included in the study. The model also identifies cruise ships as the top producers of greywater, sewage, and bilge water over all other ship types, both within the protected and conserved areas in this study and within Canadian waters as a whole. Unlike sewage, greywater, and bilge water, which can be retained and potentially disposed of at port reception facilities, nearly all scrubber washwater is disposed of where it is generated. Scrubbers were designed for use on ships to enable the continued use of HFO, the most polluting marine fuel. Thus, ships fitted with scrubbers not only produce much more pollution than other ships, they also unnecessarily contribute to excess environmental and health risks by transporting HFO through Canada's most sensitive waters.

COMPARISON TO SIMILAR STUDIES

The results of this study compare favourably with other recent studies that estimate ship operational waste production in Canada. In 2018, Vard Marine produced a study analyzing the distribution and quantity of greywater likely generated in the Canadian Arctic.[113] A companion study for waters off the coast of British Columbia was produced the following year.[114] These studies find that 33.4 million litres of greywater was likely generated by ships in the Canadian Arctic in 2017 and 1.54 billion litres of greywater was likely generated off the coast of British Columbia in 2018. Additionally, the Vard Marine reports find that 89 per cent of the greywater likely generated off the coast of British Columbia in 2018 originated from ships involved in the tourism industry (e.g., cruise ships and yachts) and projected that annual greywater generation in the Arctic could rise to over 60 million litres by 2035 due to anticipated increases in cruise activity, community demand for sealifts, and bulk carrier traffic to Milne Inlet related to the Mary River Mine. In comparison, this study concludes that ships likely generate 35.5 million litres of greywater in the Canadian Arctic and 2.34 billion litres off the coast of British Columbia each year.Similarly, our study results also point to passenger vessels as the primary source of greywater (and sewage).

Although the values estimated by Vard Marine differ somewhat from the values report here, this may be explained by key methodological differences. First, this study is based on 2019 AIS data which is not identical to the 2017 and 2018 AIS data used in the two Vard Marine studies. Second, although the Vard Marine studies also estimate the amount of greywater generated in litres per person as a function of voyage time in hours, we do not use identical waste generation metrics. Finally, this study includes fishing vessels, ferries, and tug/towing vessels, which are not accounted for in either of the Vard Marine studies.

113 Vard Marine Inc. (2018, May). *Canadian Arctic greywater report: Estimates, forecasts, and treatment technologies* (Report No. 360–000).

114 Vard Marine Inc. (2019). Greywater generation estimates for the BC coast. (Report No. 381-000).

In 2020, ICCT released a global analysis of the distribution of washwater discharges from ships.[115] This analysis is based on 2019 AIS data and ship technical characteristics from IHS Markit and supplemental information on scrubber fittings from Clarksons World Fleet Register.[116] The ICCT study concluded that ships generate and discharge 108.4 million tonnes of scrubber washwater in the Canadian waters each year. In comparison, our study finds that 145.6 million tonnes of scrubber washwater is generated. The greater amount of scrubber washwater estimated by this study may be attributed to several possible explanations. While both studies use 2019 AIS data, the ICCT study accounts for ships fitted with scrubbers or with scrubbers on order as of 2020. In comparison, this study accounts for ships fitted with scrubbers or with scrubbers on order through May 10, 2022. Some differences may also be explained by discrepancies between the attribute datasets used by each study, as well as by the approaches that were taken to address data gaps. For example, maximum ship velocity is one of the variables that influences scrubber washwater calculations. In instances when maximum ship velocity was unavailable it was inferred using the correlation between maximum ship velocity and operational speed (an attribute which was consistently available). However, the relationship between these two attributes can vary between years.

Overall, the findings of this study appear to be in good agreement with similar analyses conducted recently. Like other studies, this analysis assumes that waste is generated and potentially discharged continuously. In reality, sewage, greywater, and bilge water are discharged at more or less random intervals; however, this is difficult to accurately model. As a result, our results likely describe the distribution of sewage, greywater, and bilge water as being more diffuse than they actually are. This caveat does not apply to scrubber washwater since most washwater is generated and discharged in-situ.

Realistically, the volume of operational wastes generated by ships in Canadian waters and federally designated protected areas each year is likely greater than we have estimated. This is because this study only accounts for ships with registered IMO numbers and excludes certain ship types (e.g., naval vessels). As a result, nearly 9,000 vessels that appear in the 2019 AIS dataset are not represented in this analysis, and the sewage, greywater, and bilge water from these ships is not accounted for. Further, although this analysis succeeds in including nearly all ships with scrubbers that operate in Canadian waters, the overall volume of scrubber washwater produced annually has likely been underestimated. This is because the model uses a washwater generation rate of 45 tonnes per megawatt hour (t/mWh), which reflects the normalized rate referred to in IMO documentation. It is also commonly used in other works, such as the aforementioned ICCT analysis. However, recent studies indicate that the actual rate at which scrubber washwater is generated is closer to 90 t/mWh.[117] It should also be noted that while this study models the generation of four major operational waste streams, many others, including garbage and ballast water, have not been included. This study also does not account for illegal and accidental discharges such as stern tube lubricant leakage.

[115] The International Council on Clean Transportation (ICCT). (2020). *Global washwater discharges from scrubbers* [Map]. Retrieved November 24, 2021, from https://arcg.is/1GiPOD

[116] Clarksons Research Services Ltd. (2021). *World Fleet Register* [Dataset]. https://www.clarksons.net/portal

Conversely, this study does not estimate the percentage of sewage, greywater, and bilge water that are discharged at port reception facilities or outside of Canadian waters.

REGULATION IS NEEDED

The regulations that are currently in place in Canada to protect the marine environment from ship-source pollution do not provide adequate protection for conservation areas. This is compounded by the fact that most protected area regulations do not have their own wastewater provisions, or if they do, they do not prohibit operational discharges. In the absence of federal requirements, some ship operators have adopted best practices for protected areas that exceed regulatory requirements. These organizations should be applauded for their efforts, but the fact remains that areas set aside for conservation purposes should not have to rely on goodwill and voluntary measures for protection.

Over the next decade, Canada has committed to adding nearly one million square kilometres of new MPAs and OECMs to meet its marine conservation target of protecting 30 per cent of its ocean and coastal spaces by 2030. All new federally designated protected areas will benefit by default from minimum standards that prohibit oil and gas activities, mining, bottom trawling, and dumping. Although the minimum standards will not immediately apply to existing MPAs, they may be introduced to many of these areas over time as part of their regular management review cycles. For OECMs, however, the minimum standards do not currently apply but could be implemented on a case-by-case basis. The new minimum standards are intended to mitigate the impacts of industrial activities in ocean areas that are recognized for their ecological, scientific, and/or cultural significance. Their successful implementation will enable Canada's MPAs and OECMs to act more effectively as a cohesive network united by a common floor of protections. However, the effectiveness of the minimum standards at preventing ship-source pollution in MPAs and OECMs hinges on the definition of dumping that Canada adopts, and that this standard be implemented for all current and future MPAs and OECMs.

