The Great Bear Sea – a toilet bowl for marine vessels: quantifying waste and the ecological, social, cultural, and economic risks of marine dumping

Grand Challenges in Ocean Leadership
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Outline

I) Background: The Great Bear Sea

The Great Bear Sea (GBS) is a 32,000 sq km area in the ocean that surrounds the Great Bear Rainforest in British Columbia (BC). The GBS spans the waters from the Northern tip of Vancouver Island to the border of BC and Alaska encompassing the archipelago of Haida Gwaii (WWF, 2013). This region is one of the richest ecosystems in the world, highlighting the interconnectedness of the land and the sea, and the diversity of species that depend on them.

The rainforest supports important terrestrial life including century old trees, sea wolves, birds, grizzly and black bears, and rare and endemic spirit bears. Some of BC's largest rivers feed into this area with all five wild Pacific salmon species connecting the terrestrial systems to the marine. The GBS is home to marine megafauna including cetaceans and pinnipeds such as humpback whales, dolphins, porpoises, seals, and sea lions. All of these top species rely on the interconnectedness of healthy Great Bear terrestrial and marine ecosystems. Not only is the GBS vital for local wildlife, but it also defines the livelihoods of people who live there, including many First Nations groups such as the Haida Nation. Together, this region is highly important to the Canadian economy through wildlife tourism and its marine resources.

Proper management and strong collaboration in this area is key in order to ensure the productivity of this marine ecosystem persists for current and future generations.

Various factors threaten the health of this ecosystem that should be addressed and well managed. Here, we focus on the issue of ship and boat wastewater discharge in the area, and the potential risks it poses to the wildlife and health of the GBS ecosystem.

II) Background on Waste

Shipping in the GBS

Transport by water is both an economical and efficient way to move goods and people. A diverse fleet of international and domestic commercial and recreational vessels navigate the coastal waters of BC every year. Transport Canada defines commercial as business/for-profit operating vessels while recreational or pleasure crafts are used only for pleasure activity, like fishing, water sports, entertainment, subsistence hunting and fishing, or daily living (i.e. transport between communities) (*Transport Canada - General FAQ*, 2020). The GBS, similar to the entire coast of BC, hosts diverse marine vessel types year round. The GBS is a major shipping route with three key passageways, the Dixon Entrance, Hecate Strait and Queen Charlotte Sound. The GBS is an area with high density vessel activity. These passageways in the GBS are used by vessels voyaging up to the northern part of BC and to Alaska, or moving south to Victoria, BC, or further down the west coast to the United States (i.e. Puget Sound). It is also a very popular passageway for cruise ships and recreational vessels. All vessels that travel through the GBS are governed by the Canadian *Shipping Act* (2001), *Vessel Pollution and Dangerous Chemicals Regulations* (2012), and under conventions of the International Maritime Organization's (IMO) International Convention for the Prevention of Pollution from Ships (MARPOL).

Currently, there are seven generic vessel types that pass through the GBS (*MarineTraffic: Global Ship Tracking Intelligence | AIS Marine Traffic,* 2020). These are cargo vessels, tankers, fishing vessels, passenger vessels, pleasure crafts, tug and special crafts (research vessels) and unspecified ships (likely military). The majority of vessels travelling through this area are cargo vessels. The generic vessel type designation of "cargo" in the MarineTraffic database includes container ships, bulk carriers and general cargo ships.

Marine vessels can generate up to 40 different types of waste, including garbage, sewage, machinery lubricant, air pollution, deck runoff, scrubber washwater and more (Parks et al., 2019). Each unique vessel and vessel type creates different types and amounts of waste, some of which then is often discharged into the ocean. There are three major streams of waste which are discharged into the ocean: sewage, greywater, scrubber washwater.

