Vessel Traffic in Canada's Pacific Region

December 2020

About Us

Clear Seas Centre for Responsible Marine Shipping is an independent, not-for-profit research centre that provides impartial and fact-based information about marine shipping in Canada.

Led by a Board of Directors and advised by a Research Advisory Committee, Clear Seas' work focuses on identifying and sharing best practices for safe and sustainable marine shipping in Canada, encompassing the human, environmental and economic impacts of the shipping industry.

All Clear Seas reports are publicly released and made available at clearseas.org

About this Report

As an element of its Marine Transportation Corridors initiative, Clear Seas Centre for Responsible Marine Shipping commissioned Nuka Research and Planning, LLC (Nuka Research) to conduct an analysis of vessel traffic and oil movements in Canada's Pacific Region. This report, jointly authored by Nuka and Clear Seas, conveys the results of that analysis.

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Foreword

Looking out to the horizon over Semiahmoo Bay we see the comings and goings of Canada's economy being shipped out to other countries. There has been a significant increase in vessel traffic along the shores of the beautiful British Columbia coastline. Indigenous communities are beginning to play a more significant role in the local economy, but we need to make sure our voices are being heard at the right tables.

Indigenous communities like Semiahmoo have lived along these shorelines since time out of mind and have been the original stewards of the lands and waters, and will continue to do so. Our communities hold Traditional Knowledge, of the lands and waters we thrive upon. We have gained this knowledge over years of direct observation, hands on experience, and thousands and thousands of years of ongoing interaction with the natural experience.

This knowledge is important to ensure that we leave the best possible future for our grandchildren to flourish. We want to make sure they have a chance to experience harvesting our traditional foods such as shellfish, crab, and fish. These foods sustained our people and are an important part of who we are. Indigenous people have a connection to the land and waters which has long been dismissed by western scientists as primitive superstition.

Since colonization we have seen the increase of development and growth of industry all around our communities. The increase in vessel traffic has a direct effect on our community, and other communities who live along the coast and have seen the foreshore erosion impacts. We have also seen a decrease in foods we can harvest due to contamination and toxins in the shellfish. We do not want to see these completely wiped out and not to return. So as a leader I want to work with partners to create a plan to not only sustain our traditional resources for our future generations but to leave it a better place for them.

Canada's reconciliation plan needs to include Indigenous knowledge keepers when it comes to research within the traditional lands and waters. By including the collective understanding of Traditional Knowledge with western science we can see the bigger picture of what our future looks like. A more holistic approach is more inclusive and responsive for making important decisions that affect all of Canada.

As leaders, we are here to make important decisions for our people, our land and water that we call home. I appreciate the effort from Clear Seas to include Indigenous communities in upcoming projects. This work is important to plan for our future for our communities.

Osiem

Chief Harley Chappell

Semiahmoo First Nation

Message from the Executive Director

Canada's Pacific Coast is the gateway for trade with Asia and the American west coast. Every day, ships come and go from major ports in Vancouver and Prince Rupert. Cargo ships are loaded with vast quantities of grain, metallurgical coal, fertilizers and other commodities. Container ships offload consumer goods while cars and trucks roll off vehicle carriers. Tankers arrive to either deliver or collect oil and fuels that supply refineries and fuel distribution systems for trucks and planes. Much smaller, but just as important, tugboats pull barges laden with industrial materials or supplies destined for communities on the coast.

Even with this "day in, day out" constancy of vessel activity, the world of commercial shipping remains relatively opaque for many Canadians, even those living on the coast and in port communities. Beyond the easy recognition of cruise ships full of tourists, most people are hard pressed to tell the difference between an oil tanker and a bulk carrier loaded with grain.

The biennial public opinion polls Clear Seas undertakes in partnership with the Angus Reid Institute confirm that people are concerned about the risk of oil spills from ships, regardless of their level of knowledge about marine shipping (view 2020 report). While it is good to be aware of risk factors, it is not so good to be unreasonably fearful of them. While Clear Seas has been working to address gaps in knowledge and information, the lack of a comprehensive and digestible source of information about commercial marine shipping on Canada's coasts exacerbates public concerns about the safety and sustainability of shipping.

And this lack of information is not confined to the general public. When Clear Seas embarked on the multi-year Marine Transportation Corridors initiative to identify and describe risks related to commercial marine shipping in Canada – starting with the Pacific region – critical data on ship traffic was missing. Most concerning was the lack of data on the amount and types of oil carried by ships as cargo or as fuel. A detailed risk assessment to support risk management for marine spatial planning was made more challenging by the lack of information about how many of these ships there are, where they go, and how much oil they carry.

This fifth body of work associated with the Marine Transportation Corridors initiative for the Pacific Region is an attempt to fill these gaps in knowledge, both for the public and the marine spatial planning community. It provides a comprehensive picture of the movement of ship and barge traffic. It also includes an analysis of cruise ship traffic as these vessels are highly visible to the public and, like ocean-going cargo ships, they carry oil to burn as fuel.

The study used Automatic Identification System (AIS) data to track the movement of 6,000 individual ships and tugs over a period of three representative years (2014-2016). The result illustrates what vessels travelled where and describes the pattern of life in the region. In aggregating, characterizing and sorting the data, a clear picture emerges of a vibrant marine transportation network supporting maritime trade as essential to life on the Pacific coast.