KEY RECOMMENDATIONS

Chronic ship-source pollution has the potential to severely impact fisheries, aquaculture, coastal tourism, subsistence harvesting, and recreational ocean use. Now more than ever we need to reduce industrial pressures on wildlife. This analysis highlights the magnitude of dumping in MPAs and OECMs—and the need to implement solutions. To protect the biodiversity that underpins Canada's identity and economy and to ensure that Canada's most sensitive marine waters are not just protected in name only, WWF-Canada recommends that the Government of Canada:

1. **Create a comprehensive definition of dumping that includes all treated and untreated operational wastes, in particular sewage, greywater, bilge water, and scrubber washwater.** Given the regularity of wastewater treatment system malfunctions and the capacity of even

[117] Teuchies, J., Cox, T. J. S., van Itterbeeck, K., Meysman, F. J. R., & Blust, R. (2020). The impact of scrubber discharge on the water quality in estuaries and ports. *Environmental Sciences Europe, 32*(1). https://doi.org/10.1186/s12302-020-00380-z

fully treated waste to have negative environmental impacts, a prohibition on operational wastes discharges in MPAs and OECMs should apply to both treated and untreated effluents. The adoption of these new standards offers a unique opportunity to develop a clear definition that will prohibit the release of harmful substances in MPAs. Regulations around discharges were not written for areas requiring enhanced protection, so creating this definition will help remove ambiguity for industry on what can be dumped and where. This will also help the industry adapt and play a part in helping achieve Canada's long-term conservation goals of healthy and resilient ecosystems.

2. **Implement the minimum standards for all areas counting toward Canada's marine conservation targets, not just new federal MPAs.** OECMs protected using Canada's *Fisheries Act* currently only manage the impacts of fishing. This analysis shows that large quantities of waste are also dumped in these sites, and as areas important for fish and fish habitat, additional management attention is required.

3. **Enforce the minimum standards in existing MPAs and OECMs.** While it is the intention of the Government of Canada that minimum standards will be implemented in existing MPAs through the management planning process, these results highlight the ongoing issue with dumping, especially in high traffic areas like the Scott Islands marine National Wildlife Area.

4. **Ban scrubbers and promote the use of cleaner alternative fuels..** Scrubbers were developed for use on ships to allow them to continue to burn HFO, the most polluting type of marine fuel. Use of scrubbers also slows the decarbonization of the global shipping fleet by encouraging continued reliance on residual fossil fuels. Not only is scrubber washwater the most prevalent waste stream in our assessment, but scrubbers also encourage continued reliance on heavy fuel oil, which produces harmful black carbon and poses a severe environmental risk if spilled.

5. **Close the Arctic greywater regulatory gap.** Explicitly regulating greywater in the Canadian Arctic will add a needed layer of protection inside and outside Arctic MPAs and OECMs.

As Canada strives to create a national network of MPAs and OECMs, it will be important to ensure that these sites have the best possible outcomes for wildlife and the people that depend on them. Ensuring that substances known to cause harm to wildlife are not dumped in MPAs and OECMs will be key to achieving this outcome.

APPENDIX I: SHIP CLASSIFICATION DATA MATRIX

TABLE I. Reclassification of vessel types into ship class. Passenger ship classes include cruise ships, ferries, and yachts.

SHIP CLASS	VESSEL TYPE	SHIP CLASS	VESSEL TYPE
BULK CARRIER	Bulk carrier	NAVAL SHIP	Aircraft carrier
	Bulk/oil carrier		Destroyer
	Cement carrier		Frigate
	Chip carrier		Icebreaker AGB
	Covered bulk cargo barge		Patrol vessel
	Forest product carrier		Patrol vessel, naval
	Gypsum carrier		Research vessel, naval auxiliary
	Open hatch carrier		Submarine salvage vessel
	Ore carrier		Training ship, naval auxiliary
	Salt carrier	OFFSHORE	Accommodation vessel
	Slurry carrier		Cable layer (fibre optic)
CHEMICAL TANKER	Chemical & oil carrier		Cable, umbilicals & FP/flowline lay
CONTAINER	Fully cellular container		Crew boat
CRUISE	Cruise ship		Geophysical survey
FERRY PAX ONLY	Passenger vessel		Hydrographic survey
RO-PAX	Pass./car catamaran vessel		Maintenance
	Pass./car ferry		Multi-purpose support
	Passenger/cargo vessel		Oceanographic survey
	Passenger/ro-ro (inland)		Oilfield pollution control
	Ro-ro freight/passenger		ROV/submersible support
FISHING	Factory stern trawler		Research vessel
	Fish factory ship		Seismic support
	Fishery patrol vessel		Seismic survey
	Fishery research vessel		Semi-submersible heavy lift
	Fishery support vessel		Transport (heavy lift)
	Fishing vessel		Utility/workboat
	Live fish carrier (well boat)	OIL TANKER	Oil bunkering tanker
	Stern trawler		Shuttle tanker
	Trawler		Tanker

GENERAL CARGO	Aggregates carrier	**OTHER LIQUID TANKERS**	Asphalt & bitumen carrier
	Barge carrier		Methanol carrier
	Cement carrier		Product carrier
	General cargo		Replenishment tanker
	Heavy lift cargo vessel	**REFRIGERATED**	Reefer
	Landing craft		Reefer fish carrier
	Livestock carrier	**RO-RO**	Logistics vessel (naval ro-ro cargo)
	Multi-purpose		Pure car carrier
	Multi-purpose/heavy lift cargo		Ro-ro
	Replenishment dry cargo vessel		Ro-ro/container
LIQUEFIED GAS TANKER	Ethylene/LPG	**SERVICE OTHER**	Backhoe/dipper/grab dredger
	LNG carrier		Dredgers (stone dumping, fallpipe)
	LNG/ethylene/LPG		Trailing suction hopper dredger
	LNG/regasification	**TUG/TOWING**	Anchor handling tug
	LPG carrier		Anchor handling tug/supply
FISHING	Anti-pollution vessel		Crew/fast supply vessel
	Buoy/lighthouse tender		Fire-fighting tug
	FPSO		Ocean-going tug
	Icebreaker		Platform supply
	Jack-up drilling rig		Supply
	Jack-up production unit		Towing/pushing (inland)
	Marine research		Tug
	Pilot vessel		Tug, anchor hoy
	Salvage vessel		Tug, naval auxiliary
	Semi-submersible drilling rig		Transport (heavy lift)
	Supply tender	**YACHT**	Motor yacht
	Training ship		Sailing vessel
	Work/repair vessel		Yacht (sailing)

TABLE II. Ships classes included and excluded from the analysis

INCLUDED SHIP CLASSES	
Bulk carrier	Liquified gas tanker
Chemical tanker	Oil tanker
Container	Other liquid tankers
Cruise	Refrigerated
Ferry pax only	Ro-ro
Ferry ro-pax	Tug/towing
Fishing	Yacht
General cargo	
Non-included ship classes	
Miscellaneous others	Offshore
Naval ship	Service other

APPENDIX II: AUXILIARY ENGINE AND BOILER OUTPUT DECISION MATRIX

TABLE I. Decision matrix for determining auxiliary engine and boiler output by ship class, capacity, and operational phase.