Three key waste streams

Sewage, also referred to as blackwater, is any bodily waste from humans or other living animals, or waste and drainage from toilets, medical facilities and other receptacles which serve the same function as toilets (*Canada Shipping Act*, 2001; US Environmental Protection Agency, 2008). Sewage flows into holding tanks before being treated, at which point it becomes effluent. Different vessels have varying capacities and abilities to hold and treat sewage. Sewage is treated biologically to disinfect the waste prior to discharge; a process most commonly achieved through the use of a Marine Sanitation Device (MSD) or less commonly, through Advanced Wastewater Treatment Systems (AWTs) (US Environmental Protection Agency, 2008). AWTs provide higher levels of biological treatment, solid removal and disinfection compared to MSDs (US Environmental Protection Agency, 2008). The treatment system used depends on the size and type of vessel, while the amount of sewage produced depends on how many people are on board.

Greywater is any liquid waste produced from drainage from sinks, showers, laundry facilities, and galleries/kitchens (*Canada Shipping Act*, 2001; US Environmental Protection Agency, 2008). Greywater, like sewage, is generated from people and the services on the vessel. Vessels handle greywater through various methods: direct discharge overboard, treatment through MSDs, stored or held for later disposal, or combined with the sewage for treatment and disposal (*Vessel Waste a Growing*

Challenge in the Northern Bering Sea and Bering Strait, 2018). Greywater, unlike sewage, is not regulated by MARPOL. Most passenger vessels treat greywater through their MSD, however due to limited holding capacity and lack of regulations, some untreated greywater is discharged directly into the ocean (Alaska Department of Environmental Conservation, 2020).

Scrubber washwater is warm, acidic wastewater produced by vessels equipped with scrubbers (Teuchies et al., 2020). Scrubbers are an exhaust gas cleaning system, used by vessels to “scrub” the chemicals and pollutants (particularly sulfur) from their exhaust before washing it into the ocean or into holding tanks (Georgeff et al., 2019). Scrubbers are used by vessels which burn heavy fuel oils (HFO), and must be used to comply with IMO regulations on sulfur emissions and the regulations in specific emission control areas (ECAs) (Teuchies et al., 2020). There are no regulations in the BC coast which prevents scrubber washwater from being discharged into the ocean. Scrubbers prevent atmospheric pollution generated by vessel engine exhaust, but instead create marine pollution when discharged.

In the GBS, vessels regularly discharge sewage, greywater and scrubber washwater (STAND.Earth, 2020). Discharge from maritime vessels is regulated by the federal government through the *Shipping Act* (2001)*,* specifically the *Vessel Pollution and Dangerous Chemicals Regulations* (2012). The regulations for sewage indicate sewage can be discharged if passed through a MSD and if the effluent has a fecal coliform count of equal to or less than 250/100 mL. Depending on vessel size and number of persons on board, treated sewage can be discharged between 1-3 nautical miles from shore, and untreated sewage can be discharged after 3-12 nm from shore. New vessels (2007 + (older vessels are exempt from this regulation)), must pass their greywater through a MSD before discharge, or discharge is made at a distance of 3 nm from shore if not passed through an MSD. The *Shipping Act* and the *Vessel Pollution and Dangerous Chemicals Regulations* do not include regulations for the discharge of scrubber washwater. In addition to having poor regulations regarding marine discharge, these regulations are poorly enforced. To better understand the threat of marine discharge to the GBS, we estimated the amount of waste generated by commercial vessels in the BC coast.

Methods

To estimate the amount of waste discharged by vessels in the GBS, we used AIS-generated vessel traffic data from 2017 for the entire BC coast (Georgeff et al., 2019; Thomas, 2019). We acknowledge that using AIS data from the entire BC coast will result in overestimates for waste generation for our area of interest (the GBS), however narrowing the data to just the GBS was not completed in time for this scholarly report. In brief, we calculated the mean number of individual vessels operating in the BC coastal waters from Georgeff et al. (2019) (herein: International Council of Clean Transport (ICCT) report) and Thomas (2019) (herein: VARD Marine Inc report). We calculated the number of days spent in the area of interest (BC coast) using these averaged counts. We estimated greywater and sewage waste using the number of persons on board for each vessel from the VARD report. We used the sewage and greywater generation rates from a U.S Environmental Protection Agency Report (2008) to calculate our waste estimates. The key factors used in our analysis are identified in Table 1. Estimates of scrubber washwater were extracted from the ICCT report (2019).

A detailed description of our methodology is available in Appendix 1.1.

