Marine Policy 106 (2019) 103530

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Quantifying and mitigating three major vessel waste streams in the northern Bering Sea

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ARTICLE INFO

Keywords:
Bering sea
Bering strait
Indigenous perspective
Vessel traffic
Waste
Mitigation

ABSTRACT

More and larger vessels are operating in the Arctic's northern Bering Sea and Bering Strait and their associated waste streams pose a growing risk to the ecosystem. These collective risks are particularly concerning to Indigenous people in the region, whose culture and subsistence hinge upon preservation of a pristine marine environment. This article describes the ecological and cultural significance of the northern Bering Sea and Bering Strait waters to Indigenous people, and then discusses the risk to these waters from increasing vessel traffic and associated waste streams. The article then quantifies the amount of three principal waste streams – oil, sewage, and grey water – currently being discharged in these waters, and concludes with a discussion of ship- and area-based options to reduce the waste's impact to the region.

1. Introduction

Indigenous people in the northern Bering Sea and Bering Strait region live a subsistence way of life in this largely pristine ecosystem [1]. The region is experiencing ecosystem changes from a warming climate, including less sea ice and more open water [1]. Reduced sea ice increases the navigation window for ships wanting to take advantage of a potentially shorter route or other commercial opportunities [2]. Alaska Natives in the region have already experienced impacts from increasing vessel traffic. To help address this growing issue, this article describes and estimates the generation of three major vessel waste streams in the region—oily waste, sewage, and grey water—and examines ship- and area-based measures for reducing the cumulative impact of vessel waste.

2. The northern Bering Sea and Bering Strait region's signficance to Indigenous people

The region's Indigenous people have been addressing shipping issues in the Arctic since 2010, when the United States Coast Guard began a Port Access Route Study, through workshops and social science study. The concern for discharge into the region's oceans weighs upon the minds of the region's inhabitants.

For Alaska's first inhabitants a strong ancestral connection exists between humans and the northern Bering Sea. Inupiaq, Saint Lawrence Island Yupik and the northern coastal Yupik of the northern Bering Sea live in villages along the west coast of Alaska and its outer islands. The ocean is a central part of their existence and forms a strong basis for a maritime culture. Indigenous people of the region hunt marine mammals and seabirds, and harvest maritime benthic resources and a wide array of fish. Today's descendants live in a largely pristine environment, using and adapting traditional methods that have existed for millennia.

The northern Bering Sea and Bering Strait are vastly important to its first inhabitants because of the way the ocean has sustained an ancient culture. The sea's surface is frozen for much of the year, though the ice's annual extent has decreased substantially coincident with larger scale decreases globally [3]. Ice dependent people and marine resources have adapted to these harsh conditions and thrive on a productive ice and benthic system.

Alaska Native people rely upon maritime resources for food and they have expressed sincere concern over vessel waste and its potential impact upon people and animals [4]. Subsistence use areas are large, comparable to the size of some U.S. states, and therefore impacts could be felt over large areas [5]. Consequently, the following concerns are recurring points:

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1 Retired.

https://doi.org/10.1016/j.marpol.2019.103530
Received 6 November 2018; Received in revised form 29 April 2019; Accepted 9 May 2019
Available online 29 May 2019

- Discharge in Alaska Native ancestral waters should never be allowed;
- Alaska Natives are not prepared for a large-scale oil spill to this pristine environment;
- Climate change is dramatic with severe consequences to Alaska Natives' way of life; and
- Indigenous people must have a hand in determining their destiny with those threats in mind.

3. Threats from vessel waste streams

Northern Bering Sea and Bering Strait tribes are concerned over how quickly climate change is happening; and because they are experiencing it and increased shipping's many impacts, tribes are concerned for their future and food security. Alaska Native or Indigenous people of Alaska, also known in the vernacular as tribes, are legally recognized political entities that serve the needs of Indigenous people. Clean oceans, concern for the ecosystem, and mitigating human influence are important for tribes in the region [6].

Pollution generated from a vessel's normal operation poses potential risks such as discharges of oil, trash, sewage and grey water, emissions from engines, and noise. Marine casualties involving collisions, allisions, groundings, and sinkings significantly increase the risk to the environment as well, which is especially elevated due to the scarcity of response resources available in the region.

Discharges, including sewage, may expose maritime resources to zoonotic pathogens which are responsible for transmitting diseases between humans and animals [7]. In the northern Bering Sea, harmful algal blooms (HAB) and paralytic shellfish poisoning (PSP) could occur with greater frequency [8]. A 2016 study [9] found elevated levels of HAB toxins in marine mammals from the region. In the fall of 2017, 39 walruses washed ashore in western Alaska and of the four walruses sampled, all tested positive for biotoxins from algae [10]. The toxins found in marine mammals as a result of HAB's could pose risk to humans, as Indigenous people consume the intestines and stomach contents (where the toxins accumulate) from various marine mammals. Also, events with oiled wildlife [11], and whale entanglements have become increasingly common [12].

The Bering Sea ecosystem is undergoing rapid change, and there is growing concern that increased vessel traffic and discharge may contribute to broader cumulative effects and impacts on the marine environment and to people living there.

4. Vessel traffic is diverse and increasing

Vessel traffic through the Bering Sea and Bering Strait increased 145% between 2008 and 2015 [13] and this trend is projected to increase in the future. As the number of ships and passengers continue to grow, so will the amount of waste entering the water. Though the amount of actual vessel traffic is relatively low compared to other major waterways, this increased activity throughout the Arctic is significant for the region and poses risks to people, cultures, and the environment.