SHIP CLASS	SIZE	UNIT	AUXILIARY BOILER POWER OUTPUT (kW)				AUXILIARY BOILER POWER OUTPUT (kW)			
			Berth	Anchor	Maneu-vering	Cruis-ing	Berth	Anchor	Maneu-vering	Cruis-ing
BULK CARRIER	0–34,999	DWT	70	70	60	0	110	180	500	190
	35,000–59,999		130	130	120	0	150	250	680	260
	>60,000		260	260	240	0	240	400	1,100	410
CHEMICAL TANKER	0–4,999	DWT	670	160	130	0	110	170	190	200
	5,000–9,999		670	160	130	0	330	490	560	580
	10,000–19,999		1,000	240	200	0	330	490	560	580
	>20,000		1,350	320	270	0	790	550	900	660
CONTAIN-ER	0–999	TEU	250	250	240	0	370	450	790	410
	1,000–1,999		340	340	310	0	820	910	1,750	900
	2,000–2,999		460	450	430	0	610	910	1,900	920
	3,000–4,999		480	480	430	0	1,100	1,350	2,500	1,400
	5,000–7,999		590	590	550	0	1,100	1,400	2,800	1,450
	8,000–11,999		620	620	540	0	1,150	1,600	2,900	1,800
	12,000–14,999		630	630	630	0	1,300	1,800	3,250	2,050
	15,000–19,999		630	630	630	0	1,400	1,950	3,600	2,300
	>20,000		700	700	700	0	1,400	1,950	3,600	2,300
CRUISE	0–9,999	GT	1,100	950	980	0	450	450	580	450
	10,000–59,999		1,100	950	980	0	3,500	3,500	5,500	3,500
	>60,000		1,100	950	980	0	11,500	11,500	14,900	1,1500
FERRY PAX ONLY	0–1,999	GT	0	0	0	0	190	190	190	190
	>2,000		0	0	0	0	520	520	520	520

FERRY ROPAX	0–1,999	GT	260	250	170	0	105	105	105	105
	2,000–4,999		260	250	170	0	330	330	330	330
	5,000–9,999		260	250	170	0	670	670	670	670
	10,000–19,999		390	380	260	0	1,100	1,100	1,100	1,100
	>20,000		390	380	260	0	1,950	1,950	1,950	1,950
FISHING	All	GT	0	0	0	0	200	200	200	200
GENERAL CARGO	0–4,999	DWT	0	0	0	0	90	50	180	60
	5,000–9,999		110	110	100	0	240	130	490	180
	>10,000		150	150	130	0	720	370	1450	520
	0–49,999	CBM	1,000	200	200	100	240	240	360	240
LIQUEFIED GAS TANKER	50,000–99,999		1,000	200	200	100	1,700	1,700	2,600	1,700
	100,000–199,999		1,500	300	300	150	2,500	2,000	2,300	2,650
	>200,000		3,000	600	600	300	6,750	7,200	7,200	6,750
OIL TANKER	0–4,999	DWT	500	100	100	0	250	250	375	250
	5,000–9,999		750	150	150	0	375	375	560	375
	10,000–19,999		1,250	250	250	0	690	500	580	490
	20,000–59,999		2,700	270	270	270	720	520	600	510
	60,000–79,999		3,250	360	360	280	620	490	770	560
	80,000–119,999		4,000	400	400	280	800	640	910	690
	120,000–199,999		6,500	500	500	300	2,500	770	1,300	860
	200,000		7,000	600	600	300	2,500	770	1,300	860
OTHER LIQUID TANKERS	All	DWT	1,000	200	200	100	500	500	750	500
REFRIGER-ATED	0–1,999	DWT	270	270	270	0	520	570	560	570
	2,000–5,999		270	270	270	0	1100	1,200	1,150	1,200
	6,000–9,999		270	270	270	0	1,500	1,650	1,600	1,650
	>10,000		270	270	270	0	2,850	3,100	3,000	3,100

RO-RO	0 – 4,999	DWT	260	250	170	0	750	430	1,300	430
	5,000–9,999		260	250	170	0	1,100	680	2,100	680
	>10,000		390	380	260	0	1,200	950	2,700	950
TUG/ TOWING	All	GT	0	0	0	0	100	80	210	80
YACHT	All	GT	0	0	0	0	130	130	130	130

APPENDIX III: WASTE GENERATED IN CANADA'S MARINE PROTECTED AND CONSERVED AREAS

TABLE I. Breakdown of waste generation by Canadian marine protected and conserved areas (CPCA) for all waste streams. Blank values indicate that no waste was generated in these areas.

WASTE STREAM GENERATION WITHIN CPCAS	AREA (KM2)	GREYWATER (L)	SEWAGE (L)	BILGE WATER (L)	SCRUBBER WASHWATER (T), INCL. 2020–22
Total	**5,740,544**	**3,572,407,838**	**549,783,191**	**77,490,828**	**145,581,216**
AHIAK BIRD SANCTUARY	6,553	-	-	-	-
AKIMISKI ISLAND BIRD SANCTUARY	1,472	-	-	-	-
AKPAIT NATIONAL WILDLIFE AREA	743	485	79	111	-
ANDERSON RIVER DELTA BIRD SANCTUARY	161	-	-	-	-
ANGUNIAQVIA NIQIQYUAM MARINE PROTECTED AREA	2,358	39,681	5,525	1,739	-
AULAVIK NATIONAL PARK OF CANADA	97	-	-	-	-
AUYUITTUQ NATIONAL PARK OF CANADA	865	-	-	-	-
BAIE DE BRADOR MIGRATORY BIRD SANCTUARY	5	1,948	390	14	-
BAIE DES LOUPS MIGRATORY BIRD SANCTUARY	37	-	-	-	-
BANC-DES-AMÉRICAINS MARINE PROTECTED AREA	1,000	5,146	777	22,452	38,799
BANKS ISLAND BIRD SANCTUARY NO. 1	825	-	-	-	-
BANKS ISLAND BIRD SANCTUARY NO. 2	33	-	-	-	-
BASIN HEAD MARINE PROTECTED AREA	9	37,520	7,504	212	-
BAY OF ISLANDS SALMON MIGRATION CLOSURE	217	4,265,418	592,991	111,813	82,319
BEAUGÉ BANK SPONGE CONSERVATION AREA	215	39,696	6,518	2,997	2,041
BETCHOUANE MIGRATORY BIRD SANCTUARY	5	-	-	-	-
BIG GLACE BAY LAKE BIRD SANCTUARY	3	-	-	-	-
BOATSWAIN BAY MIGRATORY BIRD SANCTUARY	69	-	-	-	-
BONAVENTURE ISLAND AND PERCÉ ROCK MIGRATORY BIRD SANCTUARY	9	136,105	18,751	2,797	-