To estimate the total amount of greywater discharged by each vessel type, we used this formula:

$$\textit{Greywater (L)} = \textit{POB} * \textit{greywater generation rate (L per person per day)} * \textit{total days in area}$$

POB = persons on board
Greywater generation rates equal 125L per person per day for commercial vessels, and 253.6 L per person per day for cruises and yachts.

To estimate the amount of sewage discharged by each vessel type, we used this formula:

$$\textit{Sewage (L)} = \textit{POB} * \textit{sewage generation rate (L per person per day)} * \textit{total days in area}$$

POB = persons on board
Sewage generation rate is equal to 32L per person per day.

The formula used by the ICCT report to estimate scrubber washwater discharge is:

$$D_{i,t} = \frac{TED_{i,t} * r}{100}$$

$D_{i,t}$= washwater discharge of ship i over time t in tonnes
$TED_{i,t}$= total energy demand of ship i over time t in kWh
r = normalized washwater discharge rate in tonnes per MWh (assumed normalized discharge rate of 45t/MWh for all vessels, consistent with the IMO guidelines for EGCSs in Resolution MEPC.259)

Table 1. Vessel type information

Vessel Type	Number of Individual Vessels	Vessel designation	Average persons on board	Total active days in area of interest	Number vessels with scrubbers
Bulk carrier	1626	commercial	20	117,530	0

Chemical tanker	127	commercial	15	9391	0
Container ship	380	commercial	20	46,065	3
Cruise	46	commercial	Not averaged	6029	23
General cargo	176	commercial	20	14,217	0
Liquid gas carrier	19	commercial	20	267	0
Oil tanker	90	commercial	15	6503	0
Refrigerated bulk	14	commercial	15	2043	0
Roll-on/ Roll- off	11	commercial	30	2829	0
Vehicle	208	commercial	30	17,367	3
Yacht	50	pleasure	Not averaged	5807	0

Waste estimates

Table 2. Waste estimates of the three waste streams for commercial vessels (reported in L)

Vessel Type	**Sewage**	**Greywater**	**Scrubber washwater**
Bulk carrier	75,219,459	293,826,010	0
Chemical tanker	4,507,673	17,608,097	0
Container ship	29,481,329	115,161,442	380,000,000
Cruise	172,680,753	1,368,494,970	3,100,000,000
General cargo	9,099,071	35,543,246	0
Liquid gas carrier	170,880	667,500	0
Oil tanker	3,121,564	12,193,610	0
Refrigerated bulk	980,640	3,830,625	0
Roll-on/ Roll- off	2,715,680	10,608,125	0
Vehicle	16,671,937	65,124,753	0
Yacht	680,519	5,393,110	0

Table 3. Total estimated waste discharge for the three streams.

Waste Type	**Total (L)**
Sewage	315,329,505
Greywater	1,928,451,489
Scrubber washwater	34,800,000,00

We estimated over 36 billion L of waste was generated by ships along the BC coast in 2017 (Table 3). Given the weak regulations and lack of enforcements, there is plausible cause to believe much of this waste enters our ocean, especially past 3 nm of shore.

The largest contributing waste stream was from scrubber washwater, followed by greywater and sewage (Table 3). Although only two vessel types in this analysis have scrubbers implemented, the amount of scrubber waste generated was significantly larger than the other two streams combined (Table 2). Of the two vessel types with scrubbers, cruise ships produced over 90% of scrubber waste. The amount of scrubber washwater discharged into the ocean is predicted to increase in the coming decade (Georgeff, Mao, & Comer, 2019). The International Maritime Organization (IMO) has imposed a new law aiming to decrease the amount of sulfur emitted by ships by reducing the fuel sulfur limit from 3.5% to 0.5%, starting January 1st, 2020. Ships that must reduce their sulfur content could either switch to marine fuel oil which contains less sulfur, (but can cost 6-12 million USD per ship to implement, plus maintenance), or the more common alternative, which is to implement a scrubber system to dilute and reduce the sulfur emissions without switching their fuel type (Brown, 2019). Assuming most vessels opt for the latter option, IMO predicted an increase of 35% of scrubber washwater discharges to an estimated 47 million tonnes in 2020 coming from bulk ships, cruise ships, and other large vessels that will implement scrubber systems (Brown, 2019).