Vessel traffic in the region is diverse, with vessels primarily engaged in transiting between markets or supporting the extraction of natural resources, including oil, minerals, and fish. Cargo ships, either refrigerated bulk or container, transport seafood to global markets. Tankers, general cargo ships, and barges travel the northern Bering Sea, providing goods and supplies to coastal and inland communities. Vessels support many different types of resource extractive activities, both ashore and in and under the water. Passenger ships also transit through the region, as do research, government, and recreational vessels.

5. Quantifying shipboard waste generation

There are up to 40 waste streams that may be associated with vessel operations [14] (see Appendix). This article focuses on three of the largest ship-generated streams that may be discharged into the water: oily waste, sewage, and grey water. The methodology involved analyzing Automatic Information System (AIS) data to determine the number of vessels of each class that commonly transit the region's waters, the time those vessels were operating, and then estimating the average of each waste stream generated by those vessels.

Estimating the quantity of waste generated onboard vessels during normal operations is complex. Each waste stream is driven by differing variables, including the number of people on the vessel, the efficiency of installed equipment, and the type, size and weight of the vessel. Another factor complicating the calculation of shipboard generated waste is determining how much waste is stored on the vessel, as opposed to being discharged into the environment. Since almost every vessel is unique in both equipment and storage capacity, waste calculations must use multipliers that may have a significant degree of error. A final variable is the amount of shipping activity, as the total waste generation for an area will be the product of the amount of vessel activity. While estimating waste generation can provide some reasonable predictions, the only verifiable method to document actual quantities is by completing environmental compliance audits on a statistically significant population of vessels operating in the region [15].

For information related to vessel activity in the region, this article uses AIS data from June 1 to October 31 for years 2014–2017 gathered and stored by the Marine Exchange of Alaska (see Fig. 1for geographic scope) [16]. To better estimate waste generation where time is an important variable, the AIS data was used to calculate operating days rather than transit segments. AIS data can be incomplete, inconsistent, and subject to human error, but still the best tool available for identifying vessel patterns [13,17] (see Figs. 2 and 3). Some vessels are also difficult to classify correctly, as they may fit into several different groups of activities, such as a landing craft that is being used for cargo operations or lightering. A final complication is that there is no compulsory vessel reporting system present in this region.

5.1. Oily wastes

Oily wastes are generated from machinery and must be separated from bilge and cooling water through an oily water separator (OWS). After treatment through a high-speed centrifuge-type design, the residual oily waste is held onboard the ship in storage tanks and pumped off at an approved port reception facility. The left over oily water, or "effluent," can be discharged overboard from the vessel only south of 60° north latitude in Alaskan waters, and only if the oil content is less than 15 parts per million (ppm).[2] [19]

Lightering and transferring fuel from larger tank vessels to small vessels supplying coastal communities is another source of oily waste that poses a significant risk to the environment. Most lightering activity occurs relatively close to shore, and thereby closer to Indigenous communities and areas critical for subsistence [20].

The environmental impacts from oil will differ depending on the type of oil, where and when it was spilled, and how it moves. Oil is categorized as light, medium, and heavy. Light oils such as gasoline and diesel fuel are more volatile and evaporate relatively quickly, usually within days. Heavy oils such as bunker fuel used by some vessels can persist in the environment for months or even years. Light oils are acutely toxic, meaning their impact will be felt relatively quickly after exposure, where heavy oils can smother or coat wildlife leading to hypothermia, and their persistence can lead to long-term health issues [21].

Determining an exact amount of oily waste requires precise knowledge of the amount and type of fuel consumption. Oily waste

[2] As of 2017, the Polar Code bans most ships north of 60° latitude from discharging oil and oily mixtures [18].

