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Global scrubber washwater discharges under IMO's 2020 fuel sulfur limit

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Interactive map: An interactive map showing the distribution of scrubber washwater discharges can be accessed at this link: https://theicct.org/publications/global-scrubber-discharges-Apr2021

Supplemental data: A spreadsheet summarizing the amount of scrubber washwater discharges within each country's Exclusive Economic Zone, territorial seas, internal waters, major ports, and from ships that fly each country's flag can is available at the web page for this report: https://theicct.org/publications/global-scrubber-discharges-Apr2021

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

When the International Maritime Organization's (IMO) global fuel sulfur limit came into force on January 1, 2020, it reduced the maximum sulfur content for marine fuels from 3.5% to 0.50%, except for ships that have an exhaust gas cleaning system, also known as a scrubber. While most ships now use 0.50% sulfur fuel, many ship owners have installed scrubbers rather than switch to the more expensive low-sulfur fuel, and the number of ships in the international shipping fleet fitted with scrubbers increased from 243 in 2015 to more than 4,300 in 2020.

Although scrubbers are effective at reducing sulfur dioxide from ship exhaust, previous International Council on Clean Transportation research has shown that using scrubbers results in higher amounts of carbon dioxide, particulate matter, and black carbon compared with using marine gas oil (MGO), the lowest-sulfur fuel used by ocean-going vessels. Additionally, we found that using scrubbers creates water pollution that is not well regulated. The most popular type of scrubber, open loop, constantly discharges large amounts of washwater that is acidic and contains polycyclic aromatic hydrocarbons (PAHs), particulate matter, nitrates, nitrites, and heavy metals including nickel, lead, copper, and mercury, all of which are discharged to the aquatic environment where they can damage marine ecosystems and wildlife and worsen water quality. Closed-loop scrubbers emit the same pollutants in lower volumes, but higher concentrations.

Until this study, there has been no estimate of the amount and location of washwater discharges from ships with scrubbers globally. Shipping traffic is not distributed evenly. Scrubber discharges will be higher in some regions and these might therefore experience a stronger negative effect of scrubber pollution. Although several governments have already banned scrubbers in their ports, internal waters, and territorial seas, many have not. Understanding how much washwater is expected to be discharged within territories, and where, could improve policymaking. To that end, in addition to this report, we are also publishing an online, interactive map showing scrubber washwater discharges. It is available at https://theicct.org/publications/global-scrubber-discharges-Apr2021. In this report, we map and rank scrubber discharges by ship type, flag state, national waters, and major ports. We also estimate discharges within IMO-designated Particularly Sensitive Sea Areas (PSSAs), many of which contain coral reef systems that are already negatively impacted by ocean acidification.

Our results model pre-pandemic ship traffic patterns. We used 2019 ship traffic to provide a pre-pandemic baseline of ship activity and estimated the mass of scrubber washwater discharges for ships that had or were expected to have scrubbers installed by the end of 2020. For most ship types, these results are expected to be representative of the distribution and mass of scrubber washwater discharges for the next several years, beginning with 2021. The main exception is cruise ships. Unless and until cruise ships are sailing their typical routes, the amount and location of their scrubber discharges will be different from those presented here.

As shown in this report, absent additional regulations, we expect ships to emit at least 10 gigatonnes (Gt) of scrubber washwater in a year. For context, the global shipping sector carries about 11 Gt of cargo each year. Importantly, about 80% of scrubber discharges occur within 200 nautical miles of shore, with hot spots occurring in heavily trafficked regions, including the Baltic Sea, North Sea, Mediterranean Sea, the Strait of Malacca, and the Caribbean Sea. Away from shore, scrubber discharges occur along major shipping routes. Some of these routes pass through PSSAs, including the Great Barrier Reef, where about 32 million tonnes (Mt) of scrubber washwater will be discharged, mainly from ships serving coal terminals in northeast Australia; this represents 5% of the 665 Mt discharged in PSSAs globally.

Container ships, bulk carriers, and oil tankers together account for three-quarters of scrubber installations by number of ships and are responsible for about 70% of scrubber discharges worldwide. Another 15% of discharges are from cruise ships, even though they represent only 4% of the scrubber-equipped fleet by number of ships. Cruise ships are also the main contributor to scrubber discharges in port, and account for 96% or more of discharges in seven of the 10 ports with the highest total washwater discharges. We expect the results reported in this paper to be representative for the cruise sector if and when the industry returns to normal operations after the pandemic.

Ships flying the flags of Panama, Marshall Islands, and Liberia account for about 40% of global scrubber discharges. Several countries have imposed restrictions on scrubber discharges in their national waters but allow ships flying their flag to emit washwater. Panama has banned open-loop scrubber discharges in the Panama Canal and yet registers ships that account for nearly one-fifth of global scrubber washwater discharges.

Policymakers concerned about the impacts of washwater discharges can consider some or all of the actions below.

At the IMO:

» The Marine Environment Protection Committee (MEPC) could pass a resolution calling on ships to immediately stop dumping scrubber discharge water in places that should be protected, including estuaries, near-shore areas, marine protected areas, and especially PSSAs. Our analysis shows that ships with scrubbers are expected to discharge at least 665 Mt per year in PSSAs. These include areas with threatened reef systems, like the Caribbean Sea and the Great Barrier Reef, and areas with endangered marine life, such as the Galapagos Archipelago.

» The IMO could prohibit the use of scrubbers as an equivalent fuel sulfur compliance option for new ships under the International Convention for the Prevention of Pollution from Ships (MARPOL) and establish a timeline for phasing out scrubbers already installed on existing ships. MEPC could also pass a voluntary resolution calling on Administrations (flag states) to not approve the use of scrubbers for ships flying their flag. To be most effective, these provisions should cover both open-loop and closed-loop systems.

At the regional/national level:

» Authorities could prohibit all scrubber discharges in waters under their jurisdiction. If closed-loop scrubbers are used, they should be operated in zero-discharge mode. Waters of the United States, the United Kingdom, and Italy all are expected to receive more than 300 Mt per year of washwater discharges and yet do not currently prohibit the use of scrubbers in their national waters.

» Nearby countries could work together to harmonize scrubber discharge restrictions to avoid merely displacing scrubber discharges over political (but not ecological) borders. For example, Malaysia, Indonesia, and Singapore have already prohibited open-loop scrubbers in their ports, but this does not extend to the Strait of Malacca, which passes through each country's territorial seas and which is expected to receive the largest concentrations of washwater discharges in the world.

» Prominent flag states such as Panama, the Marshall Islands, and Liberia, which register ships expected to be responsible for 40% of global scrubber discharges, could agree to phase out the use of scrubbers on ships flying their flags. In the case of Panama, this would mean applying the same discharge bans to ships flying its flag as it does to ships transiting the Panama Canal.

At the local level:

- Ports could proactively ban scrubber discharges in waters under their jurisdiction and require ships to use onshore power when it is available. When not, ports could require that ships use MGO to avoid the need for using heavy fuel oil with scrubbers. Ports with heavy cruise ship traffic could install new or additional shore-side charging facilities.
- Ports could conduct ongoing water and sediment monitoring for acids, PAHs, heavy metals, nitrates, and nitrites. Pollutant monitoring could be supplemented with monitoring of photosynthetic activities using available satellite datasets and used as a bioindicator of eutrophication that may be exacerbated by nitrogen pollution from ships.

INTRODUCTION

When the International Maritime Organization's (IMO) global fuel sulfur limit came into force on January 1, 2020, it reduced the maximum sulfur content for marine fuels from 3.5% to 0.50%, except for ships that have an exhaust gas cleaning system, also known as a scrubber (Marine Environment Protection Committee [MEPC], 2019). Scrubbers allow ships to continue to use low-cost, high-sulfur heavy fuel oil (HFO) because the scrubber removes a portion of the sulfur from the exhaust before it is emitted, resulting in sulfur dioxide (SO_2) emissions that are at least equivalent to using lower sulfur fuels. Scrubbers spray the exhaust with seawater (open-loop scrubbers) or alkaline water solution (closed-loop scrubber) to control SO_2 emissions, and then dump the water overboard in the form of either washwater (open loop) or bleed-off water (closed loop).

For simplicity, this paper uses the term washwater to cover both open- and closed-loop discharges. In earlier research, we found that all scrubbers (open-loop, closed-loop, and hybrid) discharge washwater that is more acidic than the surrounding seawater and which contains polycyclic aromatic hydrocarbons (PAHs), particulate matter, nitrates, nitrites, and heavy metals including nickel, lead, copper, and mercury (Comer, Georgeff, & Osipova, 2020). Additionally, earlier work shows that, while scrubbers are effective at reducing air emissions of SO_2, emissions of carbon dioxide, particulate matter, and black carbon were higher with scrubbers compared with using marine gas oil (MGO) (Comer, Georgeff, & Osipova, 2020). Scrubber air emissions and water pollution are already occurring near shore, including within areas designated as critical habitat for threatened and endangered marine mammals, while PAHs and heavy metals have been linked to cancers and reproductive dysfunction in marine mammals (Georgeff, Mao, & Comer, 2019). The continued use of scrubbers therefore raises environmental and public health concerns, and a growing list of governments has banned the use of scrubbers in their waters.

Scrubbers cost several million dollars to install and ship owners rely on the price differential between HFO and lower sulfur fuels like very low sulfur fuel oil (VLSFO, <0.50% sulfur) and MGO (<0.10% sulfur) to make them worth the investment. As of January 2021, HFO was about $100/tonne cheaper than VLSFO or MGO, according to Ship & Bunker.[1] Large cargo ships can burn more than 100 tonnes of fuel per day and cruise ships can burn more than 200 tonnes of fuel per day. The payback period depends on both the scrubber costs (capital, operating, and maintenance) and the fuel price differential. The economics seem to be compelling, as the number of ships fitted with scrubbers increased from 243 in 2015 to more than 4,300 in 2020.

This paper presents a first global assessment of the mass and distribution of scrubber washwater discharges from ships. Additionally, we are releasing an interactive, global washwater discharges map, available at the ICCT website. The map can be used by interested states, ports authorities, policymakers, environmental protection organizations, and members of the public. We mapped and ranked scrubber discharges by ship type, flag state, national waters, and major ports. We also estimated discharges within IMO-designated Particularly Sensitive Sea Areas (PSSAs), many of which contain coral reef systems that are already negatively impacted by ocean acidification.