More greywater was produced by commercial vessels than sewage waste (Table 3). The largest producer of both greywater and sewage waste was cruise ships, which produced over 71% of total greywater waste and 55% of total sewage (Table 2). As cruise ships are passenger vessels, they produce mass quantities of greywater and sewage as they carry more passengers compared to other vessels and they provide luxury services which contribute to the amount of greywater waste produced. From our estimates, cruise ships produce the most total waste of any commercial vessel. The other substantial polluters of greywater and sewage include bulk carriers, container ships and vehicle ships (Table 2). Although the amount of waste produced by these individual vessel types is small when compared to cruises, it is not negligible when the volume of vessels is considered. Additionally, as marine trade is predicted to continue to increase (United Nations Review of Maritime Transport, 2019), we can predict more vessels to be added to commercial fleets, which will lead to greater amounts of waste generated and possibly entering the marine environment.

In comparison to the 2019 VARD report which estimated the amount of greywater produced by commercial vessels in this area, our estimates are comparably higher for total and individual vessel waste. There is no report on sewage waste for the BC coast, so we are unable to compare our estimates for sewage. We did not predict our estimates would be higher than the reports listed above given we used some of their data, in addition to data from another report (the ICCT report) to obtain our estimates. We believe our estimates are higher for total and individual waste because we assumed each vessel type would create and discharge waste similarly, despite in reality this is likely not the case. More factors likely influence discharge and production rates, instead of just persons on board, days spent in the area of interest, number of vessels, and generation rates.

As we calculated our estimates from AIS data which spanned the entire BC coast, our estimates are higher than what is discharged into the GBS alone. Our estimates provide insight into the relative abundances of the three waste streams and identify the key polluters for commercial vessels, which is relevant for mitigating pollution into the GBS. We chose to omit ferry traffic from our estimates given the vast amount of ferry traffic occurs between the mainland and east coast of Vancouver Island, which would make our waste estimates misrepresentative when interpreting the estimates in the GBS. For the scope of this report, we chose not to include information on recreational boats as the waste they produce is very small compared to commercial vessels, although they are present in large numbers in the GBS and along BC's coast. In addition, recreational vessels do not use HFO, and they are not predicted to implement scrubber systems.

The amount of waste produced by commercial vessels is especially concerning when considered in the context of the culturally and ecologically important GBS. In addition, marine waste is poorly regulated by Canada's *Shipping Act*. There are no federal regulations for the current and forecasted future largest waste stream, scrubber washwater. Regarding the other two streams, the regulations state sewage, and in some cases greywater, must pass through MSD, however these devices have been proven to be ineffective in treating waste (Alaska Department of Environmental Conservation, 2019). For example, one study by the US EPA found sewage treated by MSDs contained amounts of fecal bacteria, nutrients and heavy metals greatly above the US water quality standards. The risks and consequences of waste discharged in the GBS must be well understood in order to mitigate its effects and recommend adequate regulations/laws.

III) Risks to Marine Life

The various types of waste that enter the GBS each pose risks to the ecosystem, as well as the wildlife and people who depend on these resources. In general, wastewater discharges of any kind input chemicals, bacteria, and harmful particles into the marine environment at levels that are unnaturally high for the ecosystem and its organisms to naturally buffer. As a result, these discharges can have detrimental effects on marine life-threatening species populations as well as the resilience of this vital ecosystem. The impacts of scrubber washwater, sewage, and greywater discharge on marine ecosystems are varied and can have cascading consequences on food webs affecting organisms, from zooplankton to killer whales. This section will discuss three types of waste: sewage, greywater, and scrubber washwater, and the risks they each pose to the ecosystem. A special focus will be drawn towards scrubber washwater since this is a rising concern given the IMO 2020 guidelines, and the lack of feasibility regarding an alternate disposal location for open-loop systems.