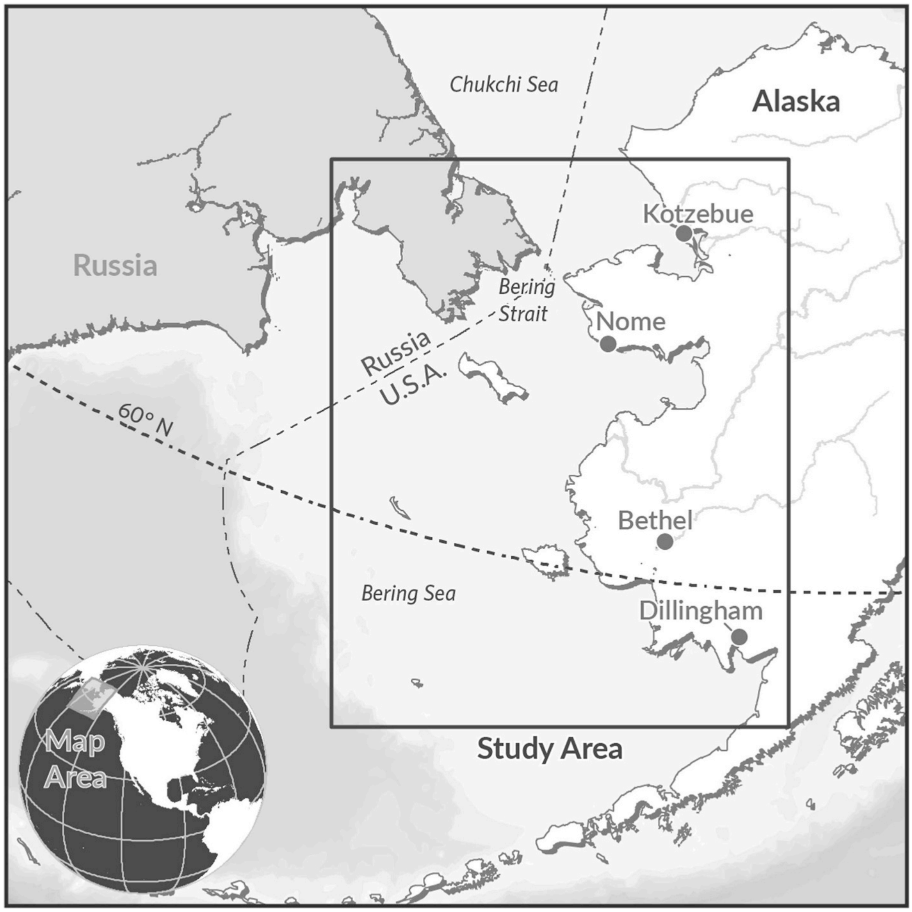

Fig. 1. Geographic scope of Automatic Information System data represented below from the northern Bering Sea.

generated by vessel machinery may range between 1 and 2% of consumed fuel for Heavy Fuel Oil (HFO) engines, but only 0.5% for lighter Marine Distillate Oil (MDO) [22]. In general, large deep draft vessels will generate more oily waste than lighter, shallow draft vessels. Despite these challenges in developing a baseline, a comparison between classes of vessels does allow for some measure of analysis.

Based on this analysis of vessel activity (see Table 1), cargo vessels account for nearly 80% of the oily waste generated in the region, due to the relatively high amount of fuel consumed on such vessels and the use of HFO, followed by tankers at 9%. Towing vessels only generated 5% even though there are more towing vessels operating in the region, since they generate less waste due to their consumption of MDO fuels. Passenger vessels, while small in numbers, can generate a significant amount of oily waste due to the high rate of fuel consumption, especially for high capacity passenger vessels. Fishing and towing vessels account for higher amounts generated, primarily due to the larger numbers of these smaller vessels operating throughout the area.

5.2. Sewage

The International Maritime Organization (IMO) defines sewage as drainage and other wastes from toilets and urinals; drainage from medical premises—dispensary, sick bay, etc.—via wash basins, wash tubs and scuppers; drainage from spaces containing living animals; or other waste waters when mixed with the drainages listed above [29]. U.S. regulations define sewage as human body wastes and the wastes from toilets and other receptacles intended to receive or retain body waste [30].

Except in designated “No Discharge Zone” areas, the U.S. Clean Water Act (CWA) requires sewage to be treated before it is discharged in “navigable waters,” which are those waters within 3 NM of shore [31].[3] The level of treatment required within 3 NM depends on the type of vessel. For most vessel types, the U.S. Marine Sanitation Device Type II treatment standard requires effluent that contains less than 200 fecal coliform (FC) per 100 mL (ml) [32]. The state of Alaska has adopted more stringent sewage treatment standards for large commercial passenger vessels providing overnight accommodations for 250 people or more, permitting a daily maximum of no more than 40 FC per 100 ml, with requirements for sampling and monitoring [33]. The Polar Code[4] contains additional limitations on the discharge of sewage, including the prohibition of untreated sewage discharged within 12 nautical miles from any ice-shelf or fast ice, and the requirement that discharges occur as far as practicable from ice concentrations exceeding 10% (see Appendix) [18]. The Polar Code also mandates that all new cargo ships and passenger vessels constructed after January 1, 2017 have an approved and operating sewage treatment plant onboard if the vessel intends to discharge sewage in U.S. Arctic waters north of 60° [18].

[3] “Navigable waters” includes the U.S territorial sea, which at the time of the CWA's enactment extended 3 NM from shore. Congress has not amended the CWA to expand its applicability to the current 12 NM breadth of the U.S. territorial sea.

[4] The International Code for Ships Operating in Polar Waters (Polar Code) was adopted by the IMO in 2014 through amendments to both the International Convention for the Safety of Life at Sea (SOLAS) and the International Convention for the Prevention of Pollution from Ships (MARPOL). The Polar Code, which became effective on 1 January 2017, covers the full range of design, construction, equipment, operational, training, search and rescue and environmental protection matters related to ships operating in waters surrounding the two poles.