The mass of scrubber washwater discharges was estimated for ships that had or were expected to have scrubbers installed by the end of 2020, according to Clarksons Research Services data when referenced in June 2020.[2] The distribution of washwater discharges was mapped using Automatic Identification System (AIS) data from exactEarth.[3] We used 2019 ship traffic patterns to provide a pre-pandemic baseline

1 World Bunker Prices: https://shipandbunker.com/prices
2 Clarksons Research Portal, World Fleet Register. See https://www.clarksons.net/portal
3 Global real-time vessel tracking service for monitoring global shipping. See https://www.exactearth.com/

of ship activity. We expect these results to be representative of the distribution and mass of scrubber washwater discharges for most ship types for the next several years, beginning with 2021. The main exception is cruise ships. The pattern of discharges presented in this study reflects pre-pandemic traffic patterns. Unless and until cruise ships are sailing their typical routes, the amount and location of their scrubber discharges will be different from those presented here.

BACKGROUND

In the 2008 amendments to the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex VI, IMO agreed in Regulation 14 to reduce the maximum allowable sulfur content of marine fuels from 4.5% to 3.5% in 2012, and then to 0.50% in 2020, except in Sulfur Emission Control Areas (SECAs), where the maximum sulfur content was limited to 1.0% in July 2010 and 0.10% in January 2015. Regulation 14 also specified that the 0.50% global limit could be delayed to 2025, depending on the outcome of a study on fuel oil availability. The IMO agreed to implement the 0.50% sulfur limit in 2020 based on research showing that sufficient quantities of compliant, low-sulfur-content fuel would be available in 2020 (Faber et al., 2016) and that doing so would prevent tens of thousands of premature deaths each year by reducing air pollution (Sofiev et al., 2018). Compliance with Regulation 14 can be achieved either by replacing the HFO commonly used in shipping with low-sulfur content fuel or by using a scrubber, which is allowed under MARPOL Annex VI Regulation 4, which deals with "equivalents," as long as the scrubbers are at least as effective at reducing emissions.

Scrubbers have been installed on ships since the 1990s. At first, scrubbers were used only within SECAs, where limits on sulfur emissions were more stringent than the global limit. For SECAs, unless a scrubber was used, the maximum allowable fuel sulfur limit was 1.5% before July 1, 2010, 1.0% from July 1, 2010, to December 31, 2014, and then 0.10% beginning January 1, 2015. It was only in 2020 with the implementation of a stricter global regulation that ships started routinely using scrubbers outside of SECAs.

Scrubbers are not tightly regulated and, until recently, have not been widely used. But according to DNV GL (2020), 4,341 ships were expected to be outfitted with scrubbers by the end of 2020, which is 83% more than in 2018.

Types of scrubbers

Scrubbers are categorized as open-loop, closed-loop, or hybrid, with hybrid scrubbers able to alternate between open- and closed-loop modes. Open-loop scrubbers take up seawater, use it to capture sulfur oxides (SO_x) in exhaust, and then release the discharge water, or washwater, back into the ocean. Open-loop scrubbers have been shown to release hot, acidic washwater containing, in varying concentrations, PAHs, particulate matter, nitrates, nitrites, and heavy metals including nickel, lead, copper and mercury (Boer & 't Hoen, 2015; Comer et al., 2020; Kjølholt, Aakre, Jürgensen, & Lauridsen, 2012; Teuchies, Cox, Van Itterbeeck, Meysman, & Blust, 2020). The washwater can be treated before discharge, but this is not mandatory and most open-loop scrubbers do not filter the washwater before dumping it overboard (European Sustainable Shipping Forum, 2017). Unlike open-loop systems, closed-loop systems collect contaminated scrubber sludge on board and store it for on-land disposal. Closed-loop scrubbers also add caustic soda to the water to neutralize some of the acidity, but they are not waste-free, as they produce highly concentrated "bleed-off" water (Magnusson, Thor, & Granberg, 2018; Winnes, Moldanová, Anderson, & Fridell, 2016).

Open-loop scrubbers are the most common type installed on ships because they are less expensive, dump the sludge they generate overboard, and do not require adding chemical additives to increase alkalinity. Later, we will show that, as of 2020, open-loop scrubbers accounted for 85% of installations; 14% were hybrid systems and the remaining 1% were closed loop.

Scrubber washwater IMO guidelines

The first IMO scrubber washwater guidelines were adopted in 2005 (Resolution MEPC.130(53)) and the first numeric discharge criteria for water pollutants were introduced in the 2008 revisions to the guidelines (Resolution MEPC.170(57)). The guidelines were later reviewed and revised—but not strengthened—in 2009, 2015, and

2020. (Comer et al., 2020). The first washwater discharge criteria that were accepted in 2008 (MEPC 57/4/1) only included numerical limits for pH, turbidity (as a proxy for heavy metals), and PAHs. Specific discharge criteria for heavy metals were never established despite numerous studies showing that washwater contains substantial amounts of heavy metals (Teuchies et al., 2020). IMO's discharge limits were initially developed based on data from just three ships operating with scrubbers, two of which were prototypes, and the discharge criteria have never been strengthened despite several rounds of review: Resolution MEPC.184(59) in 2009; Resolution MEPC.259(68) in 2015; and a new draft of the guidelines PPR/7/22/Add.1, Annex 9, in 2020. According to current IMO guidelines, washwater discharged during scrubber operation should not exceed the limits established by MEPC, and there is a recommendation—though not a requirement—that ships continuously monitor the pH, PAH, nitrates, and turbidity of the discharge.

Environmental impact of contaminants in scrubber washwater

A number of studies have shown that washwater influx can damage marine ecosystems. High concentrations of PAHs and heavy metals in washwater accumulate in sediments, especially in coastal areas, and also increase water toxicity in aquatic ecosystems (Koski, Stedmon, & Trapp, 2017; Teuchies et al., 2020; Winnes et al., 2016). Bioconcentration of PAHs and heavy metals has been linked with reproductive dysfunction and cancer in marine mammals (Georgeff et al., 2019; Martineau et al., 2002). Additionally, PAHs and heavy metals have a high likelihood of bioaccumulation in the marine food web, including in fish consumed by humans (Chouvelon et al., 2019; Valavanidis et al., 2008).

Stips et al. (2016) found that seawater acidification from washwater influx in the coastal areas of the North Sea could double the annual impact of greenhouse-gas induced acidification. A recent study by Dulière, Baetens, and Lacroix (2020) estimated that if 15% to 35% of the merchant fleet (by tonnage) operating in and near the English Channel were outfitted with open-loop or hybrid scrubbers, the rate of ocean acidification would double or quadruple in that area compared with how much it is expected to acidify due to climate change. Near Rotterdam, the annual acidification from these ships could be 50 times that expected from climate change. While the authors also stressed that there is a lack of explicit study on acidification of the ocean caused by international shipping, ocean acidification is listed as an increasing cause for the decline of the Great Barrier Reef (Mongin et al., 2016), an area we will show is being polluted by ships with scrubbers.

Comer et al. (2020) showed that all scrubbers (open, closed, and hybrid) discharge water that is more acidic and turbid than ambient seawater. Also, all scrubbers emit PAHs and heavy metals that have been linked to cancers and reproductive dysfunction in marine mammals, including threatened and endangered species like Northern and Southern resident killer whales and beluga whales.

Particularly Sensitive Sea Areas

PSSAs are intended to protect ecologically vulnerable areas from the impacts of international shipping. PSSA status is granted after a country or coalition submits a proposal to MEPC citing the need for IMO to protect this area. Measures to protect PSSAs often include "areas to be avoided" by ships (especially those carrying oil), traffic separation schemes, and mandatory ship reporting. However, shipping is still allowed in PSSAs, and there are not yet any limits on scrubber washwater discharges. There are currently 15 IMO-designated PSSAs, and among them are the Great Barrier Reef, the Florida Keys, the Galapagos, and other areas with coral reef systems and endangered species. As stated above, all scrubber washwater is more acidic than the surrounding seawater. Ocean acidification is expected to become an increasing threat to all coral building organisms, as acidic water significantly reduces their ability to produce hard exoskeletons, and this is a particular concern in the Great Barrier Reef (Kleypas et al., 2006).

IMO assessment of scrubber impacts

As a response to concerns from IMO delegates, the IMO requested that the Group of Experts on the Scientific Aspects of Marine Environmental Protection (GESAMP) conduct independent research and report on the potential environmental impacts of scrubbers (International Maritime Organization [IMO], 2019). The task team concluded that while scrubbers efficiently remove sulfur from air emissions, washwater content varied greatly depending on fuel, engine type, and a ship's operating conditions. While referencing the possible impacts of scrubbers on acidification and eutrophication, the authors noted that the study was limited in time and that a longer-term understanding was needed to fully assess the environmental impacts. Given the potential for harm, some countries have taken preventive measures and have banned the use of scrubbers in their ports and national waters (North, 2020).

With the recent and rapid increase in the number of ships using scrubbers, we saw a need to quantify and map scrubber washwater discharges and to identify the areas most affected. Shipping traffic is unevenly distributed both spatially and temporally and, as a result, regions where the concentration of pollutants is higher might experience stronger negative effects. Ports may be particularly affected by scrubber discharges. When the ambient water alkalinity is low, which is often the case in harbors situated in estuaries, less of the acidity of the washwater is neutralized. Moreover, PAHs and heavy metals are discharged in shallow water, where they can be more concentrated and accumulate in sediments, which could lead to human health risks in addition to threats to marine life.

METHODOLOGY

AMOUNT OF WASHWATER DISCHARGED

We estimated scrubber washwater discharges from all ships that were expected to be using scrubbers by the end of 2020. For each ship, hourly washwater discharges were calculated as follows, based on the methods of Georgeff et al. (2019):

$$D = TED \times r$$

D = discharge water mass, in tonnes (t);

TED = total energy demand per ship, in megawatt hours (MWh);

r = scrubber washwater flow rate, t/MWh.

Energy demand per ship in MWh was estimated using the SAVE model, which uses AIS data paired with ship registry data to estimate hourly energy use, fuel consumption, and emissions for the global fleet. The SAVE model is described in detail in Olmer, Comer, Roy, Mao, and Rutherford (2017). For the washwater flow rate, we applied a normalized flow rate of 45 t/MWh for open-loop scrubbers in accordance with IMO guidelines for exhaust gas cleaning systems in Resolution MEPC.259(68).[4] For hybrid scrubbers, we assumed they were always operated in open-loop mode with the same flow rate as open-loop scrubbers (45 t/MWh).

Typical flow rates for closed-loop scrubbers vary from 0.1 and 0.3 m^3/MWh (IMO, 2019). In this study we used a conservative flow rate value equal to 0.1 t/MWh, based on the assumption that the density of water is approximately 1 t/m^3.