Sewage: Nitrates & Eutrophication

Sewage is also known as ‘black water’ and refers to human body waste from vessel toilets. The main concern with sewage discharge harming marine life and humans is the presence of pathogens, pollutants (such as oil, grease, suspended solids), and temperature increases in the marine environment due to the rapid biodegradation of waste following a discharge. Common pathogens found in sewage waste include *Salmonella, shingella,* hepatitis A and E, and gastro-intestinal viruses (National Research Council, 1993). Risks are especially high for humans in areas where people might swim in the ocean since there is an increased chance of waterborne illnesses from sewage pathogens, as well as where there may be shellfish beds since these can absorb the pollutants and transmit them to the consumer when eaten raw. (National Research Council, 1993; Water, 2009). Oil and grease discharges of any amount have detrimental effects on small marine life such as invertebrates and fish, as oil and grease can easily cover fish’s gills or cover the ocean floor preventing benthic organisms from respiring, causing asphyxiation (Water, 2009). Similarly, suspended solids can also block respiration of organisms, as well as preventing proper development of fish larvae, and altering delicate marine environments upon which seasonal changes and species life histories depend on (Water, 2009).

Another important consequence of sewage discharge is the increase in the quantity of nitrates in the water boosting algae growth leading to eutrophication and hypoxia in the water. This is especially common in summer months when heavy ship traffic and sewage discharges coincide with seasonal algae blooms (Endres et al., 2018). Overall, sewage discharge can have dangerous consequences on both wildlife and humans if not managed properly.

Greywater & Water Quality

Greywater refers to wastewater coming from vessel sinks, baths, showers, and laundry. This is therefore more of a concern in large vessels such as cruise ships and bulk carriers, rather than smaller recreational vessels. Often, the source of greywater is potable water, which is mixed with other chemicals, most commonly soaps. In some vessels, greywater is treated or mixed with sewage waste prior to discharge, however most of the time greywater is not treated at all (Water, 2009). The discharge of both greywater and sewage water whether is separate or mixed discharges contains many unnatural chemicals in large quantities that prevent marine life from carrying out normal functioning as basic as respiration.

Consequently, this discharge decreases the water quality in the area leading to increased turbidity due to suspended solids, chemicals, and other undissolved or excess particulate matter. In comparison with treated sewage from a city that is then discharged into the ocean post treatment “discharge from a single boat over one weekend contributed to the same amount of bacterial pollution as the treated sewage from 10,000 people” (California State Water Resources Control Board, 2020). This is of concern particularly in areas of the GBS where there is high ship traffic (especially in summer months due to cruises), and where there is not much mixing of ocean water from offshore, leading to undiluted discharge concentrated in specific areas.

Scrubber Systems: PAH’s & Heavy Metals

Scrubber washwater discharge is a large and abundant source of pollution in the GBS. It originates from scrubber systems that are implemented into tankers which aim to dilute the output chemicals of the boat engine as a potential solution to decrease emissions. However, these chemicals, specifically, the SOx (sulfur oxides) that are harmful to the environment, are simply being turned into liquid form and diluted, but not necessarily reduced (Georgeff et al., 2019). There are three types of scrubber systems: open-loop systems which aim to dilute the chemicals, but discharge the output continuously into the ocean, this type makes up 80% of all scrubbers. Next are hybrids, which are seen around 18% of the time, and finally closed-loop systems which are the least common as they retain all output until they are able to discharge elsewhere. Since open-loop scrubbers are the most common and the most harmful, they will be the focus in this section.

Most of the discharge from open-loop systems originates overwhelmingly from cruise ships making up the main types of boats that discharge scrubber washwater into the GBS. A report by Georgeff et al. (2019) titled “A whale of a problem?” reported that in 2017, scrubber-equipped ships emitted 35 million tonnes of scrubber washwater into the GBS, of which 90% came from cruise ships (Georgeff et al., 2019). In this report, critical habitat for southern resident killer whales (SRKW) was given a special focus within the GBS as well as in nearby areas including the waters surrounding Vancouver Island (Georgeff et al., 2019). They found that 10% of this scrubber washwater discharge occurred within critical SRKW habitat, which suggests this waste may pose a serious threat to marine life in those areas, especially the critically endangered SRKW pods. Given the predicted increase of 35% of washwater in coming years, the concern about the consequences it will have on marine life also increases (Brown, 2019).