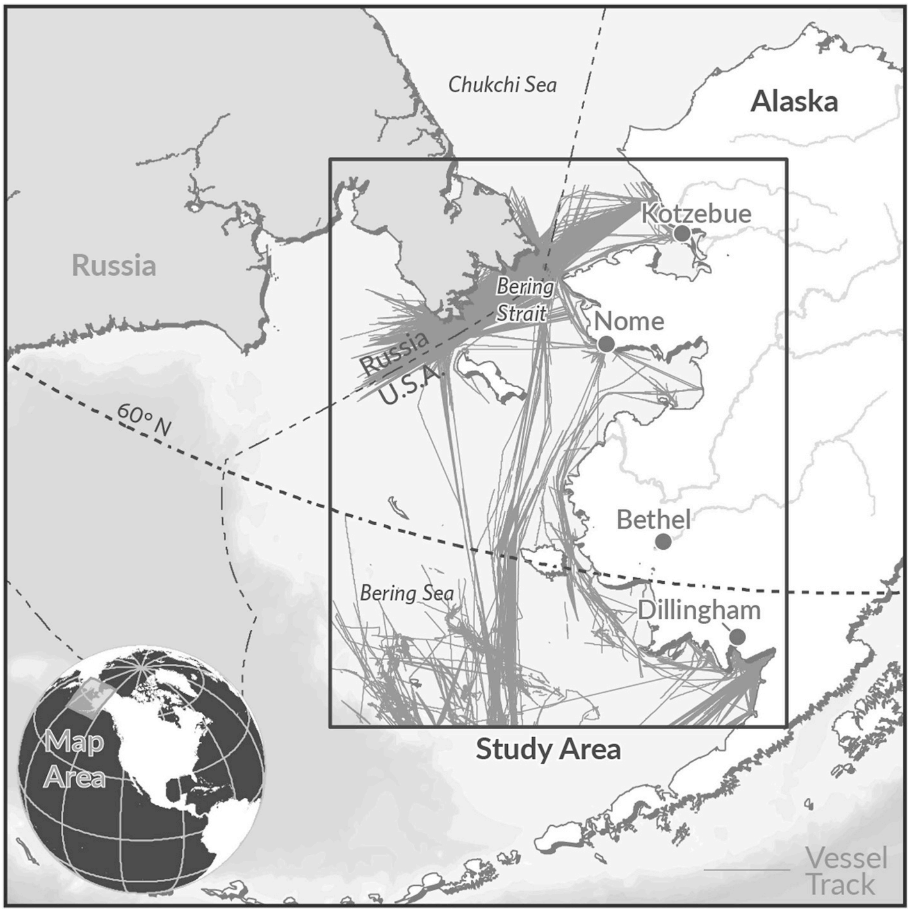

Fig. 2. Cargo vessels recorded by AIS between 2014 and 2017 show both offshore and nearshore transit patterns.

Ecosystem risks from sewage are fecal coliform, oxygen depletion, and excess nutrient enrichment [34]. The nitrogen and phosphorus components of sewage can act as a fertilizer for algae and some aquatic plants which can deplete oxygen in the water needed by fish and aquatic animals [35]. Harmful algal blooms are increasing in the region as water temperatures rise [36]. Shellfish can concentrate fecal coliform and associated pathogens from the water around them, which can be passed to humans [35].

Over 90% of the sewage generated from these vessel types can be attributed to fishing, passenger, cargo, and towing vessels (see Table 2). While fishing vessels have a small number of people for each vessel, the overall large presence in the region elevates this type to the top of this list for sewage generation.

As noted previously, while passenger vessel counts are low relative to the other types, passenger vessels carry significantly more people and generate more sewage and grey water than the other vessel types. For comparison, the city of Nome, with a population around 3800, generated an average of 582,552 gallons of sewage per day in 2016 [39]. Nome's sewage treatment reaches a monthly average of 14 FC/100 ml with a maximum of 43 FC/100 ml—comparable to the state's standard for cruise ships.

5.3. Grey water

Grey water is water from showers, sinks, dishwashers and laundry facilities onboard vessels. It does not include water from toilets or urinals, or waste streams from hospital spaces or cargo holds. Grey water may end up mixed with sewage and treated, or in other cases may be piped directly to the ocean.

The EPA has concluded that some samples of grey water from vessels contained concentrations of fecal coliform, total suspended solids, biological and chemical oxygen demand, free residual chlorine or ammonia that were similar to raw sewage [37].

The U.S. EPA's Vessel General Permit (VGP)[5] includes some requirements for grey water (see Appendix), including that it be kept onboard or discharged at least 1 NM from shore, that kitchen oil content be minimized, and that vessels must use phosphate-free and minimally toxic soaps and detergents as defined in detail in the permit [14].

The VGP places additional requirements on passenger vessels including large cruise ships (those authorized to carry 500 or more passengers), medium cruise ships (those authorized to carry 100–499 passengers), and large ferries (those authorized to carry over 100 tons of cargo or 250 or more people). These include the mandatory use of shore facilities when in port unless the vessel treats grey water to a specified standard; a prohibition on discharge within 3 NM from shore unless the vessel treats grey water to a specified standard; and a prohibition on discharge of waste from certain operations such as dry cleaners, photo labs, salons, and day spas. The VGP also contains specific requirements for the monitoring, recordkeeping, and reporting of grey water [14]. Neither the International Convention for the

[5] The VGP provides authorization for, and limitations on, incidental discharges of effluent into waters of the United States from commercial vessels greater than 79 feet in length, and for ballast water from commercial vessels of all sizes. The current VGP was issued in 2013 was to have been updated in 2018. However, Congress, in the Vessel Incidental Discharge Act of 2018, directed the EPA and Coast Guard to revamp the U.S.'s incidental discharge program and standards. Until this process is complete, the current VGP and its discharge standards remains in force [40].