DATASETS AND A SHIP'S POWER CONSUMPTION

We used three global commercial shipping datasets: AIS, IHS, and Clarksons World Fleet Register (WFR).[5] AIS data from exactEarth provided the global shipping traffic.[6] AIS reports each ship's location as frequently as every few seconds. It also reports each ship's speed over ground and draught. The IHS dataset provided key technical characteristics for each ship and ship's engine, which are used in the SAVE model.[7]

ICCT's SAVE model integrates AIS and IHS datasets to estimate ship-specific power consumption hour by hour for each ship (Olmer et al., 2017). The model incorporates a set of uncertainties related to ship age and weather conditions and calculates power demand for main engines, auxiliary engines, and boilers for each hour of all identified ships in a given year. The SAVE model's power demand assumptions for auxiliary engines and boilers have been updated from Olmer et al. (2017) to align with those in the *Fourth IMO Greenhouse Gas Study* (Faber et al., 2020).

FLEET WITH SCRUBBERS

We identified individual ships by matching the IMO numbers of each scrubber-equipped ship in Clarksons WFR with ships observed in the AIS data. Each scrubber in the Clarksons WFR dataset has a type assignment (open loop, closed loop, or hybrid) and an installation or order date. Integrating the WFR dataset with the SAVE model allows us to identify year-round shipping routes of the world fleet outfitted with scrubbers. In this study, we analyzed 2019 ship activity for ships that already had

4 This estimate is rather conservative as many sources reported higher flow rates values from the testing results (IMO, 2019; PPR 6/INF.20, 2018). Independent discharge water flowrates measurements from five ships outfitted with scrubbers in the Baltic sea reported rates of 75–150 m^3/MWh, roughly equivalent to 75–150 t/MWh given that the density of seawater is approximately 1 t/m^3.

5 Clarksons Research Portal, World Fleet Register. See https://www.clarksons.net/portal

6 Global real-time vessel tracking service for monitoring global shipping. See https://www.exactearth.com/

7 The IHS database provides technical specifications for oceangoing vessels worldwide, including capacity, build year, and reference speed used in this analysis. See https://ihsmarkit.com/industry/maritime.html

scrubbers installed by the end of 2020, according to Clarksons WFR when referenced in June 2020.

Business as usual shipping traffic under the 2020 global sulfur limit

We modeled global scrubber washwater discharges under IMO's 2020 global sulfur limit by analyzing real-world ship activity in 2019 for the 2020 scrubber-equipped fleet. We estimated expected discharge locations based on 2019 shipping traffic. The prediction excludes ship activity of 2020, where global traffic was significantly affected by the coronavirus pandemic. We expect these estimates to be valid for the near term, in 2021 and for a few years thereafter. Over time, without additional policy actions to prohibit scrubber use, we expect global scrubber discharges to increase.

REGIONS OF SPECIAL FOCUS

We summarized the amount of discharge water within each country's Exclusive Economic Zone (up to 200 nautical miles [nm]), territorial seas (up to 12 nm), internal waters, and ports. We estimated absolute discharges in tonnes (t) and discharge concentrations in tonnes per square kilometer (t/km^2). Table 1 includes all definitions and data sources used for analysis. The shapefiles for Exclusive Economic Zone (EEZ), territorial seas (TS), and internal waters (IW) were from the Flanders Marine Institute, while PSSA shapefiles were created by Hamilton (2018) based on the boundaries listed in the MEPC Resolution that established each PSSA, and the descriptions as summarized by IMO (2017). We also estimated absolute discharges within a 1 nm radius of "major ports," as defined by the World Port Index (2019).

Table 1. Data sources and definitions of the regions used in this study.

Name	Abbreviation	Definition	Source for the full definition	Source of GIS data
Territorial seas	TS	Up to 12 nm, measured from baselines determined in accordance with the United Nations Convention on the Law of the Sea (UNCLOS).	UNCLOS, 1994; Part II, Article 3	Flanders Marine Institute, 2019
Exclusive Economic Zone	EEZ	Up to 200 nm from the baselines determined in accordance with UNCLOS.	UNCLOS, 1994; Part V, Article 57	Flanders Marine Institute, 2019
Internal waters	IW	Waters on the landward side of the baseline of the territorial sea form part of the internal waters of the state	UNCLOS, 1994; Part II, Article 8	Flanders Marine Institute, 2019
Ports		Major ports and terminals worldwide	National Geospatial-Intelligence Agency, 2019	National Geospatial-Intelligence Agency, 2019
Particularly Sensitive Sea Area	PSSA	An area that needs special protection through action by IMO because of its significance for recognized ecological, socio-economic, or scientific attributes where such attributes may be vulnerable to damage by international shipping activities.	IMO Assembly Resolution A.982(24)	Hamilton, 2018; IMO, 2017

AREAS WHERE SCRUBBER DISCHARGES ARE PROHIBITED

Areas with special regulations for scrubber discharges as of June 2020 are listed in Table 2. In these areas, we assumed that scrubber discharges did not occur based on the rules listed in the table. As ports have different infrastructure and different harbor sizes, we applied a universal buffer of 5 nm around regulated ports. For assessing ban effectiveness, we calculated the discharge water mass that would have been emitted if ships had been allowed to use scrubbers in the restricted areas as usual and reported these values.

Although the list of countries with special regulations and bans on scrubbers is constantly updated, this study includes only the states that adopted and publicly announced scrubber bans as of June 2020 (North, 2020).

Table 2. Countries where scrubber discharges are restricted (as of June 2020).

Country	Rules applied
Bahrain	Open-loop scrubbers cannot be used in port or at anchor
Belgium	Scrubbers cannot be used within 3 nm of the coast
Brazil	Scrubbers cannot be used in territorial seas
China	Open-loop scrubbers cannot be used in China's domestic emission control areas
Egypt	Open-loop scrubbers cannot be used in all ports and Suez Canal
Gibraltar	Open-loop scrubbers cannot be used in Gibraltar waters*
Ireland	Scrubbers cannot be used in Dublin and Waterford ports
Malaysia	Open-loop scrubbers cannot be used in the territorial seas (12 nm)
Norway	Open-loop scrubbers cannot be used in the World Heritage Fjords sea areas of Geirangerfjord and Nærøyfjord
Pakistan	Open-loop scrubbers cannot be used in the ports of Karachi or Bin Qasim
Panama	Open-loop scrubbers cannot be used in the Panama Canal
Portugal	Open-loop scrubbers cannot be used in any port or at berth
Singapore	Open-loop scrubbers cannot be used in any port
Spain	Open-loop scrubbers cannot be used in the ports of Algeciras, Cartagena, or Huelva
United States	Scrubbers cannot be used in California ports or waters; Connecticut ports or waters; or Hawaii ports or waters, except under certain conditions
United Arab Emirates	Open-loop scrubbers cannot be used in the port of Fujairah

* We modeled a ban in the Strait of Gibraltar in this study as the regulation did not clearly define the scope of Gibraltar waters.

RESULTS AND DISCUSSION

FLEET OF SCRUBBER-EQUIPPED SHIPS

In 2019, we identified 81,297 active ships in the global fleet by matching AIS data with ship registry data based on each ship's IMO number.[8] We used the 2019 fleet as the baseline for this analysis because 2020 traffic patterns were disrupted by the coronavirus pandemic and do not reflect typical shipping traffic. Of the 81,297 ships in the fleet, we identified 3,628 that have or will have scrubbers installed by the end of 2020. This is lower than the roughly 4,300 ships that were fitted with scrubbers by the end of 2020 because, at the time of this analysis, Clarksons reported only 3,754 ships with scrubbers (we matched 3,628 to the AIS data set). Since this analysis, Clarksons has added additional ships with scrubbers to their database. Of the scrubbers installed on the 3,628 ships we could match with the AIS data, open-loop scrubbers are the most common type (85% of all scrubbers installed) and hybrids are second most popular (14%); only 1% of the scrubbers are closed loop. More than half of all scrubbers were installed in 2019 in preparation for the global marine fuel sulfur regulation that came into force at the beginning of 2020.

Bulk carriers, container ships, and oil tankers represent 74% of the fleet outfitted with scrubbers, by number of ships. Bulk carriers are the most common ship type outfitted with scrubbers—1,246 ships, or 34% of all outfitted ships. However, within each ship type, cruise ships have the largest share of their fleets outfitted with scrubbers: 34% of all cruise ships (Figure 1). Even though bulk carriers are the leaders by absolute numbers, only 10% of all bulk carriers have a scrubber installed. More information can be found in the supplemental data that accompanies this paper on the ICCT website.

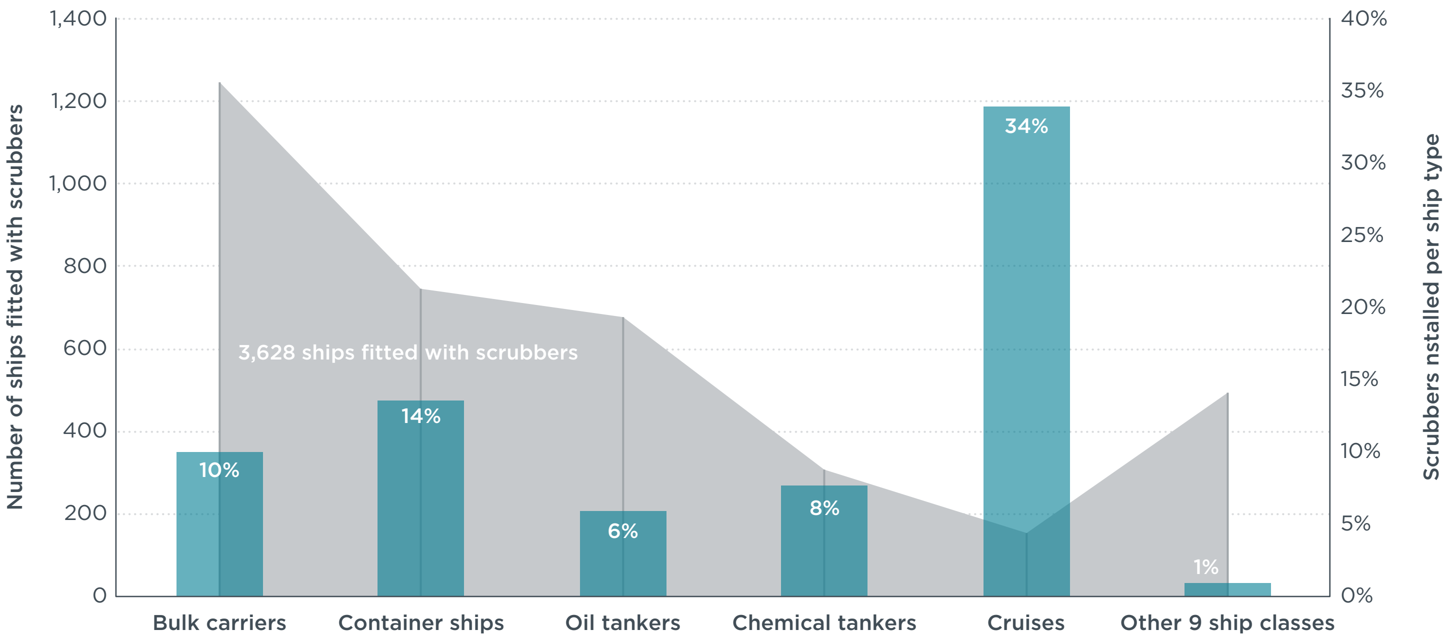

Figure 1. Total number of ships with scrubbers installed by the end of 2020 (gray area) and the proportion of ships with scrubbers (blue bars), by ship type

8 These are ships large enough to have an AIS transponder installed as well as an IMO number, which includes nearly all passenger vessels, as well as cargo vessels 300 gross tonnes and above. There are hundreds of thousands of ships in the world fleet, as explained by Olmer et al. (2017), but most of them are small and use distillate fuels, rather than HFO and scrubbers.