For all of the benefits that marine transportation brings, and despite the infrequency of oil spill incidents, the carriage of oil and other polluting substances by commercial vessels will continue to raise concerns because of the damage these substances can cause if spilled. Beyond oil spills, shipping causes other disturbances to the environment, ecosystems and marine life. Examples include underwater noise, inadvertent transport of invasive marine species, exhaust emissions, potential collisions with sea life, wake damage, and anchor drag on the seabed.

This study is, to date, the most current and comprehensive quantitative commercial vessel traffic analysis of Canada's Pacific region made available to the public. It addresses existing knowledge gaps identified by Clear Seas through ongoing dialogue with First Nations, government officials, academics and industry. Findings will be of interest and use to these groups as well as to environmental groups and the public – fostering a deeper understanding of shipping activity while dispelling some common misperceptions. With the level of detail it offers, the new knowledge contained herein can be instrumental in supporting initiatives related to proactive vessel management and marine domain awareness, and can be used to assess potential areas of friction in marine spatial planning. This deeper understanding of traffic patterns shows the most likely areas of elevated risk; a better understanding of these areas will support efforts to mitigate risks and achieve sustainable marine activity on Canada's Pacific coast.

Overview of Final Study Results

The overarching goal of the analysis in this report is to consolidate useful information about commercial vessel traffic in Canada's Pacific region – traffic that affects people and the environment on many levels. This rigorous work, presented through a neutral lens, is the most current and comprehensive quantitative commercial vessel traffic analysis of Canada's Pacific region done to date and made available to the public. Incorporating three years of traffic data from 2014-2016, the rigorous analysis uncovers insights into the complex marine transportation system and the oil pollution risks present in this system.

This Overview of Final Study Results summarizes the key messages from the Vessel Traffic Analysis. Additional analysis was performed to create illustrative graphics of the study results. The Overview provides the essence of the study's findings in a way that is informative and useful for a range of audiences. Detailed statistics and analysis are provided in the main body of the report and appendices.

Marine Transportation Corridors Initiative – Vessel Traffic Analysis

Canada's Pacific coast is home to vibrant coastal ecosystems and centres of economic activity that depend on a healthy ocean. It also features busy marine shipping corridors with vessels that range from small boats to large container ships, all carrying oil for fuel or as cargo.

Clear Seas launched the Marine Transportation Corridors initiative to support marine planning efforts in Canada and bring new perspectives on marine shipping risks. The initiative is a multi-layered geo-spatial analysis to support evidence-based decision-making and to determine and describe risks related to commercial marine shipping activities. The first region covered is the Pacific region, in the following phases: calculating the drift rates of typical vessels on the coast to find zones of no-save (view report); calculating the capabilities required by emergency towing vessels to successfully effect a rescue (view report); identifying the availability of regular tugs to rescue a vessel in distress should an emergency towing vessel not be available (view report); and assessing the sensitivity of coastal areas to an oil spill should a ship cause a spill (view report).

This report provides the final important element to support marine spatial planning efforts and complement the above work by unlocking an understanding of where and how commercial ships travel through the entire region – previously, a significant knowledge gap. Typically, this information is only available for a particular area, port or ship type. Through ongoing dialogue with First Nations, government officials, and industry, Clear Seas identified the need for a comprehensive study covering the full geographic area including adjacent U.S. territorial waters.

The Vessel Traffic Analysis study set out to improve understanding of vessel traffic in the Pacific region of Canada's waters and to dispel some common misconceptions. As such, it forms an integral part of the overall initiative by identifying where ship traffic is concentrated, how it changes through time, and how oil, both as a cargo and as a fuel, moves through the region.

The knowledge presented through a neutral lens in this report comes from a rigorous data-based analysis. As such, the findings are useful to a wide range of interested parties including (but not limited to) members of coastal First Nations, provincial and federal regulators, industry, environmental groups, and the public at large. The study results can support initiatives related to proactive vessel management, marine domain awareness and also assess potential areas of friction in marine spatial planning efforts.

Study Elements and Structure

The precision and accuracy of analytical results relies on how the data has been selected, collected, and processed so that users can have confidence applying the results toward activities such as government advocacy, policy-making and investment planning.