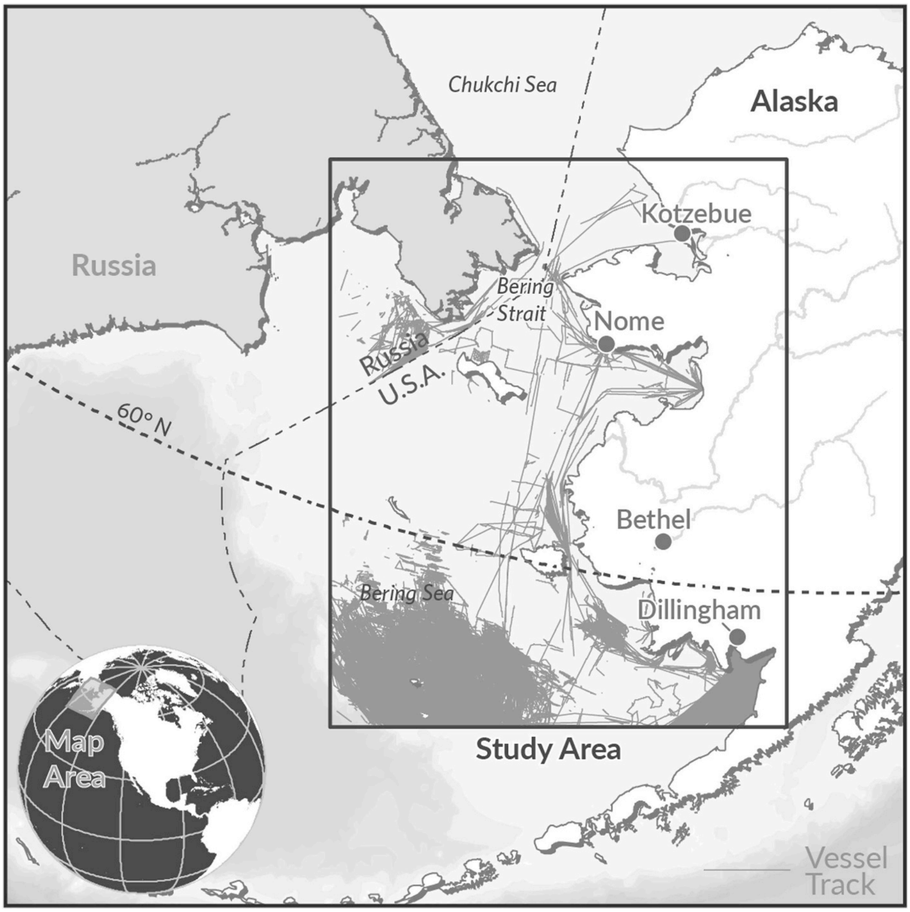

Fig. 3. Fishing vessels as recorded by AIS between 2014 and 2017 are concentrated in the more southern portion of the study area; however, fisheries may move further north as the Bering Sea warms [8].

Table 1
Estimates of oily waste generated by vessels in the northern Bering Sea from June 1 to October 31, 2014–2017.

Vessel Type	Daily Average Vessel Count[a]	Fuel Type	Fuel Consumption Per Vessel (liters/day)	Oily Waste Generation Rate (% of fuel consumed)[b]	Daily Oily Waste Generation Per Vessel (liters/day)	Daily Oily Waste Generation Per Vessel Type (liters/day)	Annual Oily Waste Generation Per Vessel Type (liters/season)[g]
Cargo	5.9	HFO	145,360[c]	1.5%	2180	12,950	1,981,299
Tanker	1.8	HFO	56,781 [23]	1.5%	852	1526	233,486
Towing Plus Long/Wide	11.7	MDO	15,142[d]	0.5%	76	885	135,434
Passenger	0.6	HFO	22,326[e]	1.5%	335	212	32,425
Fishing	37.2	MDO	2082[f]	0.5%	10	388	59,309
Tug	2.9	MDO	15,142[d]	0.5%	76	216	33,122
Total	60.1					16,177	2,475,075

[a] Vessel activity per vessel type per day, on average, from June 1 to October 31, 2014 to 2017 (153 days), based on AIS data acquired from the Marine Exchange of Alaska [16]. Operating days are based on the elapsed time between first and last timestamp for each individual vessel for each year of data. Periods when vessels had AIS transmission time gaps of more than 48 h were omitted to exclude those that were not verifiably operating. Geographic scope seen in Fig. 1. Listed vessel types comprise 85% of vessel activity. Approximately 15% of total AIS activity is associated with unknown or other vessel types from which waste calculations could not be determined.

[b] These calculations use the median of 1.5% for HFO.

[c] Based on fuel consumption rate of 25 metric tons/day, which equates to 1600 gallons/hour [24].

[d] Ocean-going tugs actively towing consume between 3000 and 5000 gallons per day [25]. These calculations assume an average of 4000 gallons/day.

[e] Large cruise ships can consume up to 80,645 gallons per day of fuel [26]. Small-medium cruise ships may use approximately 3000 gallons per day [27]. This calculation uses the weighted average of fuel consumption for passenger vessels based on the vessel activity including 25 small to medium passenger vessels (2909 gallons) and 1 large cruise ship that operated in the northern Bering Sea from June 1 to Oct. 31, 2014–2017.

[f] Calculation uses 23 gallons/hour and assumes fishing vessels operate on a 24-h schedule [28].

[g] These calculations are based on the open water season that takes place, generally, between June 1 and October 31, or 153 days.

Table 2
Estimates of sewage generated by vessels in the northern Bering Sea from June 1 to October 31, 2014–2017.

Vessel Type	Daily Average Vessel Count	Average Number of Passengers and Crew [37]	Sewage Generation Rate Per Person (liters/day)[a]	Daily Sewage Generation Per Vessel (liters/day)	Daily Sewage Generation Per Vessel Type (liters/day)	Annual Sewage Generation Per Vessel Type (liters/season)[c]
Fishing	37.2	7	34	238	8880	1,358,715
Passenger	0.6	266.3[b]	34	9072	5741	878,417
Cargo	5.9	25	34	852	5058	773,944
Towing Plus Long/Wide	11.7	6	34	204	2390	365,671
Tanker	1.8	25	34	852	1526	233,486
Tug	2.9	6	34	204	584	89,428
Total	60.1				24,181	3,699,662

[a] A European Maritime Safety Agency study said that anywhere between 0.01 and 0.06 cubic meters should be considered black water. Using the mid-point of 0.03 cubic meters, this is approximately 8 gallons [38].
[b] Based on a weighted average of passengers and crew on 25 small to medium passenger vessels and 1 large passenger vessel that operated in the northern Bering Sea from June 1 to Oct. 31, 2014–2017. This weighted average is highly dependent on the number of high capacity passenger vessels; as their numbers increase, so too will the average number of passengers and crew.
[c] These calculations are based on the open water season that takes place, generally, between June 1 and October 31, or 153 days.