DISCHARGED WASHWATER

Globally

Ships with scrubbers are expected to discharge more than 10 gigatonnes (Gt) of washwater worldwide annually. This is comparable to the total amount of cargo carried by the global shipping industry, 10.7 Gt in a single year (United Nations Conference on Trade and Development, 2019). Nearly all of the washwater will be emitted by open-loop scrubbers and hybrid scrubbers working in open-loop mode; 10 Gt will be emitted by scrubbers in open-loop mode and 0.3 million tonnes (Mt) from closed-loop scrubbers. Together, container ships, bulk carriers, and oil tankers are responsible for about 70% of the discharges. Cruise ships are expected to account for 15% of scrubber discharges, despite accounting for only 4% of scrubber installations on the basis of the number of ships with scrubbers in the fleet.

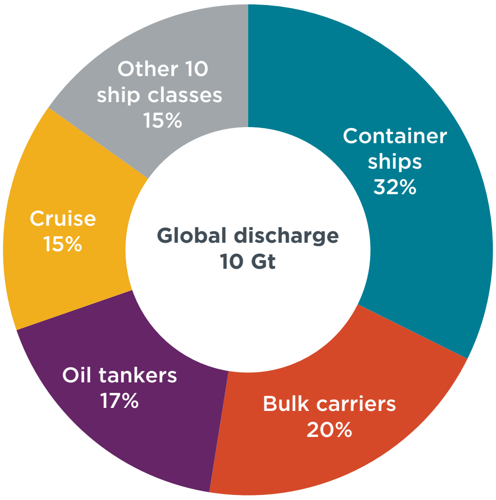

Figure 2. Scrubber washwater discharges by ship type

Global discharge water from scrubbers is distributed unevenly and we found it formed three spatial hot spots: the Caribbean Sea; the Baltic Sea, English Channel, and Mediterranean Sea in Europe; and a route through the Strait of Malacca along the South and East China Seas (Figure 3).

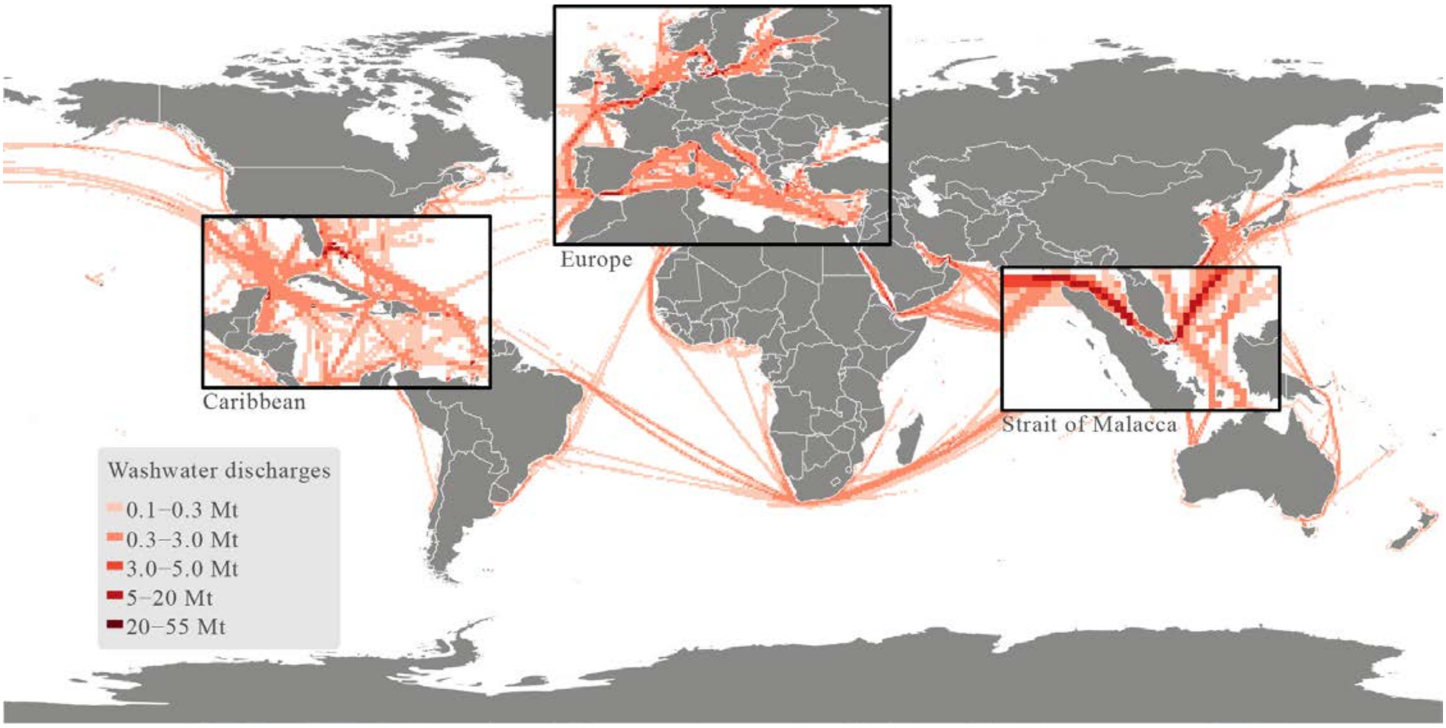

Figure 3. Global scrubber washwater discharges distribution and the sites with the largest washwater hot spots

There are many locations in which shipping traffic bottlenecks. This bottlenecking is due to natural geographic channels and straits as well as artificial canals and locks. Within these bottlenecks are increased amounts of discharge water. Several of the most extreme cases of shipping bottlenecking are in Europe, and these include the English Channel, the Great Belt of Denmark, and the Bosporus Strait of Turkey. Due to the high number of ships and intensive shipping activity in these areas, millions of tonnes of washwater are being discharged.

One well-known bottleneck occurs in the Strait of Malacca in Southeast Asia. Singapore, Indonesia, and Malaysia, which surround the strait, have already banned open-loop scrubber washwater in their ports, but not in the strait itself. Between the northern tip of Sumatra and the start of the Singapore Strait, more than 180 Mt of washwater will enter this narrow area.

Even where bottlenecking is not occurring, there are areas of extreme washwater concentrations, such as the Caribbean Sea. This area is home to several popular cruise ship ports of call, including Miami and other southern U.S. ports. Before the IMO's global sulfur regulation took effect at the start of 2020, cruise ships already accounted for one-third of all scrubbers in operation (DNV GL, 2020). As we will show later, popular cruise destinations like Georgetown, Freeport, and Nassau are where in-port discharges are the highest.

As shown in Figure 4, of the 10 Gt of discharge water we expect to be emitted, about 8 Gt or 80% would be discharged within 200 nm of shore (i.e., within the EEZ, TS, or IW of a country). The remaining 20% is expected to be discharged on the high seas. Approximately 1.3 Gt is expected to be emitted within TS and 0.5 Gt inside IW.

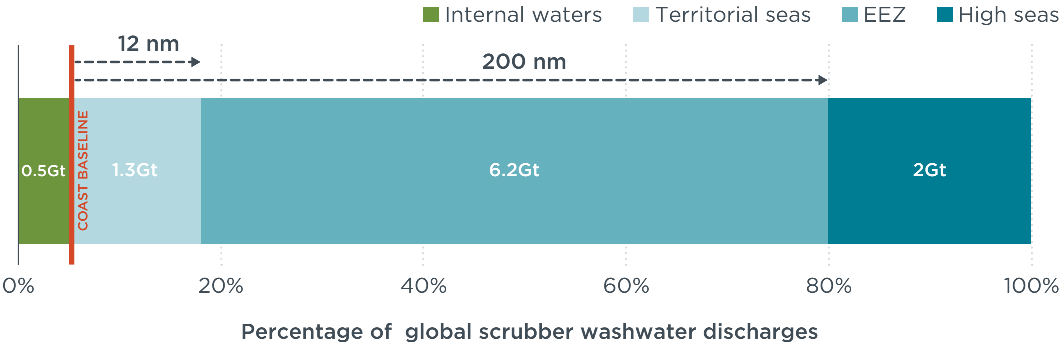

Figure 4. Location and amount of scrubber washwater discharges

The prevalence of water pollution near coastal areas can be explained by the fact that scrubber-equipped ships spend approximately 40% to 50% of their time at anchor or at berth in or near ports (Figure 5).