Vessel Types

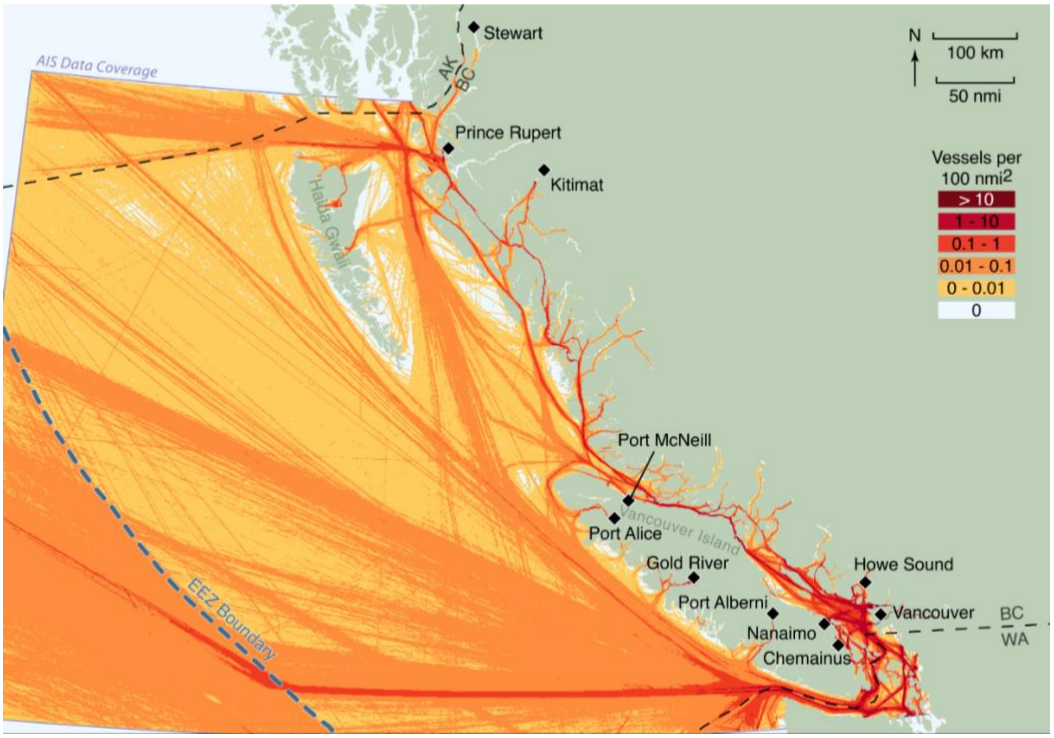
Of the many vessels that travel Pacific waters, this study reports only on commercial shipping vessels – vessels that transport goods and materials for commercial or trade purposes – and cruise ships. Other vessel types, such as fishing vessels (both commercial and recreational), ferries, government vessels, and pleasure craft were not included. This selection focuses on the types of ships that, because of the volume and type of oil carried, represent the largest potential risk for oil spills.

Accordingly, the study examines all ocean-going commercial vessel traffic (typically greater than 300 gross tons) and larger tugs (typically greater than 15 m) that push or tow barges. Ship types include Bulk Carriers, Container Ships, Vehicle Carriers, General Cargo Ships and Tankers. While not commercial shipping vessels, Cruise Ships are an important and visible type of vessels found in the Pacific Region, and thus were included; and because unlike small craft, Cruise Ships very often carry heavy fuel oil as a fuel.

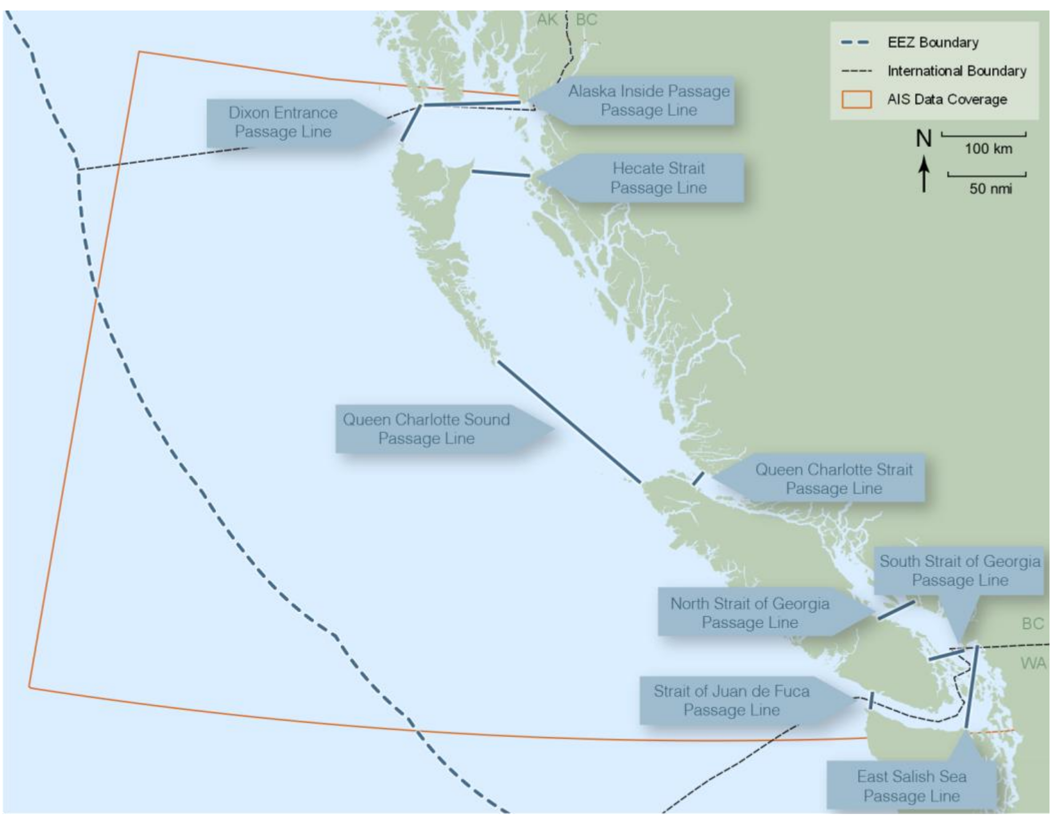
Building the Analysis Platform

Two complementary approaches were used to build an analysis platform capable of achieving a rigorous characterization of vessel traffic and the oil that is carried by this traffic.