Table 3
Estimates of grey water generated by vessels in the northern Bering Sea from June 1 to October 31, 2014–2017.

Vessel Type	Daily Average Vessel Count	Average Number of Passengers and Crew [37]	Grey water Generation Rate Per Person (liters/day) [37]	Daily Grey water Generation Per Vessel (liters/day)	Daily Grey Water Generation Per Vessel Type (liters/day)	Annual Grey Water Generation Per Vessel Type (liters/season)[b]
Fishing	37.2	7	170	1192	44,403	6,793,595
Passenger[a]	0.6	266.3	246	65,524	41,465	6,344,130
Cargo	5.9	25	170	4259	25,292	3,869,730
Towing plus Long/Wide	11.7	6	170	1022	11,950	1,828,362
Tanker	1.8	25	170	4259	7630	1,167,434
Tug	2.9	6	170	1022	2923	447,144
Total	60.1				133,663	20,450,395

[a] Based on a weighted average of passengers and crew on 25 small to medium passenger vessels and 1 large passenger vessel that operated in the northern Bering Sea from June 1 to Oct. 31, 2014–2017. This weighted average is highly dependent on the number of high capacity passenger vessels; as their numbers increase, so too will the average number of passengers and crew.
[b] These calculations are based on the open water season that takes place, generally, between June 1 and October 31, or 153 days.

Prevention of Pollution from Ships (MARPOL) nor the IMO's Polar Code amendments specifically address grey water or restrict its discharge.

As grey water generation is heavily dependent on both the number of vessels and the number of people on the different types of vessels, over 90% of generated grey water can be associated with fishing vessels, cargo vessels, passenger ships, and towing vessels operating in the region (see Table 3).

Passenger vessels pose a particular challenge to the marine environment, primarily because of the generation of large volumes of grey water and sewage, which may be discharged overboard. A small number of passenger ships can generate substantial volumes of wastewater that far exceed all the wastewater generated by all other vessel types. Seven cruise ships are scheduled to come through the Port of Nome in 2019, which will be the most ships to visit there in one summer [41].

It is worth noting that in addition to the waste streams from normal vessel operations, any growth in vessel traffic also increases the potential risk for marine casualties and accidental oil spills, which pose an additional threat to the northern Bering Sea ecosystem.

6. Reducing the cumulative impacts of vessel waste

Ship traffic is growing, and with no meaningful regulatory changes or technological advances, so will the pollution. There are measures that, cumulatively or individually, can be utilized to reduce vessel generated waste and its impact. Such measures can be created at the state, federal, or international level, and be either ship-based or area-based in nature.

6.1. Ship-based measures

Ship-based measures apply directly to the construction or equipment onboard, or how a vessel operates, with the intention of reducing or mitigating the pollutants entering the water.[6]

6.1.1. Testing and monitoring of onboard treatment equipment and reporting of discharges

To limit the discharge of vessel-generated waste into the northern Bering Sea, federal and international regulators could require vessels to verify that their shipboard pollution control systems continue to meet the standards they were designed and proven to meet initially, and to

[6] To cover the majority of vessels transiting the region, most of these measures would have to be international in nature. The law of the sea, while permitting coastal States—nations bordering the seas that possess limited prescriptive and enforcement jurisdiction over foreign vessels in their adjacent waters that diminishes the further such a vessel is from the coastal State—to unilaterally prescribe and enforce pollution laws against foreign vessels in the waters off their coast, generally prohibits such measures from applying to the design, construction, manning or equipment of foreign ships. For examples of such limitations in the United Nations Convention on the Law of the Sea (UNCLOS), see Articles 21(2.) and 211 0.6(c) [42].

report certain discharges. The U.S., as an example, requires vessels to have type-approved marine sanitation devices to treat sewage, but does not have requirements for testing, monitoring, or reporting of discharges to ensure those devices are working as intended, outside of specific requirements for cruise ships in Alaska.[7] Studies have shown that MSDs often perform much worse than intended, with MSD-treated sewage resulting in higher concentrations of bacteria than untreated domestic wastewater [34].

Similarly, MARPOL does not require the testing of sewage control systems by covered vessels [29]. The frequency of testing and monitoring of a vessel's treatment system should be proportionate to the amount of waste a vessel, or class of vessels, produces. For vessels processing lower amounts of waste (including sewage, grey water, and oily water), tests could be required at intervals to coincide with commercial vessel intermediate and special surveys performed by the classification society every 2.5 years.

In addition, vessels could be required to log sewage and grey water discharges in a record book, similar to the requirements for documenting oily waste and garbage [43]. Such records would encourage accountability and provide an enforcement mechanism, either by the flag State or the U.S., for violations of pollution controls and limitations. For example, the State of Alaska issued 15 notices of violation to cruise ships for operations exceeding permit levels in 2018 [44].