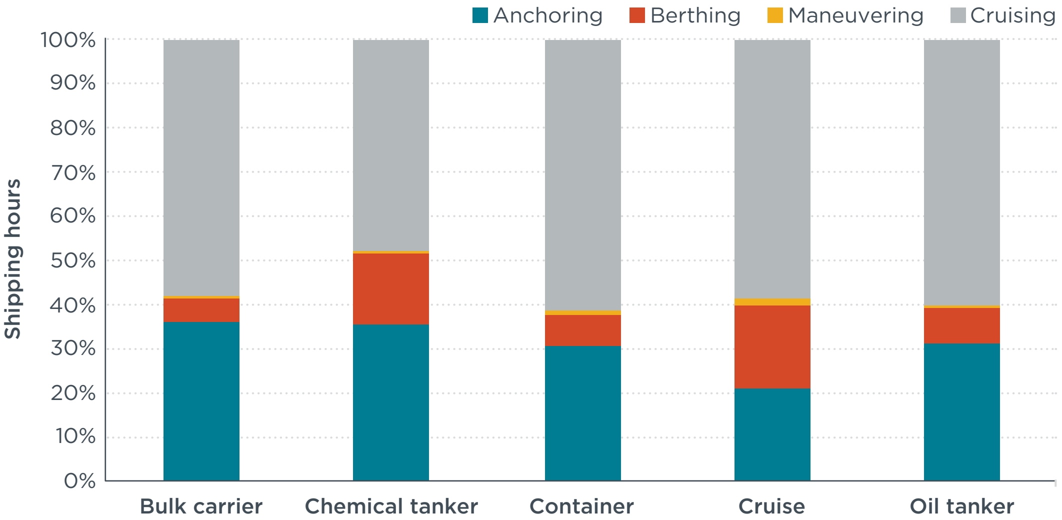

Figure 5. The proportion of hours that scrubber-equipped ships spend in different operational phases

Distribution by flag

Scrubber-equipped ships are currently registered to 52 flag states. Most of the time, foreign-flagged ships are responsible for the majority of scrubber discharge water in a country's territorial seas. As shown in Table 3, in only 11 out of 154 states are the largest contributors to washwater discharges in their territorial seas from ships flying their flag. We found that only Lithuania and Italy had 50% or more of scrubber discharges from ships flying their flag. The interactive map of the washwater discharges shows the flag state that discharges the most washwater in each country's TS. The map can be accessed at https://theicct.org/publications/global-scrubber-discharges-Apr2021.

Table 3. Territorial seas in which the largest portion of discharges are from ships flying that country's flag.

Country	Total washwater discharge in TS, Mt	Washwater discharged by ships flying their flag, Mt	% washwater from ships flying their flag
Lithuania	0.88	0.49	56%
Italy	66	33	50%
Finland	17	6	35%
Bahamas	15	5	33%
Marshall Islands	0.03	0.01	33%
Greece	95	30	32%
Turkey	35	10	29%
France	32	9	28%
Malta	2	0.48	24%
Norway	10	1.9	19%
Panama	8.9	1.4	16%

Figure 6 illustrates scrubber washwater discharges by flag state. Ships flying the flag of the top five flag states generated more than a half of worldwide discharges (5.5 Gt). Ships flying Panama's flag accounted for the most discharges (1.8 Gt discharge water, 532 ships), followed by Marshall Islands (1.2 Gt discharge water, 662 ships), and Liberia (1 Gt of discharge water, 462 ships). Together, they make up 40% of discharges worldwide. These countries have open registries and are also the top three flag states by tonnage of ships registered to them. Panama, which has banned open-loop scrubber discharges in the Panama Canal, registers ships that account for 18% of global scrubber washwater discharges.

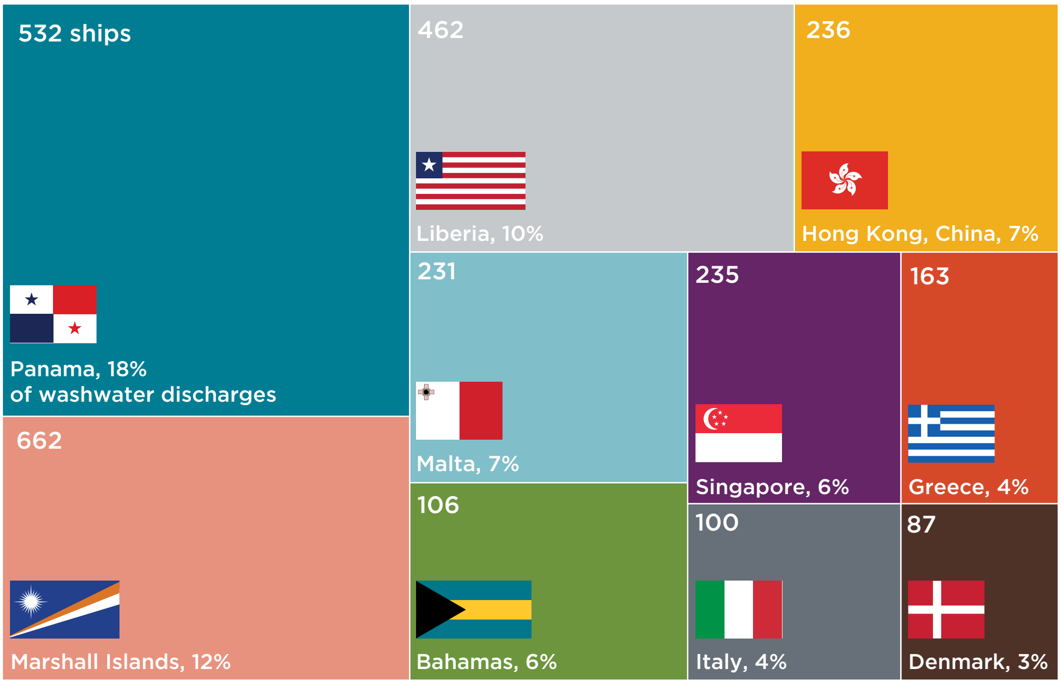

Figure 6. Scrubber washwater discharges by flag state

Territorial seas and internal waters

The 10 countries with the largest amounts of scrubber discharges in their TS and IW are shown in Figure 7. Global washwater discharges by mass and concentration in IW, TS, and EEZs of all coastal states can be accessed at https://theicct.org/publications/global-scrubber-discharges-Apr2021 and in the aforementioned supplemental data that accompanies this report on the ICCT website.

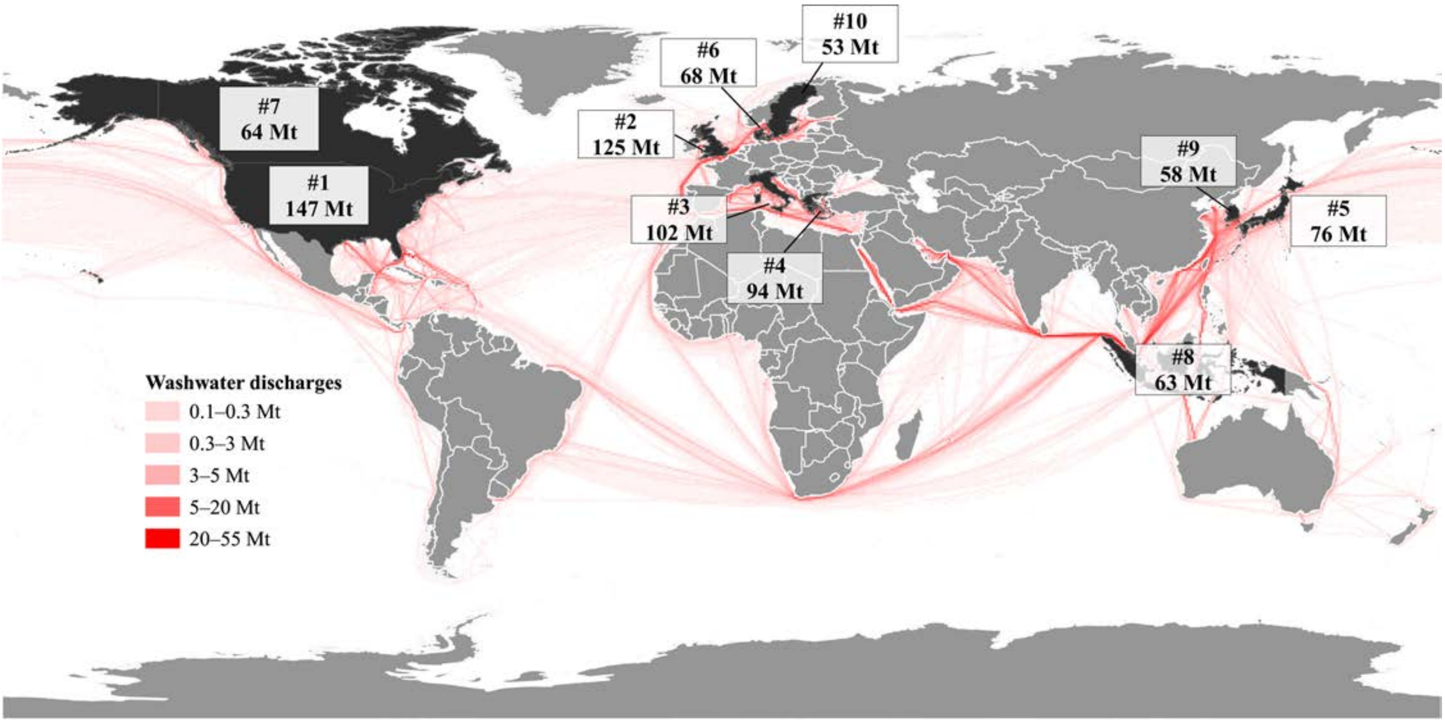

Figure 7. 10 countries with the highest washwater discharges in their territorial seas

The countries with the largest national waters tend to experience the most discharges. These 10 countries account for 36% of all national waters (TS + IW), by area, and receive almost half of the 1.8 Gt discharged in national waters. The three countries with the highest expected washwater discharges are the United States, the United Kingdom, and Italy (Table 4). Ships discharge 374 Mt of washwater in these three countries combined, equivalent to approximately 20% of scrubber washwater discharges in national waters. The United States has one of the largest areas of national waters in the world and experiences the highest total amount of scrubber washwater discharges; however, if ranked by discharge per unit area, the United States is 51st out of 154 countries.

Table 4. Top 10 countries by washwater discharge mass in territorial seas and internal waters

Rank	State	TS + IW (km^2)	Washwater discharges (Mt)	Washwater discharges (t/km^2)
1	**United States**	875,000	147	168
2	**United Kingdom**	224,000	125	559
3	**Italy**	155,000	102	654
4	**Greece**	184,000	95	514
5	**Japan**	397,000	76	190
6	**Denmark**	209,000	68	324
7	**Canada**	2,847,000	64	22
8	**Indonesia**	284,000	63	223
9	**South Korea**	84,000	58	696
10	**Sweden**	83,000	53	637

The United Kingdom ranks second after the United States mainly due to its overseas territories. Mainland United Kingdom's national waters are expected to receive only 52.5 Mt or 42% of the United Kingdom's total washwater discharges. The rest of the discharge water occurs in 14 British overseas territories. Of these, the Cayman Islands are most impacted (55 Mt or 44% of all UK discharges, Figure 8).