The main contaminants of particular concern in scrubber washwater are polycyclic aromatic hydrocarbons (PAH's) and heavy metals. PAH's are the product of incomplete combustion of heavy fuel oils used by boats, which results in small non-biodegradable particulate matter entering the oceans. The smaller the particles, the more damaging to marine life as they can be ingested by zooplankton, and then consequently bioaccumulate in larger organisms higher up in the food chain, for instance in marine mammals, specifically whales (Endres et al., 2018; Marsili et al., 2001). Research has shown that PAH's are ingested by the whales when eating contaminated fish and are stored in their blubber layer (Formigaro et al., 2014). Consequently, when a whale accesses its blubber layer for energy reserves, the PAH's can enter its bloodstream altering its DNA leading to health issues and illnesses such as cancer. In the St. Lawrence River, belugas were found to have more incidents of digestive tract cancer correlated with higher PAH concentrations in the water (Martineau et al., 2002).

Georgeff et al. (2019) estimated PAH levels in the GBS based on data from 2017. They found that around 1,740 kg of PAH's were discharged in the study area of the GBS, including Vancouver Island and offshore waters. Around 165 kg (~10%) of this discharge was within their defined critical habitat for SRKW's, an amount that was projected to increase by 36% by 2020 (Georgeff et al., 2019). Given the COVID-19 pandemic, this amount was likely overestimated due to the unprecedented decline in cruise ship traffic, however these estimates will likely carry forward in the coming years if tourism resumes.

Heavy metals in scrubber washwater can also have detrimental effects on marine life once absorbed as they can also be released into the bloodstream when accessing fat reserves, or during pregnancy and lactation (Kakuschke & Prange, 2007). Studies have also shown that exposure to high amounts of heavy metals specifically lead, mercury and copper can lead to difficulties locating prey, poor metabolism, and reproductive dysfunction (Jakimska, Konieczka, Skóra, & Namieśnik, 2011). Given that the SRKW populations are already critically endangered, discharge contaminants pose an additional threat to their populations and therefore the viability and intrinsic value of the GBS ecosystem. This concern doesn't only affect wildlife, but it also poses many socioeconomic risks to people, especially the local communities who depend on the thriving ecosystem of both the Great Bear rainforest, and the Great Bear sea.

IV) Socioeconomic risks

The GBS and its surrounding regions are home to 32 First Nations and 30 non-Indigenous communities. As these communities are deeply intertwined with the GBS, the effects of wastewater on the GBS ecosystem could cascade into serious cultural and economic impacts for Indigenous and non-Indigenous communities alike. Since the Province of British Columbia has introduced Bill 41 to affirm the application of the United Nations Declaration of the Rights of Indigenous Peoples (UNDRIP) in the province, following the principles of UNDRIP, such a risk assessment into the effects of vessel discharge would require extensive consultation with the Indigenous communities, especially in terms of understanding the history of settler-Indigenous relations in this area, as well as Indigenous modes of relating to the land and non-human beings (United Nations General Assembly, 2007; British Columbia, 2019). As immigrants and settlers on Indigenous land, “we acknowledge the risk of further perpetuating colonial hegemony, co-opting Indigenous ideas and assertions, and appearing to ‘speak for’ or on behalf of Indigenous peoples. We do not wish to reproduce and perpetuate these problems. Instead, as members of a settler society that has, and continues to oppress and marginalize Indigenous peoples, we aim to play a part in illuminating the legacy of our ancestors’ problematic approach and draw settlers’ attention to the legitimacy of Indigenous knowledges and the rights to self-determination” (Moore et al. 2017). Furthermore, we recognize that such a risk assessment should rely on Indigenous leadership in the GBS and on long-term relationships previously built with these communities.

First Nations: community & cultural values

The Great Bear region is the traditional, ancestral and unceded territory for the First Nations residing within it. The people of the First Nations have depended on the resources of the land and sea for thousands of years. The GBS holds great cultural significance through tradition, community values, and spirituality, while providing economic livelihood through commercial fisheries and tourism.