6.1.2. Higher waste treatment standards

Sewage and grey water discharge, especially if untreated, can have harmful impacts to the water column by introducing pathogens and chemicals, and depleting oxygen needed for marine life. Grey water, despite these known threats, is not recognized or regulated by the IMO as a pollutant, and U.S. regulations only apply out to 3 NM from the coastline and lack specific treatment standards. Sewage treatment requirements exist, yet differ widely among state, federal, and international jurisdictions (see Appendix).

To reduce the negative impacts from sewage and grey water, the U.S. could close a regulatory gap beyond 3 NM by amending the Clean Water Act to extend federal agency authority out to 12 NM. The IMO could amend MARPOL to recognize grey water as a pollutant, and regulate it similarly to sewage. MARPOL could also be amended to ban the discharge of untreated sewage and grey water in waters beyond 12 NM from shore, and to tighten the standard for treated wastewater from its current level at 100 fecal coliforms per 100 ml. Though the U.S. is not a party to MARPOL Annex IV (prevention of pollution from sewage) and would not be bound to these proposed changes, the U.S. should align with these more stringent international standards, since any diminution in fecal bacteria entering the water would reduce the nutrient load and associated harmful consequences in the northern Bering Sea.

6.1.3. Offload to a port reception facility

There are limited port waste reception options in the U.S. Arctic. Vessels can currently utilize a private contractor to haul its sewage in the Port of Nome, but not oily waste [39]. Access to Nome, located in the Arctic Circle, is seasonal and with a current depth of only 22 feet, cannot accommodate larger ships. One study suggests that Nome's ability to accept sewage from vessels, without modification or addition to its current capabilities, will be at capacity 2027 if not sooner [39]. The closest deepwater port to the Arctic is in Dutch Harbor, located in the Aleutian Islands. Increasing the availability of port reception facilities, where vessels could offload various types of waste shoreside, could reduce waste entering the water. Port facilities should include sufficient infrastructure to enable vessels operating in Arctic waters to dispose of their oily waste, sewage, and grey water ashore for treatment, and those facilities should at least meet the international standards for shipboard treatment systems. This will be especially important in areas where vessels may not be able to regularly discharge waste, such as within Polar Code boundaries, and may only discharge as far as practicable from areas of ice concentration exceeding 10%.

Locating adequate port reception facilities in the Arctic faces a number of challenges including: higher operating costs due to relatively low, seasonal traffic; concerns for facilities located in or near sensitive areas; capacity for the community to safely manage increased waste from ships; and the high cost of constructing or updating port facilities in remote areas.

6.1.4. Increase onboard storage

Vessels could plan to keep their waste on board rather than discharging it to the water. Ships are already required to hold oily waste and garbage (aside from ground food) in Polar Code waters. Most large ships already have a holding or storage tank available in addition to the ballast water holding tank.

The Polar Code could be strengthened to require all vessels to have an increased capability to hold sewage and grey water until the vessel can safely offload the waste at a port reception facility or treat it to an acceptable standard. This increased storage capacity would enable vessels to operate near sensitive areas without discharging wastewater for some specified period of time.

There are cost and configuration constraints associated with this remedial option; however these may be minimized by creative solutions such as including more efficient waste systems that reduce the need for larger holding tank capacity [45] or utilizing some ballast water storage for sewage [46].

6.2. Area-based measures

Area-based measures are international or domestic mechanisms intended to minimize the direct impact of vessel discharges by routing vessels away from, or restricting discharge of waste in, sensitive areas.

6.2.1. International - Particularly Sensitive Sea Area

IMO member States may propose the adoption of area-based protective measures, including a Particularly Sensitive Sea Area, or PSSA. A PSSA is defined as “an area that needs special protection through action by IMO because of its significance for recognized ecological or socio-economic or scientific attributes where such attributes may be vulnerable to damage by international shipping activities” [47]. To obtain this designation the area must meet certain criteria, including: ecological; vulnerability to degradation; social, cultural and economic; and scientific or education.

The strength of a PSSA is the protective measures associated with it. Associated protective measures may include one or a combination of the following (which are discussed in more detail below):

- recommended routes;
- Areas to Be Avoided;
- mandatory vessel reporting; or
- the designation of a Special Area permitted by various MARPOL Annexes.

If a PSSA is adopted, its associated protective measures become binding on all vessels flagged by IMO member States. Areas in the northern Bering Sea region that are critically important to Indigenous peoples' food security and culture, as well as maintaining the health of the marine ecosystem, could be considered for PSSA designation.

6.2.2. International - Recommended Routes and Areas to Be Avoided

In areas that may not warrant a PSSA designation, member States may still propose one or more protective measures for their waters,

[7] Periodic testing requirements currently only exist domestically for cruise ships operating in Alaska's state waters and the Alexander Archipelago. These requirements include fecal coliform testing twice monthly, a monthly discharge report, and a log book with details of each discharge [33].

including measures to guide traffic around sensitive or hazardous places using recommended routes, traffic separation schemes, and Areas to Be Avoided or ATBAs. Any proposal for the adoption of such measures must be supported by general criteria and approved by members of the IMO.

ATBAs are areas "within defined limits in which either navigation is particularly hazardous, or it is exceptionally important to avoid casualties, and which should be avoided by all ships, or by certain classes of ships" [48]. Their purpose is to increase safety for vessels, and also to protect important cultural or ecological areas. In May 2018 the IMO approved three ATBAs in the northern Bering Sea [49], requested by the U.S. and based on a Coast Guard vessel traffic study in the region [13].