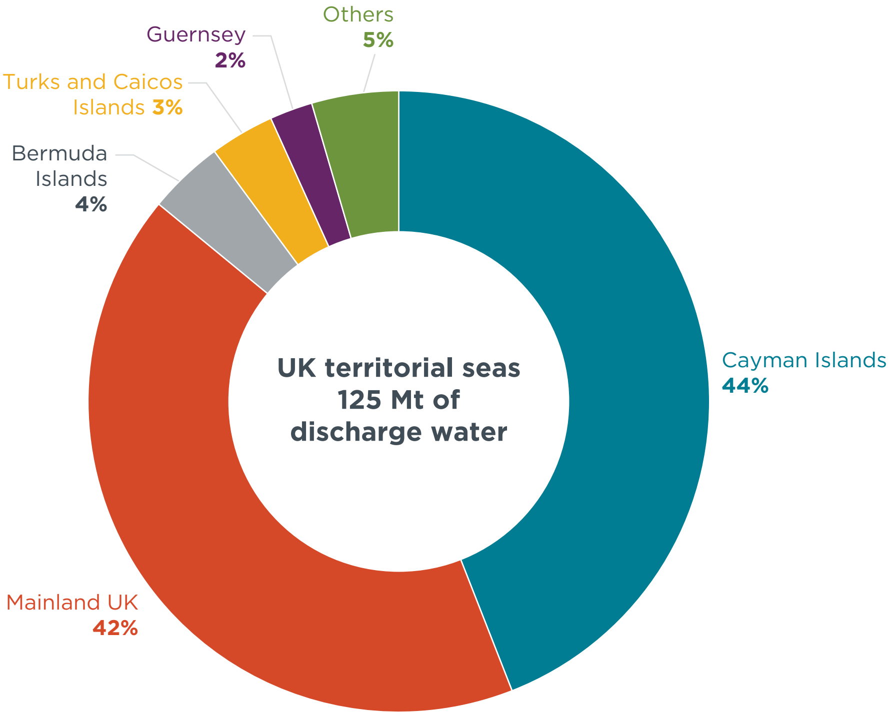

Figure 8. Shares of scrubber discharges in the United Kingdom and its overseas territories

When ranked by the discharge per km², countries with smaller national waters tend to have large washwater discharges per unit area (Table 5). The three countries with the highest concentration of washwater per km², Singapore, Jordan, and Slovenia, have small national waters. Singapore, despite its ban on washwater discharges in its ports, still ranks first: 15,000 t/km² will be discharged within its 700 km² of national waters. Jordan is next but is one-fifth the amount at 3,100 t/km². Singapore's national waters include a portion of the Strait of Malacca, one of the world's busiest shipping channels and a natural choke point for ship traffic to and from Asia.

Table 5. 10 states with the highest intensity (t/km²) of washwater discharge in territorial seas and internal waters

Rank	State	TS + IW (km²)	Washwater discharges (t/km²)	Washwater discharges (Mt)
1	**Singapore**	714	15,000	11.0
2	**Jordan**	97	3,098	0.3
3	**Slovenia**	214	3,080	0.7
4	**Monaco**	74	3,010	0.2
5	**Togo**	1,100	2,600	2.8
6	**Belgium**	1,400	2,100	3.1
7	**Germany**	24,500	2,063	51
8	**Netherlands**	28,500	1,300	36
9	**Malta**	3,990	864	3.5
10	**Lithuania**	2,240	756	1.7

Major ports

As shown in Figure 9, analyzing washwater discharge by port reveals there are prominent hot spots in North America and the Caribbean, as well as in Europe, including the English Channel, the North Sea, the Baltic Sea, and the Mediterranean Sea.

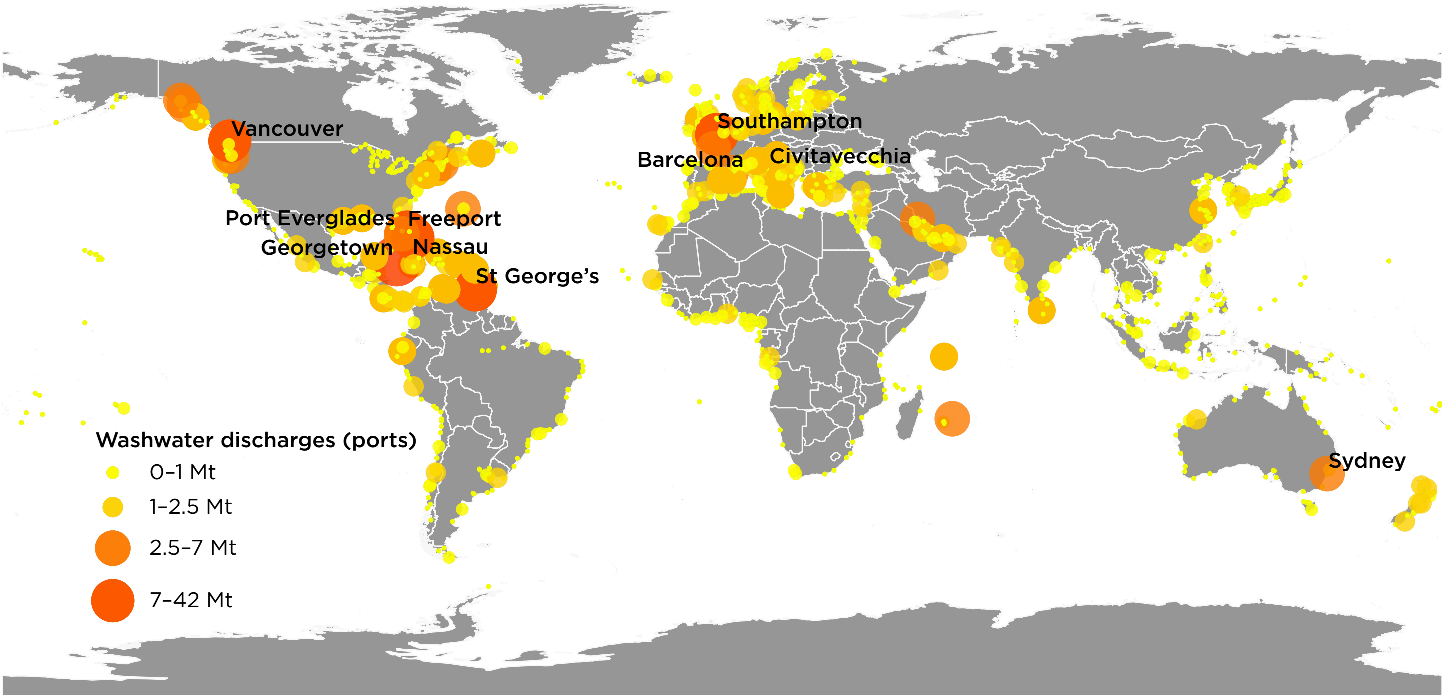

Figure 9. Scrubber washwater discharges within 1 nautical mile of port

Nearly 300 Mt of washwater is expected to be discharged in major ports worldwide. About 83 Mt, or 28%, is to be discharged in the 10 ports with the highest washwater amounts (Table 6) and about half of this amount will be discharged solely in the Port of Georgetown in the UK overseas territory of the Cayman Islands. This is due to heavy cruise ship traffic: out of 50 scrubber-equipped ships identified in Georgetown Port, 49 were cruise ships, making them responsible for nearly all of the discharges. Cruise ships dominate discharges in all 10 ports. Cruise ships spend 25% of their time in ports and have the highest in-port energy consumption of any ship type; average power consumption for a scrubber-equipped cruise ship in port is 12 MW/h, compared with oil tankers, which consume, on average, 4 MW/h in port, as shown in Figure 10.

Table 6. Top 10 ports by washwater discharge masses

Rank	Port name	Affiliated country	Washwater discharges (Mt)	Proportion of global in-port discharges	Ship type responsible for the most discharges (%)
1	**Georgetown**	United Kingdom, Cayman Islands	41.8	14.1%	Cruise ships (100%)
2	**Southampton**	United Kingdom	7.2	2.5%	Cruise ships (96%)
3	**Freeport**	Bahamas	5.5	1.9%	Cruise ships (74%)
4	**Vancouver**	Canada	5.2	1.8%	Cruise ships (100%)
5	**Nassau**	Bahamas	4.8	1.6%	Cruise ships (99%)
6	**St George's**	Grenada	4.5	1.5%	Cruise ships (100%)
7	**Barcelona**	Spain	3.7	1.3%	Cruise ships (75%)
8	**Sydney**	Australia	3.6	1.2%	Cruise ships (100%)
9	**Civitavecchia**	Italy	3.5	1.2%	Cruise ships (73%)
10	**Port Everglades**	United States	3.2	1.1%	Cruise ships (98%)
Total of top 10:			83	28%	

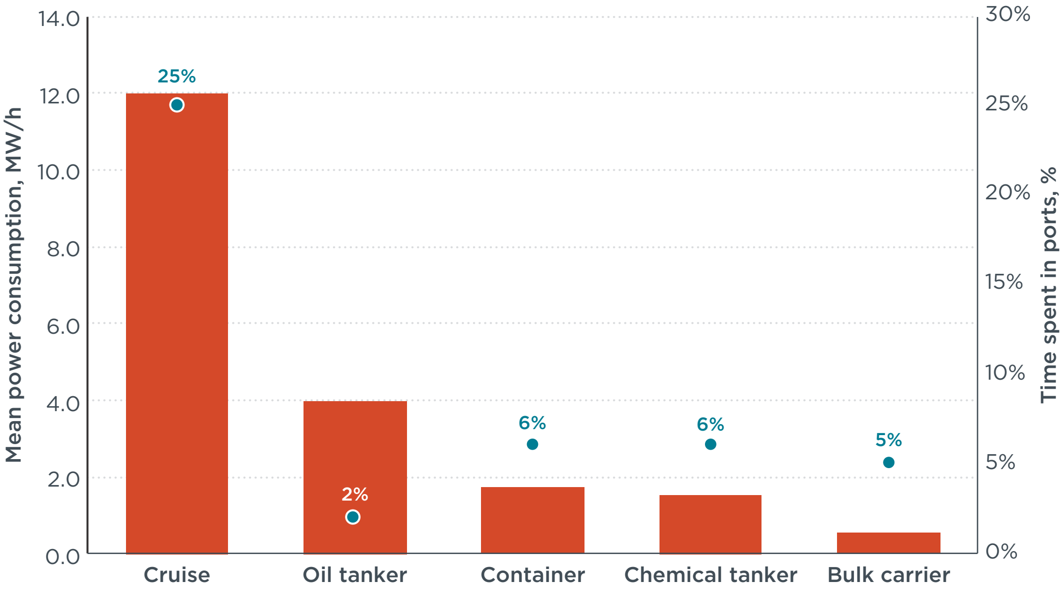

Figure 10. Mean power consumption and proportion of hours spent in port by ship type

Particularly Sensitive Sea Areas

Figure 11 shows the locations of the 15 IMO-designated PSSAs. The amount and intensity of washwater discharged in each is reported in Table 7 and shown on the map in Figure 12.