1. **Tracking** – The study uses 2014-2016 Automatic Identification System data transmitted from all commercial vessels and received by ground- and satellite-based receivers. This data is broadcast as points, with each ship transmitting its location, unique ship identifier, type and many other metrics, several times each minute. A computer program connects the points together into vessel tracks – lines that illustrate each distinct journey taken by commercial vessels travelling in the study area. A database with these vessel tracks, together with basic information about each vessel's size, cargo capacity, fuel capacity, age and flag state was then constructed. The database was used to create a comprehensive set of traffic density maps – similar to the vessel traffic density map below – and to complete the other analyses contained in this report.
2. **Passage Lines** – Passage lines represent analytical "tripwires", between two points of opposing shoreline, which count and record the characteristics of each vessel that crossed the line during the study. Nine passage lines were defined at key locations along the coast, including at the entrances to the main ports, as shown in the study area map below. These passage lines were selected to support the analysis of traffic patterns throughout the study area.



Vessel Traffic Density: All Vessel Types (2014-2016)



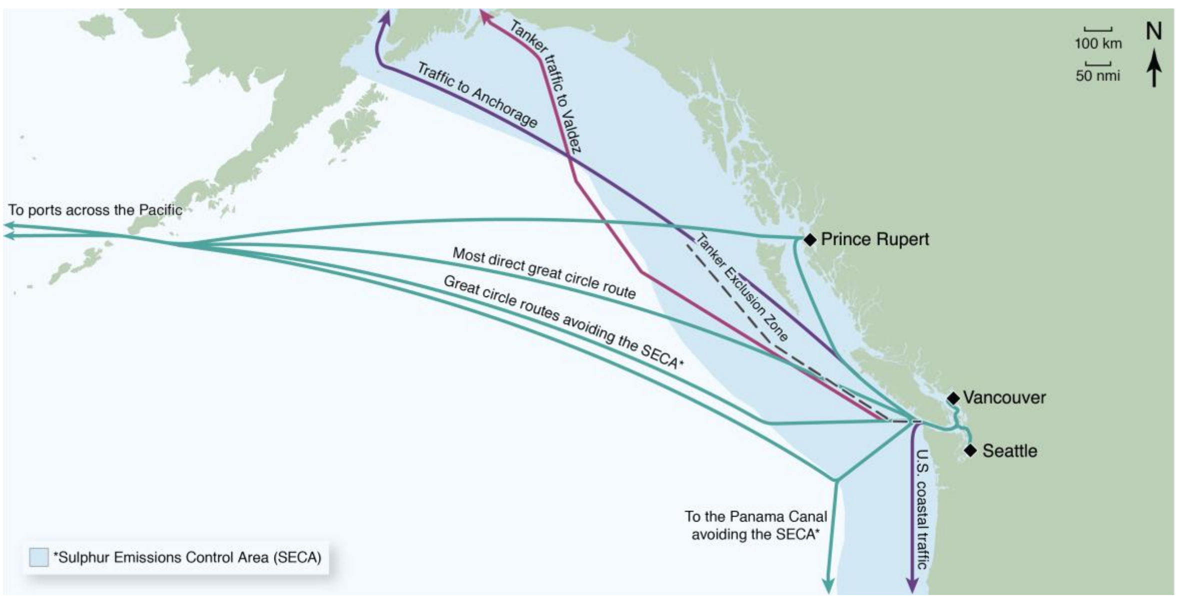
Study Area with Passage Lines

Key Takeaways from the Vessel Traffic Analysis

Global Trade Defines the Big Picture for Ship Traffic

Typical vessel paths in Canada's Pacific waters highlight the role of Canada's western ports as a gateway to trans-Pacific trade. Traffic transiting between Asia and Canada is representative of Canada's economy, with commodity shipments dominating the exports from Canada and manufactured goods dominating the imports from Asia. As visualized in the map of international trade routes below, the shortest distance between the Pacific coast and Asia is a route that passes through the Aleutian Islands. Some ships will take a more southerly route avoiding U.S. territorial waters. These "great circle" routes represent the shortest distance between two points on the globe.

The other major trade pattern is North-South with traffic moving along the west coast of North America between Canadian and United States ports and beyond to the Panama Canal and South America. Tankers bringing oil from Alaska to the refineries in Washington stay further off shore in compliance with the existing voluntary Tanker Exclusion Zone, which was established through an agreement in 1985 by the Canadian Coast Guard, the U.S. Coast Guard and the tanker industry, to help avoid potential oil spill along B.C.'s coast.