BOOT ISLAND NATIONAL WILDLIFE AREA	1	-	-	-	-
BYLOT ISLAND BIRD SANCTUARY	1,765	130,102	17,697	3,278	106
CAP-SAINT-IGNACE MIGRATORY BIRD SANCTUARY	1	-	-	-	-
CAPE JOURIMAIN NATIONAL WILDLIFE AREA	4	-	-	-	-
CENTRAL GULF OF ST. LAWRENCE CORAL CONSERVATION AREA	1,284	40,276	7,764	3,537	12,786
CORSAIR AND GEORGES CANYONS CONSERVATION AREA (RESTRICTED BOTTOM FISHERIES ZONE)	8,797	17,641,173	2,437,381	427,482	530,209
DAVIS STRAIT CONSERVATION AREA	17,298	99,763	15,824	13,543	9,277
DISKO FAN CONSERVATION AREA (PORTION CLOSED TO ALL BOTTOM-CONTACT FISHING)	7,485	65,177	11,355	7,725	8,556
DIVISION 3O CORAL CLOSURE	10,422	985,857	142,137	36,441	133,684
EAST OF ANTICOSTI ISLAND SPONGE CONSERVATION AREA	939	84,103	13,626	4,324	11,805
EASTERN GULF OF ST. LAWRENCE CORAL CONSERVATION AREA	423	945,690	145,846	46,626	121,875
EASTERN HONGUEDO STRAIT CORAL AND SPONGE CONSERVATION AREA	2,338	11,042,635	1,654,976	427,095	907,338
EASTPORT – DUCK ISLAND MARINE PROTECTED AREA AND ROUND ISLAND MARINE PROTECTED AREA	2	-	-	-	-
ENDEAVOUR HYDROTHERMAL VENTS MARINE PROTECTED AREA	97	1,619	317	369	-
ESQUIMALT LAGOON MIGRATORY BIRD SANCTUARY	1	-	-	-	-
FORILLON NATIONAL PARK OF CANADA	4	27	4	11	-
FUNK ISLAND DEEP CLOSURE	7,274	259,548	36,459	21,596	12,012
GEORGE C. REIFEL MIGRATORY BIRD SANCTUARY	2	-	-	-	-
GILBERT BAY MARINE PROTECTED AREA	62	-	-	-	-
GRAND MANAN BIRD SANCTUARY	1	48	6	12	-
GROS-MÉCATINA MIGRATORY BIRD SANCTUARY	22	16	3	4	-

GULF ISLANDS NATIONAL PARK RESERVE OF CANADA	6	440,942	87,883	3,652	134
GULLY MARINE PROTECTED AREA	2,363	60,552	10,000	5,614	12,509
GWAII HAANAS NATIONAL MARINE CONSERVATION AREA RESERVE & HAIDA HERITAGE SITE	3,473	341,787	47,038	30,632	20,906
HANNAH BAY BIRD SANCTUARY	61	-	-	-	-
HATTON BASIN CONSERVATION AREA	42,459	133,901	22,901	27,985	4,433
HAWKE CHANNEL CLOSURE	8,837	505,801	71,787	21,630	20,211
HECATE STRAIT AND QUEEN CHARLOTTE SOUND GLASS SPONGE REEFS MARINE PROTECTED AREAS	2,410	22,707,779	3,054,893	259,811	1,667,219
HOPEDALE SADDLE CLOSURE	15,411	138,328	22,974	45,075	734
IKATTUAQ BIRD SANCTUARY	191	-	-	-	-
ÎLE À LA BRUME MIGRATORY BIRD SANCTUARY	38	1,349	270	17	-
ÎLE AUX BASQUES MIGRATORY BIRD SANCTUARY	6	-	-	-	-
ÎLE AUX CANES MIGRATORY BIRD SANCTUARY	1	-	-	-	-
ÎLE DU COROSSOL MIGRATORY BIRD SANCTUARY	3	-	-	-	-
ISULIJARNIK BIRD SANCTUARY	1,592	-	-	-	-
IVVAVIK NATIONAL PARK OF CANADA	79	-	-	-	-
JACQUES-CARTIER STRAIT SPONGE CONSERVATION AREA	346	241,061	38,686	15,007	17,017
JOHN LUSBY MARSH NATIONAL WILDLIFE AREA	5	-	-	-	-
JORDAN BASIN CONSERVATION AREA	49	48,139	6,712	964	3,162
KEJIMKUJIK NATIONAL PARK AND NATIONAL HISTORIC SITE OF CANADA	1	-	-	-	-
KENDALL ISLAND BIRD SANCTUARY	133	-	-	-	-
KOUCHIBOUGUAC NATIONAL PARK OF CANADA	42	-	-	-	-
KUUGAAYUK BIRD SANCTUARY	132	-	-	-	-
L'ISLE-VERTE MIGRATORY BIRD SANCTUARY	3	-	-	-	-

LAURENTIAN CHANNEL MARINE PROTECTED AREA	11,580	2,487,433	419,212	163,363	439,277
LOBSTER AREA CLOSURE (GLOVERS HARBOUR)	94	17	3	1	-
LOPHELIA CORAL CONSERVATION AREA	15	328	66	63	223
MACHIAS SEAL ISLAND BIRD SANCTUARY	10	35	7	4	-
MAGDALEN ISLANDS LAGOONS CLOSURES (6 OVERLAPPING CLOSURES)	136	71,250	14,192	8,255	-
MIRAMICHI BAY CLOSURE	1,468	70,454	10,803	2,821	1,953
MONTMAGNY MIGRATORY BIRD SANCTUARY	1	-	-	-	-
MOOSE RIVER MIGRATORY BIRD SANCTUARY	5	-	-	-	-
MUSQUASH ESTUARY MARINE PROTECTED AREA	7	-	-	-	-
NANUIT ITILLINGA NATIONAL WILDLIFE AREA	215	-	-	-	-
NINGINGANIQ NATIONAL WILDLIFE AREA	2,834	7v5	9,673	1,043	-
NIRJUTIQARVIK NATIONAL WILDLIFE AREA	1,442	64,744	8,701	919	-
NORTH OF BENNETT BANK CORAL CONSERVATION AREA	821	1,491,588	227,985	65,596	155,962
NORTHEAST CHANNEL CORAL CONSERVATION AREA (RESTRICTED BOTTOM FISHERIES ZONE)	391	164,508	23,893	5,805	18,887
NORTHEAST NEWFOUNDLAND SLOPE CLOSURE	55,353	2,736,116	386,750	66,354	191,615
OFFSHORE PACIFIC SEAMOUNTS AND VENTS CLOSURE	82,530	21,441,667	3,211,241	1,169,976	3,747,165
PACIFIC RIM NATIONAL PARK RESERVE OF CANADA	228	9,159	1,351	2,181	-
PARENT BANK SPONGE CONSERVATION AREA	530	298,218	51,086	12,839	10,423
PINGO CANADIAN LANDMARK	5	-	-	-	-
PORT HEBERT BIRD SANCTUARY	3	-	-	-	-
PORT JOLI BIRD SANCTUARY	3	-	-	-	-
PRINCE LEOPOLD ISLAND BIRD SANCTUARY	240	80,754	10,852	1,119	-
QAQSAUQTUUQ SANCTUARY	287	-	-	-	-