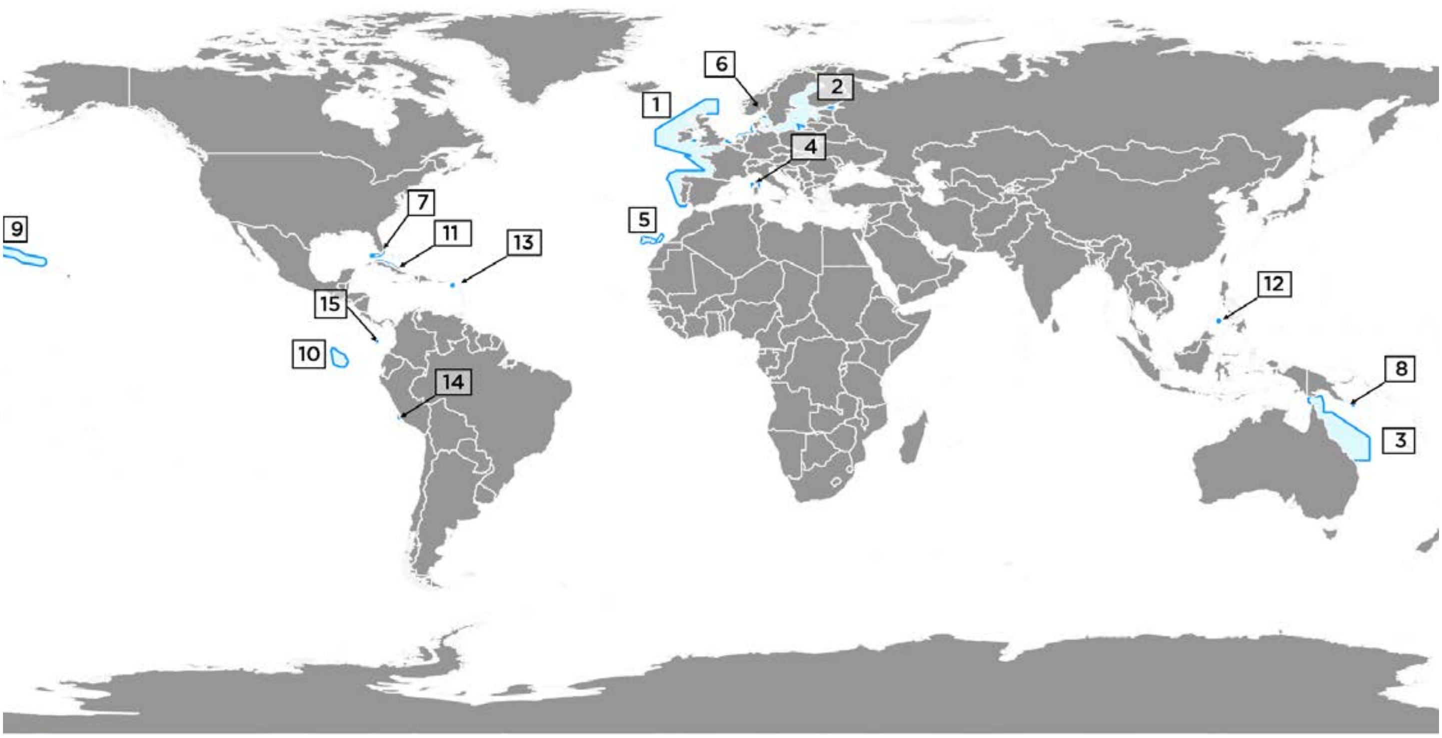

Figure 11. A map of PSSAs designated by IMO

The PSSAs in Western European Waters (#1) and the Baltic Sea (#2) experience the most scrubber discharges, with 605 Mt of washwater discharges combined (Figure 12, Inset B), which is equivalent to 91% of scrubber washwater discharged in PSSAs. The Strait of Bonifacio (#4) will experience the highest discharges per km^2 (825 t/km^2). The Great Barrier Reef PSSA (#3) has the third highest discharges (32 Mt), which seems to be driven mainly by three coal-exporting ports (Inset C). Nearby Jomard

Entrance in Papua New Guinea (#8) will experience the second highest discharge water intensity at 686 t/km² concentrated within a small area of 860 km². The Florida Keys PSSA (#7) faces more than 2 Mt of discharges (Inset A). Scrubber washwater is emitted even within the Galapagos Archipelago (#10). The only PSSA spared is Malpelo Island (#15), the smallest of the PSSAs at only 600 km², where no scrubber washwater was discharged.

Table 7. Washwater discharges in PSSAs

№ on the map (Figure 11)	Name	Region	Reason for designation	Year	Designation	Area (km²)	Discharge water (Mt)	Discharge water (t/km²)
1	**Western European Waters**	Western Europe	Protecting endangered marine life	2004	MEPC.121(52)	1,700,000	310	179
2	**Baltic Sea**	Baltic Western Europe	Unique geography	2005	MEPC.136(53)	960,000	295	306
3	**Great Barrier Reef**	Eastern Australia	Threatened reef system	1990	MEPC.268(68)	1,300,000	32	25
4	**Strait of Bonifacio**	France/Italy	Unique geography	2011	MEPC.204(62)	16,000	13	825
5	**Canary Islands**	Western Spain	Unique geography	2005	MEPC.134(53)	62,000	8.4	137
6	**Wadden Sea**	Netherlands, Denmark and Germany	Protecting endangered marine life	2002	MEPC.101(48)	31,000	3.2	102
7	**Florida Keys**	South Florida, United States	Threatened reef system	2002	MEPC.98(47)	13,000	2	153
8	**Jomard Entrance**	Papua New Guinea	Threatened reef system	2016	MEPC.283(70)	860	0.59	686
9	**Papahānaumokuākea Marine**	Western Hawaii, United States	Threatened reef system	2007	MEPC.171(57)	440,000	0.16	0.4
10	**Galapagos Archipelago**	Far west of Ecuador	Protecting endangered marine life	2005	MEPC.135(53)	144,000	0.13	0.9
11	**Archipelago of Sabana-Camagüey**	Northern Cuba	Threatened reef system	1997	MEPC.74(40)	38,000	0.08	2
12	**Tubbataha Reef**	Philippines	Threatened reef system	2017	MEPC.294(71)	4,500	0.06	13
13	**Saba Bank**	Caribbean, Netherlands	Threatened reef system	2012	MEPC.226(64)	2,700	0.009	3
14	**Paracas National Reserve**	Coast of Peru	Protecting endangered marine life	2003	MEPC.106(49)	2,900	0.003	1
15	**Malpelo Island**	Columbian waters	Protecting endangered marine life	2002	MEPC.97(47)	637	n/a	n/a
Total:							**665**	

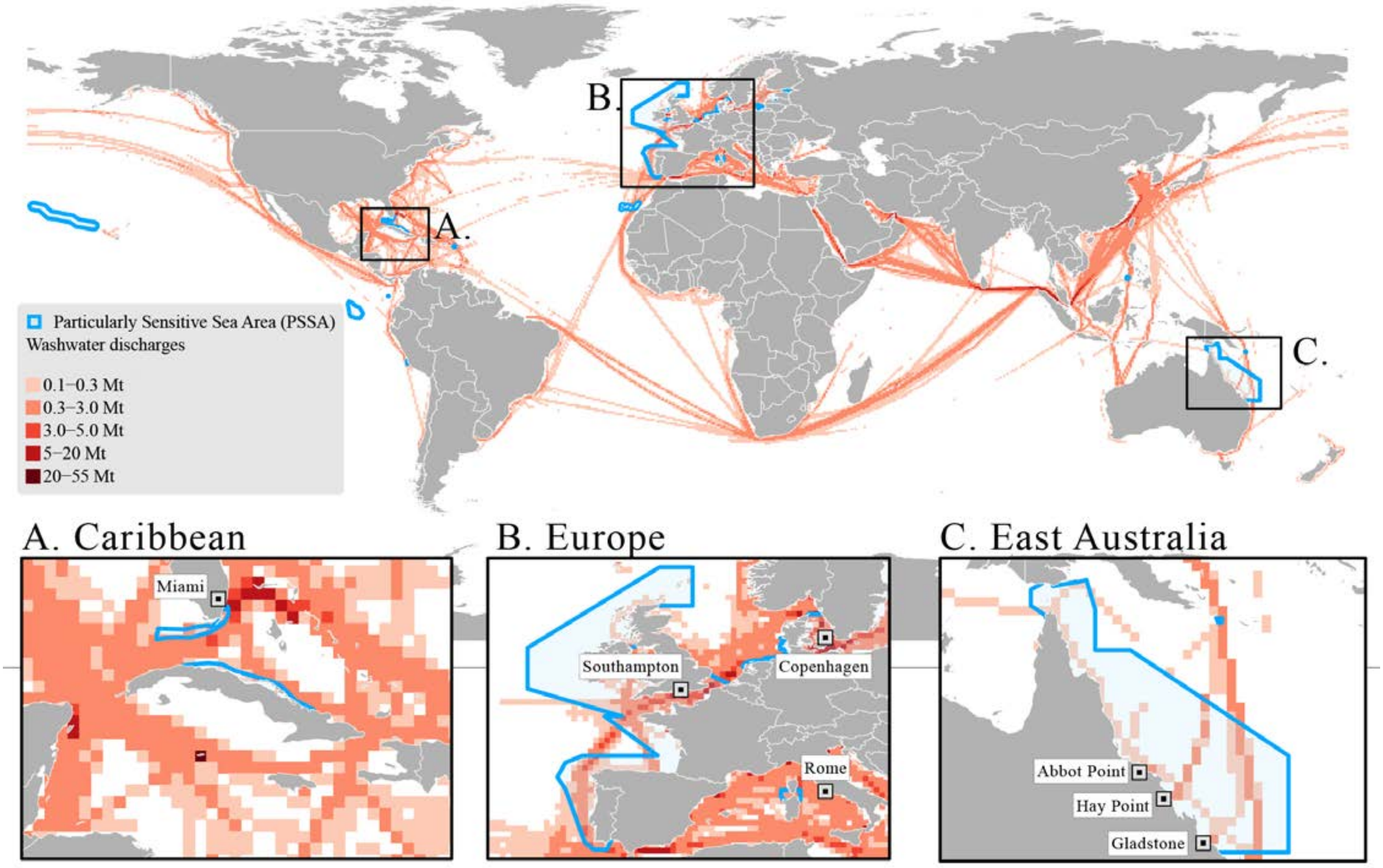

Figure 12. Scrubber washwater discharges expected within PSSAs

EFFECTIVENESS OF NATIONAL AND SUB-NATIONAL SCRUBBER REGULATIONS

Recall from Table 2 that 16 countries had banned scrubbers either in their ports or territorial seas as of June 2020. We estimate that approximately 421 Mt of discharge water will not be released globally due to these national regulations, and that means that about 4% of potential scrubber discharges are avoided by these restrictions.