Culturally, the First Nations have a different relationship with the sea and different understandings of both responsibilities and accountabilities between human and non-human beings. At the basis of this relationship, the sea provides sustenance for First Nations communities. Additionally, the sea is also seen as what connects the community socially and intergenerationally (O’Donnell et al. 2013). Social bonds and the sense of being a part of a community (or social capital) are of particular importance to First Nations communities. As seafaring and fisheries gave people access to seafood as a resource, a tradition of gifting and trading seafood emerged as a practice that brought communities together. The act of bringing someone seafood is a special gesture that builds a strong bond between the giver and receiver, even if the two were strangers prior to the interaction. Recipients also try to gift something back in return, sometimes at a later date, giving them a reason to go out and interact with members of their community. Over time these interactions build trust, strengthen relationships, and improve connections between the communities and members within them Not only does being a fisherman give people ways to contribute to and connect with their community, it also carries a certain reputation in the community (O'Donnell et al. 2013).

Having access to resources such as fish or seafood allows fishermen to gift, participate, and contribute to collective actions that benefit the community. As such, being a fisherman gives you social capital and a positive reputation as someone who takes care of the community. The reputation that comes with being a fisherman reflects the community values of the First Nations. These values are passed down from generation to generation as cultural traits that Indigenous people are proud to identify with. The tradition of passing information intergenerationally is a widespread practice in almost all aspects of Indigenous culture.

One example of such a practice is the accumulation and education of Traditional Ecological Knowledge (TEK). TEK refers to the vast and diverse holistic knowledge of the First Nations community that has been gathered and refined over thousands of years and is not subjected to segmentation of contemporary science (Green Fire Productions, 2018). TEK can include specific details and features about local places, climates, ecosystems, sustainable use of resources and the interconnections between all things. This knowledge can be passed down in many ways including but not limited to storytelling, ceremonies, dances, food gatherings, spirituality, and hunting. It is important to recognize that TEK is the intellectual property of Indigenous peoples and while some may share their knowledge with others, some of the knowledge and wisdom is considered private to the individual and their communities (Green Fire Productions, 2018). Not only do these activities connect Indigenous peoples of different generations, they also have an impact in managing the local ecosystem sustainably. The people of the First Nations have worked in unison with the GBS allowing both to flourish for thousands of years. Through their cultural connections to the GBS, ecological impacts in the GBS would greatly affect the livelihood of First Nations communities and their cultural practices.

As Indigenous people face the paradox of needing to survive in a capitalistic modern world while keeping alive and passing down alternative possibilities of non-capitalist existence based on reinvigorated Indigenous ways of knowing and being, it is easy to attempt to translate Indigenous cultures, knowledge and modes of relating to human and non-human beings into non-Indigenous social and knowledge structures (Ahenakew, 2016). We, once again, recognize that proper representation of Indigenous cultures, knowledge and ways of being should rely on Indigenous leadership and consultations based on pre-existing long-term relationships with Indigenous communities.

Economic Value of the Great Bear Sea: Seafood and Tourism

As the GBS is interconnected with the culture of the First Nations, it also provides a source of livelihood. The GBS supports commercial fisheries for both Indigenous and non-Indigenous communities. Being the fourth largest primary industry in the province, commercial fisheries play a major role in the economy of BC. In 2010, commercial wild-caught fisheries in the GBS yielded an estimated landed value of at least $175 million and an estimated wholesale value of at least $415 million (O'Donnell et al. 2013). These values indicate that the GBS was responsible for more than half of the estimated total wholesale value for the entire BC coast and ~10% of Canada's nation-wide values. With the inclusion of aquaculture and aquaculture on the rise, the total product value of the seafood sector in the GBS could be well over $500 million annually (DFO, 2016; O'Donnell et al. 2013). As such, ignoring the ecological impacts associated with wastewater contamination in the GBS could have serious implications for the BC and Canadian economy. Additionally, the GBS also attracts more than $60 million in tourism revenues each year (Molnar et al. 2009). The GBS is a popular route for cruise ships travelling to and from Alaska. As cruise frequencies are expected to grow with the cruise ship industry, wastewater input from cruise ships becomes a major concern in the GBS (Molnar et al. 2009). Lastly, the GBS itself and the many ecosystem services it provides are invaluable and almost impossible to place tangible values on. As the GBS ecosystem feeds and supports the culture and livelihoods of Indigenous and non-Indigenous communities in BC, damage to the ecosystem could be of great detriment to any and all living and non-living beings associated with the GBS.