QAQULLUIT NATIONAL WILDLIFE AREA	396	112	15	32	-
QAUSUITTUQ NATIONAL PARK OF CANADA	1,178	48	6	16	-
QUTTINIRPAAQ NATIONAL PARK OF CANADA	2,381	-	-	-	-
ROCHERS AUX OISEAUX MIGRATORY BIRD SANCTUARY	6	156	31	1	-
SABLE RIVER BIRD SANCTUARY	3	-	-	-	-
SAGUENAY-ST. LAWRENCE MARINE PARK	1,247	41,557,018	6,741,806	692,370	1,050,405
SAGUENAY FJORD UPSTREAM CLOSURE	109	-	-	-	-
SAINT-AUGUSTIN MIGRATORY BIRD SANCTUARY	54	6,239	1,245	71	-
SAINT-OMER MIGRATORY BIRD SANCTUARY	<1	-	-	-	-
SAINT-VALLIER MIGRATORY BIRD SANCTUARY	4	-	-	-	-
SAINTE-MARIE ISLANDS MIGRATORY BIRD SANCTUARY	40	80	16	2	-
SAMBRO BANK SPONGE CONSERVATION AREA	260	121,037	18,219	6,165	12,950
SCALLOP BUFFER ZONE (SFA 21)	477	493,088	98,557	77,979	7,513
SCALLOP BUFFER ZONE (SFA 22)	2,853	132,951	20,776	17,086	1,688
SCALLOP BUFFER ZONE (SFA 24)	2,095	15,052,281	2,900,654	109,854	105,523
SCOTT ISLANDS MARINE NATIONAL WILDLIFE AREA	11,571	56,592,265	7,640,878	722,421	4,126,495
SEYMOUR ISLAND BIRD SANCTUARY	51	-	-	-	-
SGAAN KINGHLAS – BOWIE SEAMOUNT MARINE PROTECTED AREA	6,103	163,391	32,263	27,643	112,345
SHOAL HARBOUR MIGRATORY BIRD SANCTUARY	1	-	-	-	-
SIRMILIK NATIONAL PARK OF CANADA	233	-	-	-	-
SLOPE OF MAGDALEN SHALLOWS CORAL CONSERVATION AREA	335	1,456,464	221,993	67,001	160,777
SOUTH-EAST OF ANTICOSTI ISLAND SPONGE CONSERVATION AREA	845	19,596	3,919	2,132	4,786
ST ANNS BANK MARINE PROTECTED AREA	4,364	4,956,798	708,260	116,323	386,073
STRAIT OF GEORGIA AND HOWE SOUND GLASS SPONGE REEF CLOSURE (SECHELT)	33	1,881,329	339,420	13,379	29,495

TALLURUTIUP IMANGA NATIONAL MARINE CONSERVATION AREA	108,367	9,371,295	1,331,454	264,589	41,676
TARIUM NIRYUTAIT MARINE PROTECTED AREA	1,750	2,846	569	673	-
TERRA NOVA BIRD SANCTUARY	12	-	-	-	-
TROIS-SAUMONS MIGRATORY BIRD SANCTUARY	2	-	-	-	-
TUVAIJUITTUQ MARINE PROTECTED AREA	319,411	3,208	642	518	-
UKKUSIKSALIK NATIONAL PARK OF CANADA	3,079	-	-	-	-
VICTORIA HARBOUR MIGRATORY BIRD SANCTUARY	19	7,386,921	995,374	80,464	84,845
WALLACE BAY NATIONAL WILDLIFE AREA	3	-	-	-	-
WAPUSK NATIONAL PARK OF CANADA	805	-	-	-	-
WATSHISHOU MIGRATORY BIRD SANCTUARY	108	-	-	-	-
WESTERN HONGUEDO STRAIT CORAL CONSERVATION AREA	496	3,729,107	548,752	121,734	243,385
WESTERN/EMERALD BANKS CONSERVATION AREA (RESTRICTED FISHERIES ZONE)	10,234	865,154	147,012	83,433	175,301
Total	**787,665**	**233,221,208**	**34,606,748**	**5,448,787**	**14,725,897**
Per cent of Total in Canadian waters	**13.72**	**6.53**	**6.29**	**7.03**	**10.12**

TABLE II. Waste generation by ship type on each coast and within MPAs and OECMs.

GREYWATER (L)							
SHIP TYPE	**WEST COAST**	**ARCTIC**	**EAST COAST**	**CENTRAL**	**TOTAL REGIONS**	**MPAs**	**MPA PER CENT OF TOTAL**
BULK CARRIER	37,927,673.35	3,819,663.54	43,425,572.94	74,775.21	85,247,685.03	8,769,867.75	10.29
CHEMICAL TANKER	3,458,589.60	1,001,991.51	19,990,537.89	64,943.68	24,516,062.70	1,912,570.35	7.80
CONTAINER	19,443,468.91	-	20,054,654.86	-	39,498,123.77	3,394,033.29	8.59
CRUISE	1,710,482,495.62	24,831,630.21	751,243,144.76	-	2,486,557,270.59	183,460,677.47	7.38
FERRY PAX ONLY	13,102,222.77	-	23,631,529.69	-	36,733,752.46	3,630,651.66	9.88
FERRY RO-PAX	516,761,332.29	-	276,041,904.42	-	792,803,236.71	27,798,280.94	3.51
FISHING	6,962,759.96	2,594,707.44	12,528,266.69	-	22,085,734.08	1,089,869.00	4.93
GENERAL CARGO	2,067,349.86	2,290,370.47	15,309,301.26	219,476.99	19,886,498.59	1,889,041.52	9.50
LIQUEFIED GAS TANKER	499,813.24	-	552,823.20	-	1,052,636.44	87,305.50	8.29

OIL TANKER	2,199,388.02	-	8,552,135.00	-	10,751,523.02	561,000.93	5.22
OTHER LIQUID TANKERS	372,842.92	255,681.42	5,252,598.98	-	5,881,123.32	322,957.73	5.49
REFRIG-ERATED	751,548.75	-	392,759.54	-	1,144,308.29	18,576.65	1.62
RO-RO	10,709,486.75	-	11,159,625.22	-	21,869,111.97	1,121,586.26	5.13
TUG/ TOWING	10,476,250.60	446,605.04	11,910,097.34	28,810.11	22,861,763.09	419,427.76	1.83
YACHT	874,104.91	197,978.90	447,075.57	-	1,519,159.38	133,983.76	8.82
Total	**2,336,089,327.53**	**35,438,628.53**	**1,200,492,027.36**	**388,006.00**	**3,572,407,989.43**	**234,609,830.57**	**6.57**

GREYWATER (L)