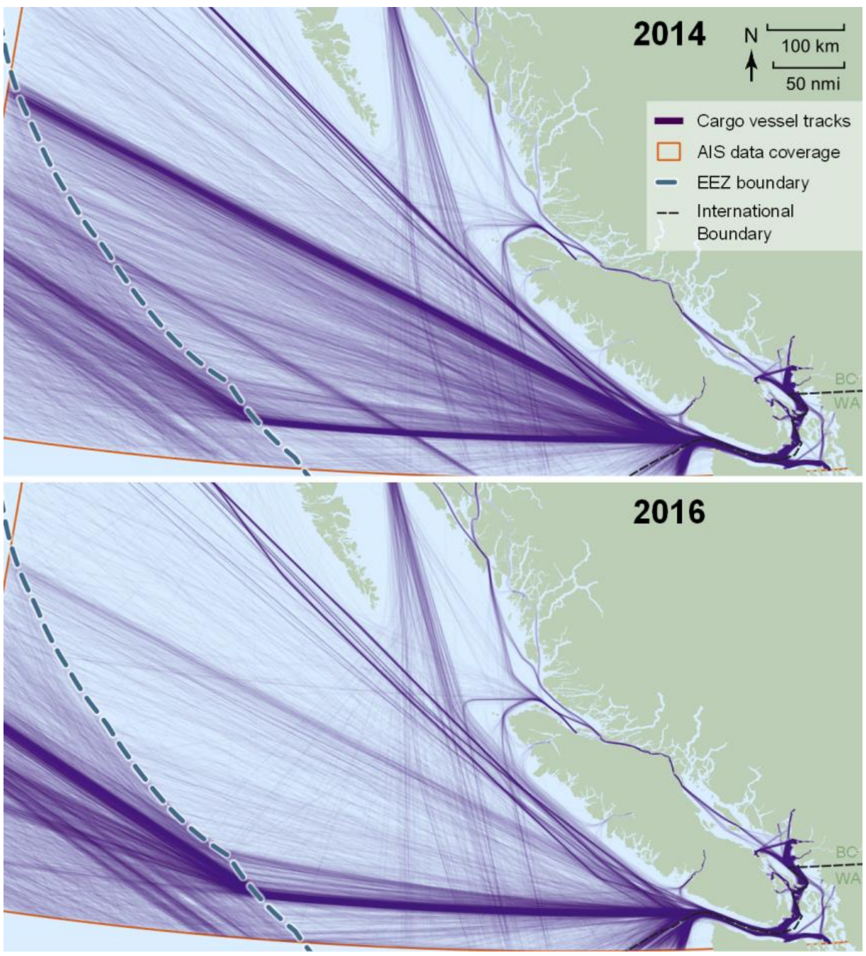
Common International Trade Routes of the North Pacific Region

Trade Routes are Influenced by Environmental Protections

The existence of the family of different great circle routes provides a fascinating insight into the interplay between environmental protection, economics and global trade patterns. As the global trade routes map shows, the shortest distance to or from Asia is via the direct great circle route. So why do so many ships (73% of them in 2016) take a longer route? The answer is that they are reducing time spent in Canada's Exclusive Economic Zone (EEZ) with its pollution reduction regulations.

Ship fuels historically contained high levels of sulphur that, following combustion in the engine, became air pollution from the ship's exhaust. In concert with the International Marine Organization, several countries established Sulphur Emission Control Areas in heavily trafficked areas to protect air quality in ports and coastal communities – including one that extends 200 nautical miles from the North American coast, the extent of Canada's EEZ. Starting in 2012, ships were only allowed to burn fuels with less than 1.0% sulphur content in the Emissions Control Area; in 2015, this was reduced to just 0.1% sulphur. Low-sulphur fuel is more expensive so ship operators want to minimise the amount of it they burn and will switch over to cheaper conventional fuel at the first opportunity.[1]

Comparing the snapshots of traffic from 2014 and 2016 show that even by 2014, some ships had begun to use the longer route that minimised the time spent burning low-sulphur fuel. Once the tighter 2015 limits came into effect, the price difference for the 0.1% sulphur fuel was even greater, pushing the majority of traffic to make the trade-off of increased emissions and a slightly longer voyage (approximately 60 km) in exchange for a lower fuel bill.



Environmental Protection Changes Vessel Traffic Patterns

[1] Ships equipped with exhaust gas cleaning systems or "scrubbers" can continue to burn regular high-sulphur fuel but need to turn on the scrubber when they enter the Emission Control Area and will therefore continue to follow the shorter direct great circle route. According to 2020 data from United Nations Conference on Trade and Development (UNCTAD) and DNV-GL, only 4.5% of cargo ships globally are equipped with this expensive pollution control device.

Although ship operators pay less for the fuel used, the extra distance travelled means that ships burn more of it and emit more greenhouse gases. The added distance, multiplied by the number of cargo ships travelling this path in 2016 and the extra fuel they burned, generated 24 kilotonnes CO_2eq of greenhouse gas emissions, or the equivalent of 5,161 cars on the road per year – an unintended consequence of the implementation of air pollution regulations.

Some ships will even take the longer more southerly route marked on the trade routes map above to further reduce the time spent burning more expensive low-sulphur fuel in exchange for an even longer total journey[2]. Similar behaviour is exhibited by ships on routes to or from the Panama Canal. Many of them choose to take the longer offshore route further off the coast of North America rather than the more direct coastal route, again in order to reduce the total fuel cost. Even tankers traveling between Alaska and the refineries in Washington will take a route further from shore than is required by the Tanker Exclusion Zone in order to escape the limitations of the Sulphur Emissions Control Area for at least a part of their voyage.

With the reduction in sulphur limits for all marine fuels that came into effect in 2020 and lower global oil prices, the price gap between the ultra-low sulphur fuel required for the Emissions Control Area and regular fuel has closed, eroding the business case for the longer detour routes. It will be interesting to see if traffic reverts back to its former more efficient pattern, which in some cases will bring ship traffic closer to the shore again.