In addition, States can designate recommended routes that minimize risk to vessels and sensitive marine areas. Following the same vessel traffic study, the U.S. and Russia jointly proposed a series of two-way traffic routes, connected by precautionary areas through the northern Bering Sea and Strait [49]. The routes in U.S. waters were developed to work in concert with ATBAs to keep maritime traffic away from important habitat areas and increase vessel usage of hydrographically surveyed areas to diminish the risk of vessel groundings or collisions.

6.2.3. International - Special Area

A "special area" is an IMO designation for sea areas that, due to certain oceanographic and ecological criteria, warrant enhanced protection from vessel pollution covered by various MARPOL annexes, including: oil, noxious liquid substances, sewage, garbage, and air emissions. Special area designations permit enhanced pollution control measures, up to and including no discharge whatsoever, in associated waters [50].

The Arctic has not officially been designated as a MARPOL special area; however, the Polar Code amendments to MARPOL included special area protections from oil and noxious liquid substances by banning discharge of both, as well as for sewage by limiting discharge from new cargo and passenger vessels built after 2017 [18]. The Polar Code's sewage provisions could be strengthened by expanding the age and class of vessels to which they apply. This is especially warranted by the AIS data analyzed in this paper, which demonstrate that fishing vessels and towing vessels, currently not covered by the Polar Code's sewage provisions, are significant contributors of sewage in the region.

6.2.4. U.S. - Marine Protected Areas

U.S. law permits the creation of Marine Protected Areas (MPAs), which are defined in Executive Order 13,158 as, "any area of the marine environment that has been reserved by Federal, State, territorial, tribal, or local laws or regulations to provide lasting protection for part or all of the natural and cultural resources therein" [51].

National MPAs are designated from authority contained in federal law including the National Marine Sanctuaries Act, National Wildlife Refuge System Administration Act, and National Park Service Organic Act [52]. The authority used to create the MPA will have an impact on the management focus and level of enforcement. Being entirely in U.S. waters, MPAs can be established without having to undergo the extensive process necessary to establish international analogs like PSSAs; however, without the international seal of approval, U.S. enforcement options on foreign vessels are extremely limited.

There are ten MPAs in the northern Bering Sea and Bering Strait region, and approximately half of them were established and managed wholly or in part with the explicit purpose of supporting the continued extraction of renewable living resources (e.g. fish) [52]. The other MPAs in the region were established to protect or restore the area's ecological health. A third possible conservation focus is cultural heritage, but there is no MPA in the region with that designation [53].

To enhance the protection and preservation of vital Arctic marine areas, new MPA designations could be proposed, or the protection level of existing MPAs—most of which restrict commercial fisheries and little else—could be increased. The level of protection could be as strong as "no access," which requires special permission for entry. More likely, however, would be the "no impact" protection level, which allows access to an area but prohibits any activities that could harm its ecological or cultural properties, like discharging pollutants. California's Channel Islands National Marine Sanctuary and Florida's Tortugas Ecological Reserve are examples of MPAs that limit vessel discharge and could serve as a model for the Northern Bering Sea.

6.2.5. State - No discharge zones

The state of Alaska has already taken steps to limit the nearshore discharge of both grey water and sewage from large passenger vessels out to 3 NM (see Appendix). While its standard is one of the most stringent for vessel wastewater discharge, it is limited both in the vessels to which it applies – large passenger vessels only – and by the fact that it only limits, but does not prohibit, nearshore discharges.

U.S. law permits states such as Alaska to petition the U.S. Environmental Protection Agency to establish a No Discharge Zone (NDZ) in state waters [31]. The effectiveness of a NDZ would be limited, as it would only apply to sewage, not to grey water (unless it is mixed with sewage), and because the NDZ would only extend a maximum of 3 NM from the coast.[8] Nonetheless, given the recent increase in regional cases of harmful algal blooms and paralytic shellfish poisoning in marine mammals and birds, establishing a NDZ for sewage in nearshore areas may be helpful in reducing nutrient loads and its harmful impacts.

7. Conclusion

This article has demonstrated that vessel traffic in the northern Bering Sea and Bering Strait is increasing and has quantified the expected discharges of three main pollutants – oil, sewage, and greywater – for each class of vessel that operates in these waters. Such discharges will increase linearly as vessel traffic continues to grow. The increasing pollution risk posed by vessels is causing great concern to Indigenous people in the region, whose culture and food security is based upon the harvest of living resources that are untainted by pollutants. Though the issue of vessel-generated waste in this region has not yet reached crisis proportions, preventative actions now to maintain, as near as possible, the status quo will be much less costly and less difficult to implement than corrective measures to undo a deteriorated situation in the future. While there are numerous impediments to adopting preventative measures before an actual crisis is reached – political will, cost, lack of data, operational and infrastructure challenges in the harsh Arctic environment, to name a few - this article proposes a range of achievable preventative measures that, singly or in combination, should be considered as a means of minimizing the effect of vessel-generated waste in this pristine and sensitive region.

Declaration of interest

None.

Funding

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

[8] Though the U.S. is entitled under international law to enact pollution control measures throughout its territorial sea, i.e. out to 12 nm, it has chosen to make the Clean Water Act, upon which NDZs are based, applicable only out to 3 nm from the baseline.

Acknowledgements

The authors would like to extend their gratitude to Michael Wissner, GIS Officer with The Pew Charitable Trusts, for his Automatic Information System data analysis and maps of Alaska and vessel traffic; Tim Close, Capt. U.S. Coast Guard (ret) and Greg Sundgaard, Capt. U.S. Coast Guard (ret), for their earlier research on vessel wastewater that contributed to this analysis.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.marpol.2019.103530.

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