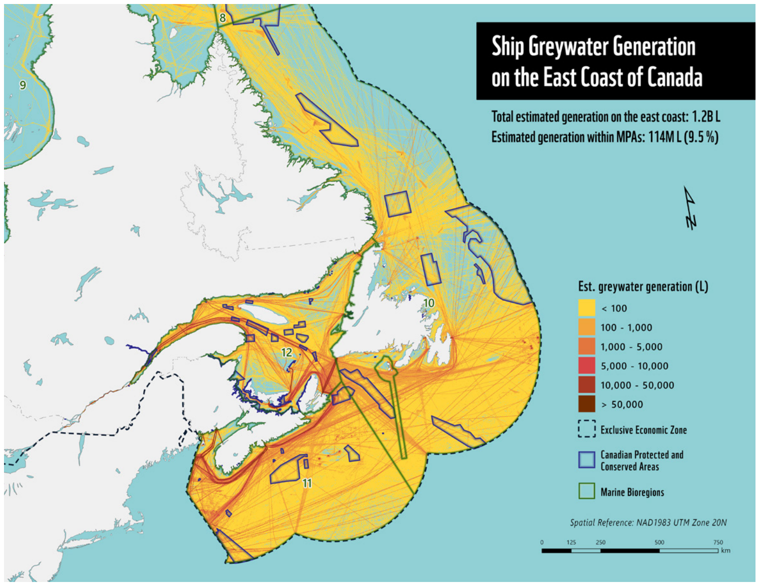
SHIP TYPE	WEST COAST	ARCTIC	EAST COAST	CENTRAL	TOTAL REGIONS	MPAs	MPA PER CENT OF TOTAL
BULK CARRIER	7,585,534.67	763,932.71	8,685,114.59	14,955.04	17,049,537.01	1,753,973.55	10.29
CHEMICAL TANKER	691,717.92	200,398.30	3,998,107.58	12,988.74	4,903,212.54	382,514.07	7.80
CONTAIN-ER	3,888,693.78	-	4,010,930.97	-	7,899,624.75	678,806.66	8.59
CRUISE	229,867,212.85	3,337,057.02	100,957,576.77	-	334,161,846.64	24,654,794.60	7.38
FERRY PAX ONLY	2,620,444.55	-	4,726,305.94	-	7,346,750.49	726,130.33	9.88
FERRY RO-PAX	103,352,266.46	-	55,208,380.88	-	158,560,647.34	5,559,656.19	3.51
FISHING	935,706.87	348,695.86	1,683,640.58	-	2,968,043.32	146,464.61	4.93
GENERAL CARGO	413,469.97	458,074.09	3,061,860.25	43,895.40	3,977,299.72	377,808.30	9.50
LIQUE-FIED GAS TANKER	99,962.65	-	110,564.64	-	210,527.29	17,461.10	8.29
OIL TANKER	439,877.60	-	1,710,427.00	-	2,150,304.60	112,200.19	5.22
OTHER LIQUID TANKERS	74,568.58	51,136.28	1,050,519.80	-	1,176,224.66	64,591.55	5.49
REFRIG-ERATED	150,309.75	-	78,551.91	-	228,861.66	3,715.33	1.62
RO-RO	2,141,897.35	-	2,231,925.04	-	4,373,822.39	224,317.25	5.13
TUG/ TOWING	2,095,250.12	89,321.01	2,382,019.47	5,762.02	4,572,352.62	83,885.55	1.83
YACHT	117,468.64	26,605.86	60,081.30	-	204,155.81	18,005.72	8.82
Total	**354,474,381.77**	**5,275,221.14**	**189,956,006.72**	**77,601.20**	**549,783,210.84**	**34,804,325.00**	**6.33**

BILGE WATER (L)							
SHIP TYPE	WEST COAST	ARCTIC	EAST COAST	CENTRAL	TOTAL REGIONS	MPAs	MPA PER CENT OF TOTAL
BULK CARRIER	4,474,474.34	509,056.25	5,174,260.78	7,697.01	10,165,488.39	1,051,077.69	10.34
CHEMICAL TANKER	448,798.49	116,378.49	2,692,917.29	7,460.43	3,265,554.70	255,703.79	7.83
CONTAIN-ER	8,122,100.39	-	5,313,417.86	-	13,435,518.25	1,108,969.82	8.25
CRUISE	15,352,377.13	318,947.33	7,144,969.49	-	22,816,293.95	1,807,859.22	7.92
FERRY PAX ONLY	73,778.43	-	90,657.36	-	164,435.79	11,193.42	6.81
FERRY RO-PAX	2,289,754.71	-	2,120,238.31	-	4,409,993.01	177,915.14	4.03
FISHING	2,334,355.24	1,405,069.90	5,171,387.14	-	8,910,812.28	398,528.20	4.47
GENERAL CARGO	172,240.28	204,712.28	1,326,553.56	19,221.02	1,722,727.15	174,077.29	10.10
LIQUE-FIED GAS TANKER	70,139.82	-	87,876.23	-	158,016.04	12,314.29	7.79
OIL TANKER	582,508.34	-	1,973,211.33	-	2,555,719.67	130,947.37	5.12
OTHER LIQUID TANKERS	66,917.42	42,686.22	893,037.97	-	1,002,641.61	54,184.22	5.40
REFRIG-ERATED	59,381.80	-	37,865.90	-	97,247.70	2,070.91	2.13
RO-RO	1,328,777.94	-	966,536.01	-	2,295,313.95	130,902.18	5.70
TUG/ TOWING	2,360,584.44	118,794.55	3,695,802.79	5,674.91	6,180,856.70	102,965.29	1.67
YACHT	190,709.45	36,050.83	83,554.99	-	310,315.27	25,890.85	8.34
Total	**37,926,898.22**	**2,751,695.87**	**36,772,287.01**	**40,053.36**	**77,490,934.46**	**5,444,599.69**	**7.03**

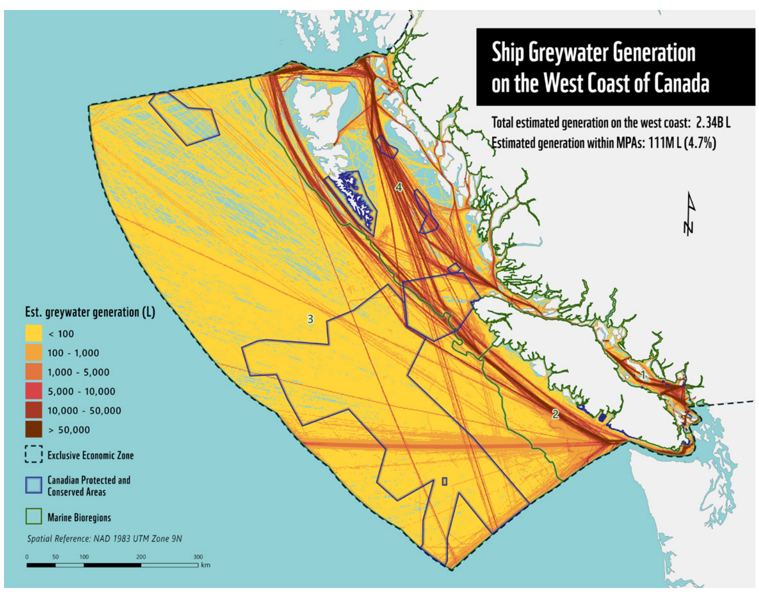
SCRUBBER WASHWATER (T)							
SHIP TYPE	WEST COAST	ARCTIC	EAST COAST	CENTRAL	TOTAL REGIONS	MPAs	MPA PER CENT OF TOTAL
BULK CARRIER	4,738,297.53	189,908.03	5,766,144.56	1,496.77	10,695,846.88	1,639,274.19	15.33
CHEMICAL TANKER	525,616.38	49,181.57	7,172,454.81	-	7,747,252.75	492,214.29	6.35
CONTAIN-ER	12,999,753.68	-	4,051,543.12	-	17,051,296.80	2,646,686.09	15.52
CRUISE	68,312,789.36	-	27,800,377.53	-	96,113,166.88	8,816,249.59	9.17

FERRY PAX ONLY	-	-	-	-	-	-	
FERRY RO-PAX	-	-	-	-	-	-	
FISHING	-	-	-	-	-	-	
GENERAL CARGO	44,651.40	106,488.31	2,913,523.22	8,005.80	3,072,668.72	337,575.20	10.99
LIQUE-FIED GAS TANKER	60,123.99	-	16,528.07	-	76,652.05	8,381.17	10.93
OIL TANKER	34,830.33	-	1,551,020.25	-	1,585,850.57	69,719.85	4.40
OTHER LIQUID TANKERS	83,656.05	71,207.73	179,997.98	-	334,861.77	28,658.16	8.56
REFRIG-ERATED	-	-	-	-	-	-	
RO-RO	727,829.57	-	8,175,790.25	-	8,903,619.82	685,374.51	7.70
TUG/ TOWING	-	-	-	-	-	-	
YACHT	-	-	-	-	-	-	
Total	**87,527,548.28**	**416,785.63**	**57,627,379.78**	**9,502.57**	**145,581,216.26**	**14,724,133.05**	**10.11**