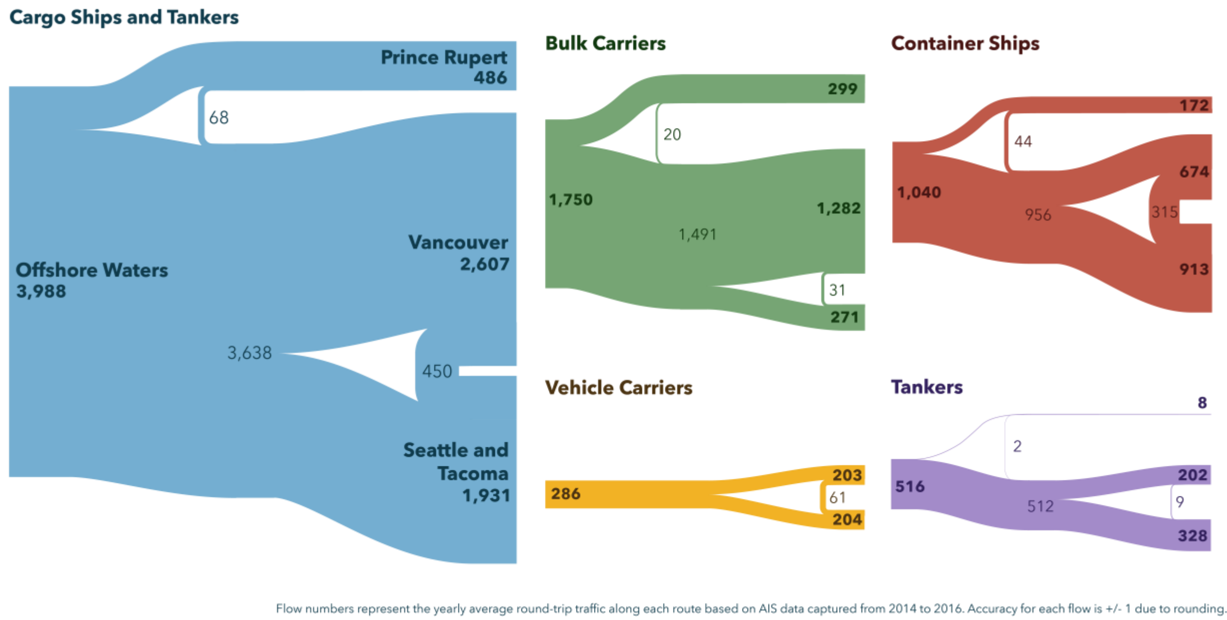
Bulk Commodity Exports and Containers Are the Dominant Traffic in the Region

On average, each year, more than 4,000 large ships travel the trade routes through the waters in Canada's Pacific region. A small fraction (approximately 5%) are just passing through on their way to other destinations, but the majority – around 4,000 ships in an average year – enter Canadian waters to load or offload cargo.

The illustration below shows the flow of this traffic once it enters Canadian waters, where the width of the lines represents the average volume of ship traffic in one year. Most of the 3,988 ships entering Canadian waters pass through the Strait of Juan de Fuca to enter the Salish Sea (around 3,570) because they are bound either for Vancouver or the U.S. ports in Seattle and Tacoma. Around 2,607 ships per year call on the Port of Vancouver terminals in Burrard Inlet, the Fraser River and at Roberts Bank. Slightly fewer, around 1,931, call on the U.S. ports in Seattle and Tacoma, and around 450 ships or 13% of total traffic entering the Salish Sea call on both port complexes during the same voyage. As can be seen in the flow diagram, these dual visitors are primarily Container Ships and Vehicle Carriers whose itineraries reflect the optimisation of a complex intermodal supply chain that includes the onward rail journeys for their cargos.

The much smaller, but fast-growing Port of Prince Rupert to the north accounts for approximately 486 vessels per year, almost exclusively bulk carriers or container ships. Again, some of the traffic (around 14% or 68 ships per year) is shared with the ports to the south.

[2] The track lines of these voyages extend outside of the study area so could not be analysed for this report.



Flow of International Vessel Traffic Entering Canadian Waters Destined for Ports (2014-2016)

Bulk Carriers are the most common ship in the study (1,750 per year), the majority bound for Vancouver, followed by Container Ships (1,040 per year), the majority bound for Seattle or Tacoma. Vehicle Carriers account for around 286 ships per year offloading their cargos in Vancouver or the U.S.

Tankers carrying oil as cargo merit scrutiny. As illustrated in the flow diagram above, the study found that tankers of all types and sizes primarily call at the U.S. oil refineries in Puget Sound (approximately 328 ships per year) or the Canadian Parkland refinery and Westridge Marine Terminal in Burrard Inlet (approximately 202 ships per year). Tankers calling in Canada are predominantly (more than 80%) small (less than 50,000 deadweight tonnes) and mostly carrying refined petroleum products like gasoline, diesel or jet fuel. Vessels calling at U.S. refineries usually carry crude oil from Alaska.

Currently, roughly three in every five tankers entering the Salish Sea through the Strait of Juan de Fuca call at ports in the U.S.; however, this pattern will change with the projected increase in tanker traffic to support the Trans Mountain Expansion Project. Even with this increase in tanker traffic, tankers still represent a small fraction of overall ship traffic in the region.