V) Recommendations

From our hybrid review and analysis of the problem of vessel wastewater discharge in the GBS, we provide the following three recommendations.

Pumpout Stations or No-Discharge Zones (NDZ) in the in GBS

We recommend investigating the feasibility of installing pumpout stations or designating sections or the entire GBS as a NDZ given the amount of vessel traffic, the gross amounts of waste generated by vessels, and because the current predominant method in Canada of treating greywater and sewage through MSDs has been proven ineffective. All three waste streams pose potential threats to any ecosystem, and beyond this, the cultural and economic importance of the GBS should make this ecosystem a priority for regulation and conservation. The current regulations allowing for the discharge of waste 3 nm offshore does not demonstrate prioritization of conserving this ecosystem. Furthermore, the current and projected-future largest waste stream scrubber washwater has no federal regulations. Installing pumpouts in key areas of the GBS can prevent sewage and potentially greywater from polluting this ecosystem. It is unclear if scrubber washwater can be treated using pumpouts, however designating the GBS as a NDZ would be effective in mitigating scrubber discharge. If neither of these prove feasible, federal regulations on discharged waste must be revisited to ensure better protection of such a key ecosystem.

Prioritizing Cruise Ship Waste Management

We also recommend future regulations prioritize mitigating waste from cruise ships, given these vessels contributed between 55-90% of each waste stream.

Scrubbers vs. Green Fuel

Finally, given the IMO 2020 regulations of reducing the sulfur content in ship fuel from 3.5% to 0.5%, many ships are predicted to implement scrubber systems thus increasing the amount of scrubber washwater entering the GBS in coming years. As a result, we recommend ships invest in switching to the greener option of using marine gas oil rather than heavy fuel oil with scrubbers. In the long term, this would save vessel owners money, and would reduce the amount of harmful chemicals from washwater entering the GBS.

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VII) Appendix

1.1.Detailed methodology for waste estimates.

To estimate the number of individual vessels operating in the BC coast, we averaged the individual vessel counts from VARD and the ICCT reports. Although the reports both used AIS data from 2017 to calculate the number of vessels, the individual vessel counts differed between the two reports. This may be due to the fact the VARD report used AIS from ExactEarth, while the ICCT report did not specify where their AIS data originated from. The VARD report also provided us with the average number of persons on board (passengers and crew) and the total days spent in the area of interest (entire BC coast). The number of people on board for cruises and yachts were not averaged, instead greywater estimates were individually calculated for each unique vessel. We used the VARD report's total days spent in area of interest and their individual vessel counts to obtain an average number of days spent in area of interest for each vessel type. The average number of days was then multiplied by our calculated individual vessel counts, to obtain an estimate of the total number of days in the area. To keep the waste estimate manageable, we chose to focus only on the number of persons on board and ship type. We acknowledge that using averages for persons on board could lead to either an over or underestimated value of waste. We also acknowledge that the discharge rates for each vessel is unique and not constant throughout the entire voyage for a vessel, and certain situations (such as time spent at port) would influence the discharge rates over the voyage. We acknowledge this limitation in our estimate of time spent in the area of interest and the waste generation per person estimates, however we chose to accept these simplifications to obtain estimates for the different waste streams. Table 1 illustrates the key variables used in our analysis.

Estimates for scrubber washwater discharge were obtained through the ICCT report. We chose not to attempt estimates ourselves, as washwater discharge is influenced by a variety of vessel-specific factors, namely the total energy demand of each vessel. Total energy demand is a function of the power demand of the main engine, auxiliary engine and boilers, and depends on the speed of the vessel and whether the vessel is cruising, maneuvering, anchored or at berth. The ICCT report estimated washwater discharge by using output from their Systematic Assessment of Vessel Emissions (SAVE) model, which estimates fuel consumption per hour by first estimating the vessel's power demand, and combining that output with AIS data. The ICCT report used publicly available data (*Alternative Fuels Insights for the Shipping Industry – AFI Platform*, 2020) to calculate the percentage of ships with scrubbers in 2017.