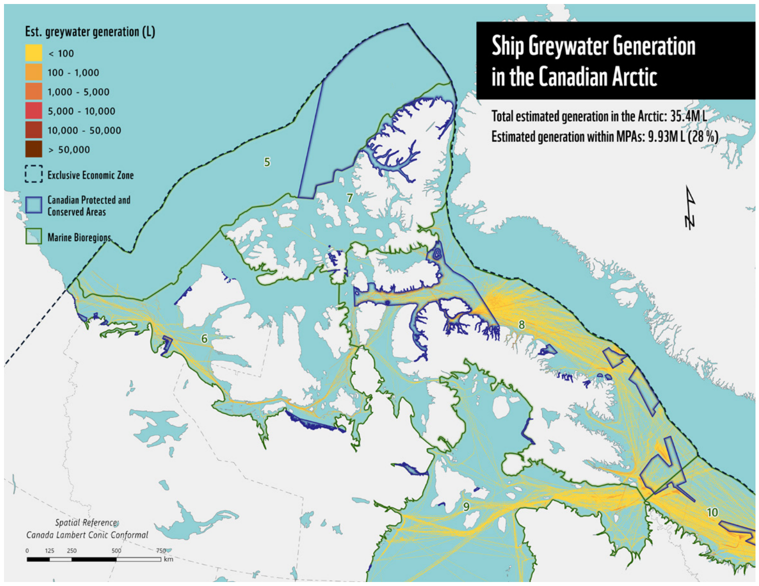
APPENDIX IV



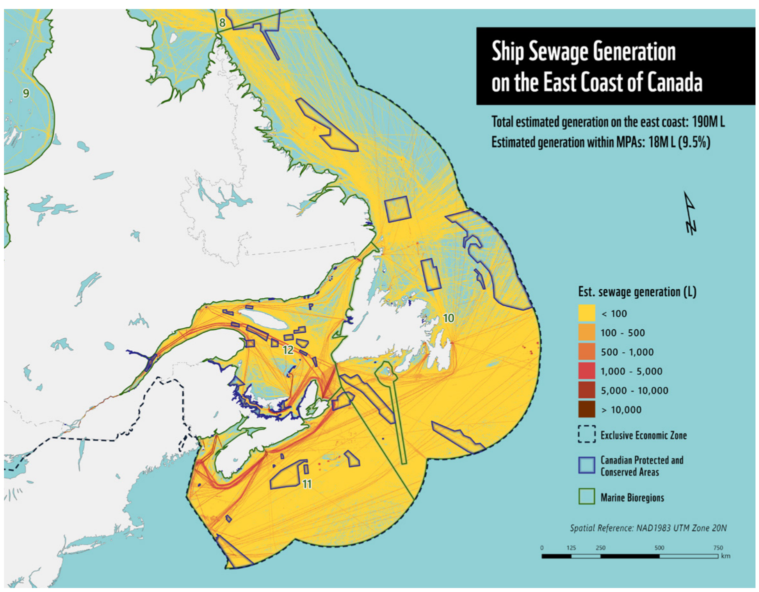
MAP I. Modeled greywater generation on Canada's East Coast.



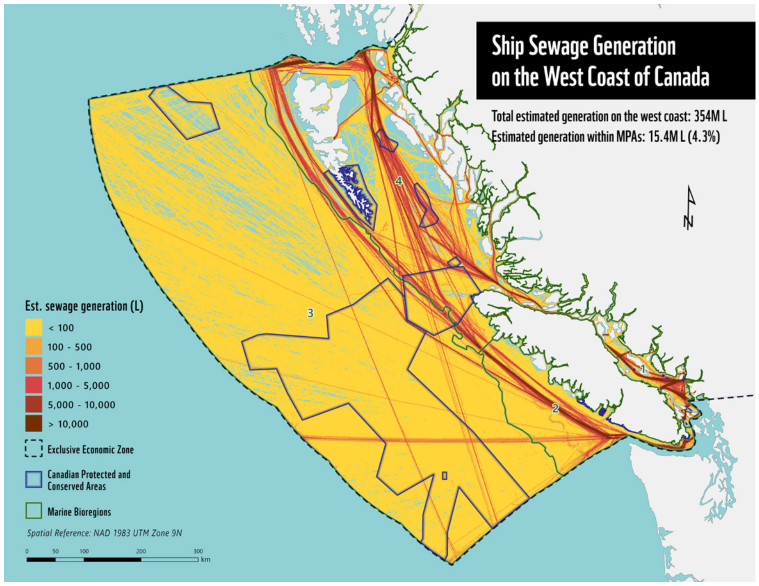
MAP II. Modeled greywater generation on Canada's West Coast.



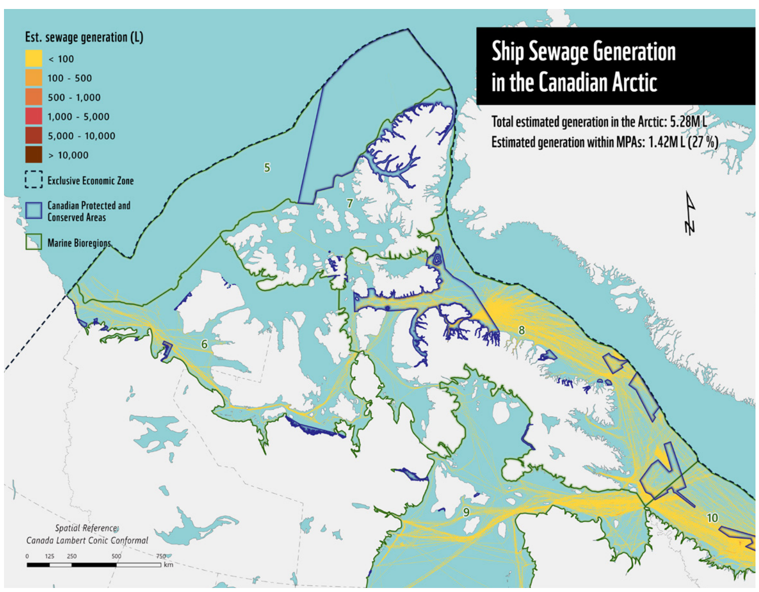
MAP III. Modeled greywater generation in the Canadian Arctic.



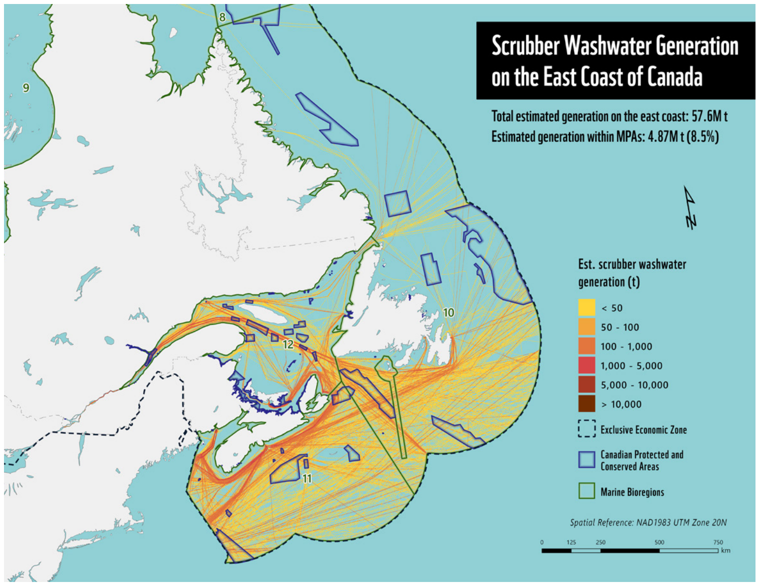
MAP IV. Modeled sewage generation on Canada’s East Coast.