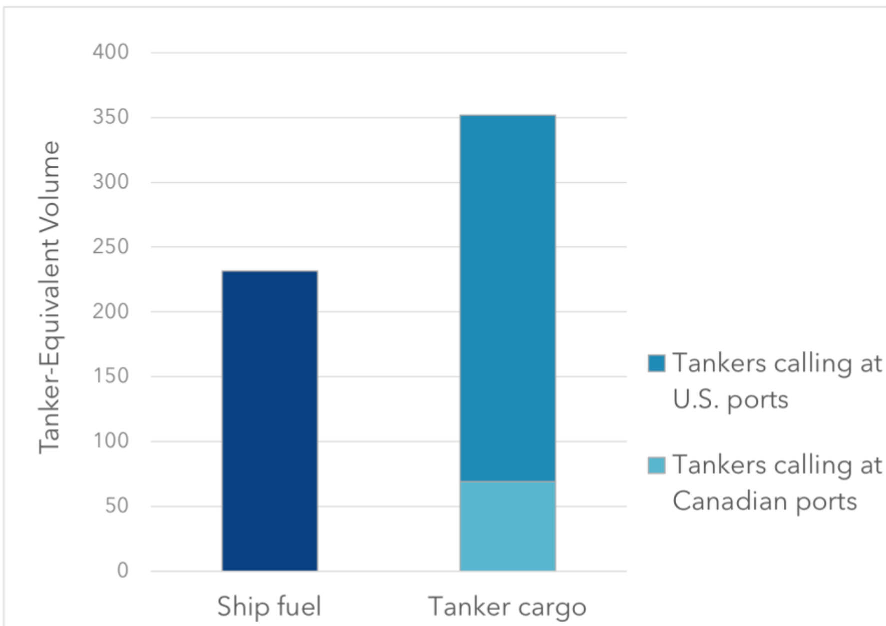
Oil Carried Both as a Fuel and as Cargo are Potential Pollution Threats

Just counting the number of ships does not give the full picture when it comes to oil. To get a clearer picture of the risk exposure related to the carriage of oil on vessels travelling in Canada's Pacific region, the study digs deeper into the volumes and types of oil carried by ships both as a cargo and as fuel. Two broad types of oil are relevant to marine health and protection – persistent oils and non-persistent oils. The difference between the two lies in how long spilled oil is likely to remain in the marine environment. Non-persistent oils include jet fuels, gasoline, diesel, marine diesel, marine gas oil, home heating oil, and some light crude oils. When spilled, non-persistent oils will evaporate or dissolve in the water.

Persistent oils include most crude oils (unrefined) and both intermediate and heavy fuel oils. They last longer in the marine environment than non-persistent oils and are more likely to spread in a slick and strand on shore, potentially coating or smothering wildlife.

Some ships carry both persistent and non-persistent oil as cargo and as fuel for their own propulsion (referred to as bunker fuel). The term “oil carriage” is used to reference the total amount of oil on board a vessel, whether as cargo or bunker fuel.

The oil carriage analysis focuses on the Salish Sea because of the higher volume of ship traffic in the area. The bar chart below identifies the amount of persistent oil – of most concern for its environmental damage potential – moving through the Salish Sea onboard a ship in a representative year. The volumes have been converted into tanker-equivalents using the size of a typical oil tanker in the region.



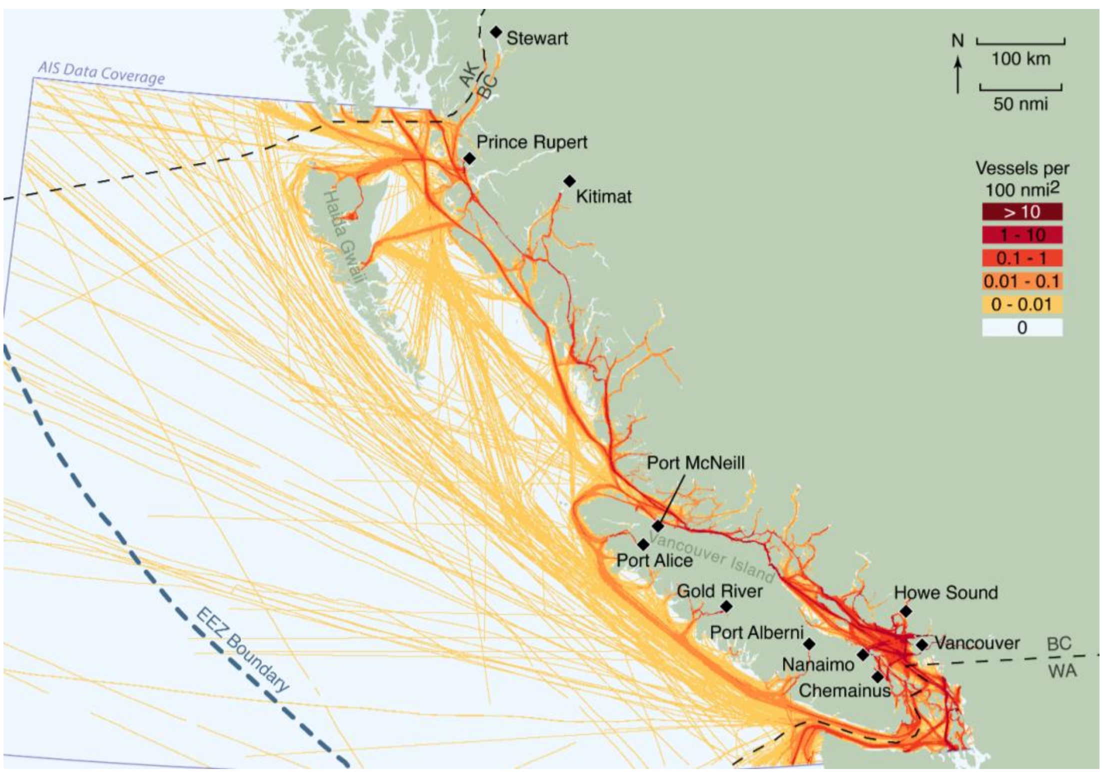
Persistent Oil Moving Through the Salish Sea (2016)