Table 8 shows avoided washwater discharges in ports and national waters because of these regulations. Only two countries, Brazil and Malaysia, have adopted a full ban in their national waters so far, and this eliminated 116 Mt of discharge water in their national waters in total, more than one-quarter of all avoided discharges. Additionally, countries with relatively small national waters have successfully decreased discharges by banning scrubbers in their ports. By banning discharges in their ports, Egypt, Singapore, and Bahrain reduced total discharges within their national waters by 67%, 69%, and 100%, respectively. Nevertheless, Singapore still has the highest discharge water discharges per km^2 in the world.

In some areas, banning discharges only in ports is not as effective at reducing discharges. Pakistan's ban on scrubbers in its ports reduces scrubber discharges by only 40%, suggesting that restrictions in all national waters would be more effective. Countries that adopted bans on scrubbers only for selected ports ended up with the lowest effectiveness—less than 14% in all cases (Table 8).

The impacts of bans in special zones are inconsistent. Gibraltar will avoid 63% of discharge water because of the ban on open-loop scrubbers. China will avoid 89% of scrubber discharges in their waters by prohibiting open-loop scrubber discharges in domestic emission control areas. However, when the regulated areas are relatively small in relation to total size of national waters (as in the United States, Panama, and Belgium) or restricted only to internal waters (as in Norway), the effectiveness of the ban is the lowest (1%–27%).

Table 8. Avoided discharges in territorial seas and internal waters due to scrubber discharge bans (as of June 2020).

Country	Washwater in territorial seas, internal waters, and ports, combined (Mt)		Ban implemented in	Banned discharge water (%)
	No-ban scenario (discharged)	Ban scenario (not discharged)		
Malaysia	82	82	Territorial seas	100%
Brazil	34	34	Territorial seas	100%
Bahrain	2	2	All ports	100%
China	223	199	Special zones	89%
Singapore	35	24	All ports	69%
Egypt	52	35	All ports	67%
Gibraltar	8	5	Special zones	63%
Portugal	7	3	All ports	43%
Pakistan	1	0.4	All ports	40%
Panama	11	3	Special zones	27%
Belgium	4	0.7	Special zones	18%
Ireland	7	1	Some ports	14%
United States	170	23	Special zones	14%
Spain	57	8	Some ports	14%
United Arab Emirates	20	0.9	Some ports	5%
Norway	31	0.4	Special zones	1%
Total:	744	421.4		57%

CONCLUSIONS AND POLICY RECOMMENDATIONS

We expect ships to emit at least 10 Gt of scrubber washwater discharges in a year, absent additional regulations. About 80% of these discharges occur within 200 nautical miles of shore, with hot spots occurring in heavily trafficked regions, including the Baltic Sea, North Sea, and Mediterranean Sea, the Strait of Malacca, and the Caribbean Sea. Away from shore, scrubber discharges occur along major shipping routes. Unfortunately, some of these routes pass through PSSAs, some of which contain threatened coral reef systems. The Great Barrier Reef PSSA is one such example: About 32 Mt of scrubber washwater will be discharged in the Great Barrier Reef PSSA, mainly from ships serving coal mines in northeast Australia, and this represents 5% of the 665 Mt discharged in PSSAs globally.

Container ships, bulk carriers, and oil tankers together account for about three-quarters of scrubber installations by number of ships and are responsible for about 70% of scrubber discharges worldwide. An additional 15% of discharges are from cruise ships, even though they represent only 4% of the scrubber-equipped fleet. Cruise ships are also the main contributor to scrubber discharges in port. We found that cruise ships spend about 25% of their time in port. Moreover, when cruise ships are in port, they consume, on average, three times more energy per hour than oil tankers, and six times more than container ships.

We see the impact of cruise ships clearly in our results. Cruise ships account for 96% or more of discharges in seven of the 10 ports with the highest total washwater discharges. The port exposed to the most scrubber washwater is the Port of Georgetown in the Cayman Islands, a UK overseas territory in the Caribbean. More than 40 Mt of discharges occur within 1 nautical mile of this port, which is 14% of global in-port discharges. Nearly all 40 Mt are discharged by cruise ships. The second most impacted port is Southampton, located in mainland United Kingdom, with 7 Mt of discharges, 96% from cruise ships. Once more, our results model pre-pandemic ship traffic patterns, and thus cruise ships almost certainly did not discharge as much washwater in ports in 2020 and early 2021; however, while idling at anchor offshore, many cruise ships will have been using scrubbers. For cruise ships, we expect the results reported in this paper to be representative if and when the cruise industry returns to normal operations.

Ships flying the flags of Panama, Marshall Islands, and Liberia account for about 40% of global scrubber discharges. These are also the three largest flag states by tonnage of ships registered to them. Because scrubber use is concentrated in the large flag states with open registries, oftentimes the waters of a given country are polluted by foreign-flagged ships. We also note that several countries have imposed restrictions on scrubber discharges in their national waters but allow ships flying their flag to emit washwater on the high seas and within the waters and ports of other countries that have yet to impose their own restrictions. One example is Panama, which has banned open-loop scrubber discharges in the Panama Canal and yet registers ships that account for 18% of global scrubber washwater discharges.

An important caveat: our results are based on ships that have or will have scrubbers installed by the end of 2020 and are reflective of what we expect to be the mass and distribution of scrubber annual discharges for most ship types for the next several years, beginning in 2021. The main exception is cruise ships because the pattern of discharges presented in this study reflect pre-pandemic traffic patterns. For now, scrubber discharges from cruise ships will be concentrated in areas where these ships are congregating, waiting for no-sail orders to lift. Overall, we consider these results to be conservative. We assumed an open-loop discharge rate of 45 t/MWh because this is IMO's assumption for a normalized discharge rate, even though actual discharge rates are likely higher for most ships. Additionally, we were able to identify and model about 3,600 ships with scrubbers, although the total number of ships with scrubbers is actually more than 4,300.

Policymakers concerned about the environmental and public health impacts of scrubbers can refer to the following policy recommendations for the IMO, countries, and individual ports. IMO's regulations agreed to under MARPOL are legally binding. The IMO therefore has an important role to play in global scrubber policy.

At the IMO:

- MEPC could pass a resolution calling on ships to immediately stop dumping scrubber discharge water in places that should be protected, including estuaries, near-shore areas, marine protected areas, and especially PSSAs. Our analysis shows that ships with scrubbers are expected to discharge at least 665 Mt in PSSAs. These are areas with threatened reef systems, including the Caribbean Sea and the Great Barrier Reef, and endangered marine life, such as the Galapagos Archipelago.
- The IMO could prohibit the use of scrubbers as an equivalent fuel sulfur compliance option for new ships under MARPOL and establish a timeline for phasing out scrubbers already installed on existing ships. This rule would take several years to become enforceable under IMO rules of procedure but would eventually stop the use of scrubbers. In the meantime, MEPC could pass a voluntary resolution calling on Administrations (flag states) to not approve the use of scrubbers for ships flying their flag. These provisions should cover both open-loop and closed-loop systems.

Independent of any IMO action, individual countries, particularly countries located in hot-spot areas, could prohibit scrubber discharges in their waters, following the example of the countries that have already done so. Specifically, policymakers could consider the following actions at the regional or national level.

At the regional/national level:

- Authorities could prohibit scrubber discharges in waters under their jurisdiction. This includes open-loop discharges as well as closed-loop bleed-off water. If closed-loop scrubbers are used, they should be operated in zero-discharge mode. Jurisdictions could offer on-land reception facilities to properly dispose of sludge and water collected by closed-loop scrubbers. Waters of the United States, the United Kingdom, and Italy are all expected to receive more than 300 Mt of washwater discharges and yet do not currently prohibit the use of scrubbers in their territorial seas.
- Nearby countries could work together to harmonize scrubber discharge bans to avoid merely displacing scrubber discharges over political (but not ecological) borders. For example, Malaysia, Indonesia, and Singapore have already prohibited open-loop scrubbers in their ports, but this does not extend into the Strait of Malacca, which passes through each country's territorial seas and which is expected to receive the largest concentrations of washwater discharges in the world.
- Prominent flag states such as Panama, the Marshall Islands, and Liberia, which register ships expected to be responsible for 40% of global scrubber discharges, could agree to phase out the use of scrubbers on ships flying their flags. In the case of Panama, this would mean applying the same discharge bans to ships flying its flag as it does to ships transiting the Panama Canal.

Ports can also take action. Many ports are especially affected by discharges from cruise ships but will also see growing contributions from other ship types as more ships install scrubbers. Ports can consider the following actions.

At the port level:

- Ports could proactively ban scrubber discharges in waters under their jurisdiction. We have published rankings for the ports most affected by washwater discharges. These include the ports of Georgetown, Southampton, Freeport, and Vancouver.
- Ports could require ships to use onshore power when it is available. When not, ports could require ships use MGO to avoid the need for using HFO with scrubbers and the associated washwater discharges. Ports with heavy cruise ship traffic could install new or additional shore-side charging facilities. In seven of the 10 ports most impacted, 96% or more of scrubber washwater is discharged by cruise ships. Cargo ships can also use shore power.
- Ports could conduct ongoing water and sediment monitoring for acids, PAHs, heavy metals, nitrates, and nitrites. Pollutant monitoring can be supplemented with monitoring of photosynthetic activities and used as a bioindicator of eutrophication, which may be exacerbated by nitrogen pollution from ships. Ports could also keep a record of all ships that call on the port that used scrubbers within the port boundary and require ship officers to report the amounts of fuel consumption and scrubber discharges that occurred in the port.

The number of scrubbers is expected to grow over time, as more ships install them to comply with IMO's 2020 fuel sulfur regulation. Existing policies already avoid 421 Mt of scrubber discharges in the national waters and ports of 16 countries, preventing more than half of the washwater that would have otherwise been discharged in these countries' waters. Until and unless scrubbers are outlawed internationally, it will be up to individual national and sub-national governments concerned about their impact to take action.

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