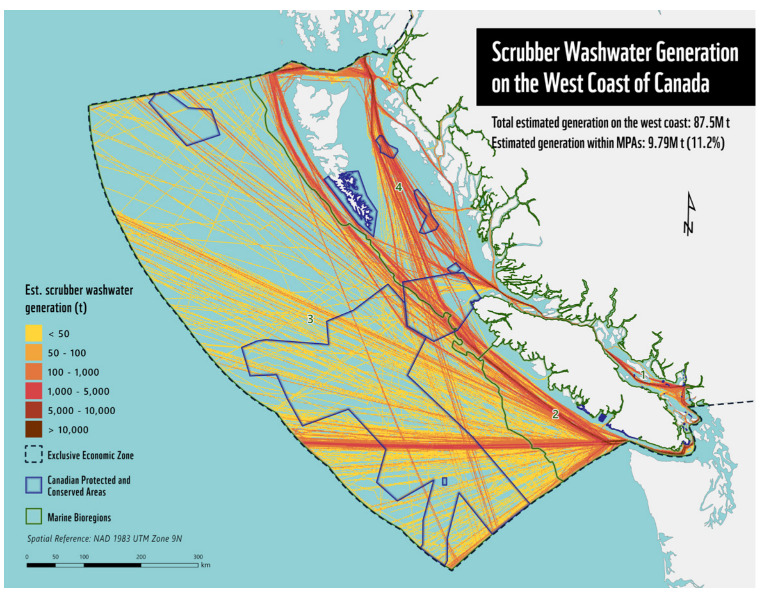
MAP V. Modeled sewage generation on Canada's West Coast.



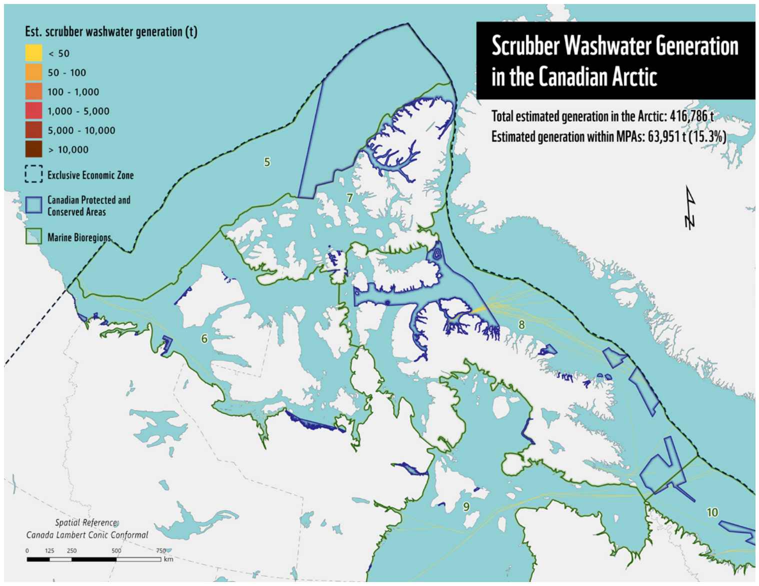
MAP VI. Modeled sewage generation in the Canadian Arctic.



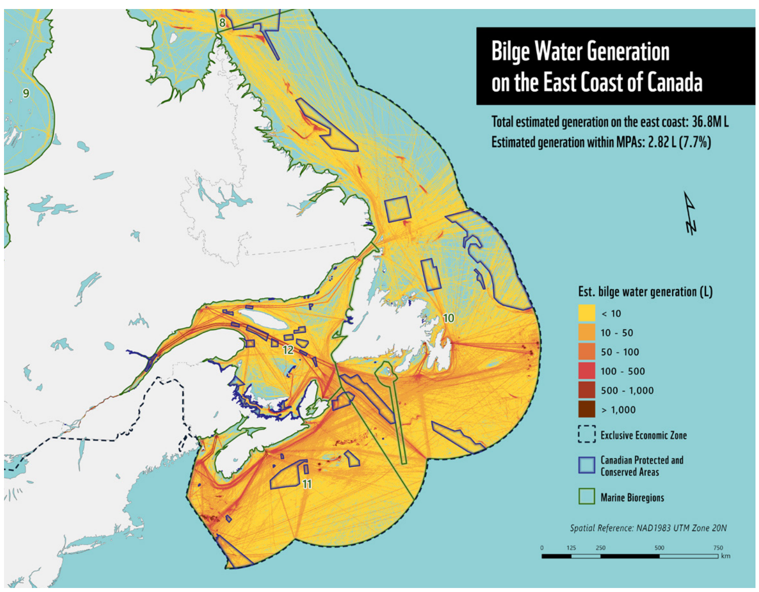
MAP VII. Modeled scrubber washwater generation on Canada's East Coast.



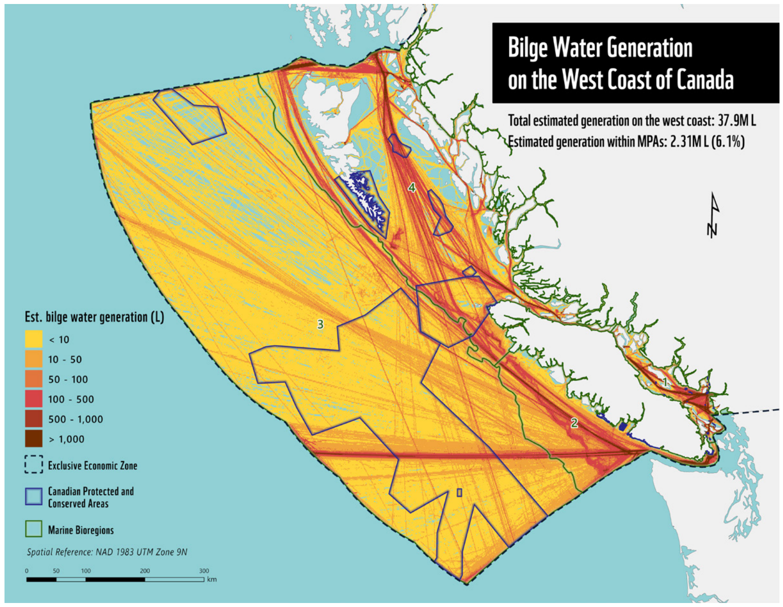
MAP VIII. Modeled scrubber washwater generation on Canada's West Coast.



MAP IX. Modeled scrubber washwater generation in the Canadian Arctic.



MAP X. Modeled bilge water generation on Canada’s East Coast.



MAP XI. Modeled bilge water generation on Canada's West Coast.

THANK YOU

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