The chart shows that of the 583 total tanker-equivalent volumes of persistent oil moving through the Salish Sea, oil cargos bound for U.S. refineries represent the largest quantity of persistent oil, but heavy fuel oil used as ship fuel is almost as large in quantity, representing more than 200 tanker-equivalents. Interestingly, the volume of persistent oil originating from Canada’s terminals is currently relatively small in comparison. Although the Flow of International Vessel Traffic diagram above shows more than 200 tankers per year calling on Vancouver, they are typically smaller than those calling on U.S. ports and often carry non-persistent oil. Even with the increase in crude oil exports expected from the Trans Mountain Expansion Project, Canadian oil cargo exports by tanker will still be the smallest source of persistent oil in the Salish Sea.

While the figure above demonstrates the total annual fuel carried by all the cargo ships in aggregate is not insignificant and close to the total carried by a tanker as cargo, when considered on an individual ship basis, the volume of oil carrier by oil tankers compared to other vessel types is still greater. Given this increased risk, a number of additional measures are in place in Canada to mitigate the risk of an oil tanker spill, including mandatory double hulls and tug escorts.

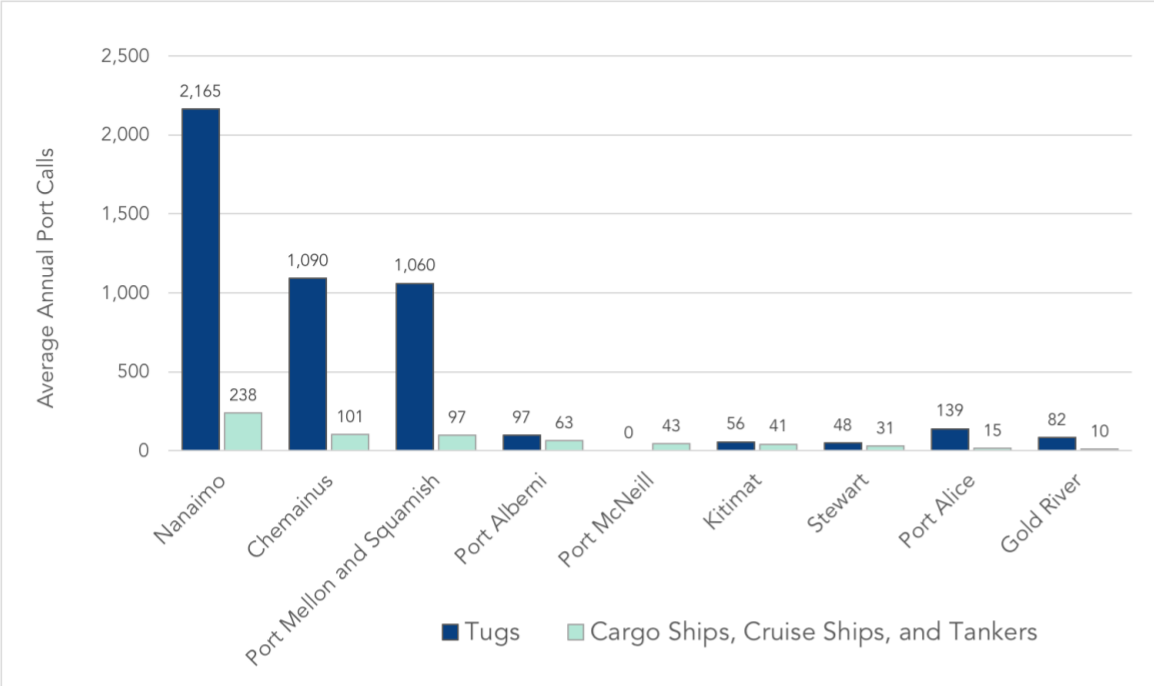
Small Ports Play a Big Part

Vessel traffic in Canada's Pacific waters is more than just large cargo vessels engaged in international trade. Tugs make up a key part of coastal traffic, providing essential transport of goods to remote and coastal communities, and delivering raw materials and finished goods to support key sectors of the local economy like sawmills and pulp mills. Tugs also assist ships while they dock and escort tankers near shore. As shown in the vessel density map below, they form the arteries that connect the smaller ports along Canada's Pacific with each other and the economic centres. The goods in the barges moved by tug make up the bulk of domestic trade in the study area.



Tug Traffic Vessel Density Map (2014-2016)

The highly visible ferry services of B.C. Ferries and Seaspan Ferries transport some trucks, trailers, and containers, but tugs and barges transport the majority of goods including containers, bulk goods, fuel and raw materials. Although small ports like Nanaimo are the destination for some large international commercial vessels, the bar graph below shows that many of the small ports along Canada's Pacific coast are mostly concerned with the movement of tug and barge traffic.

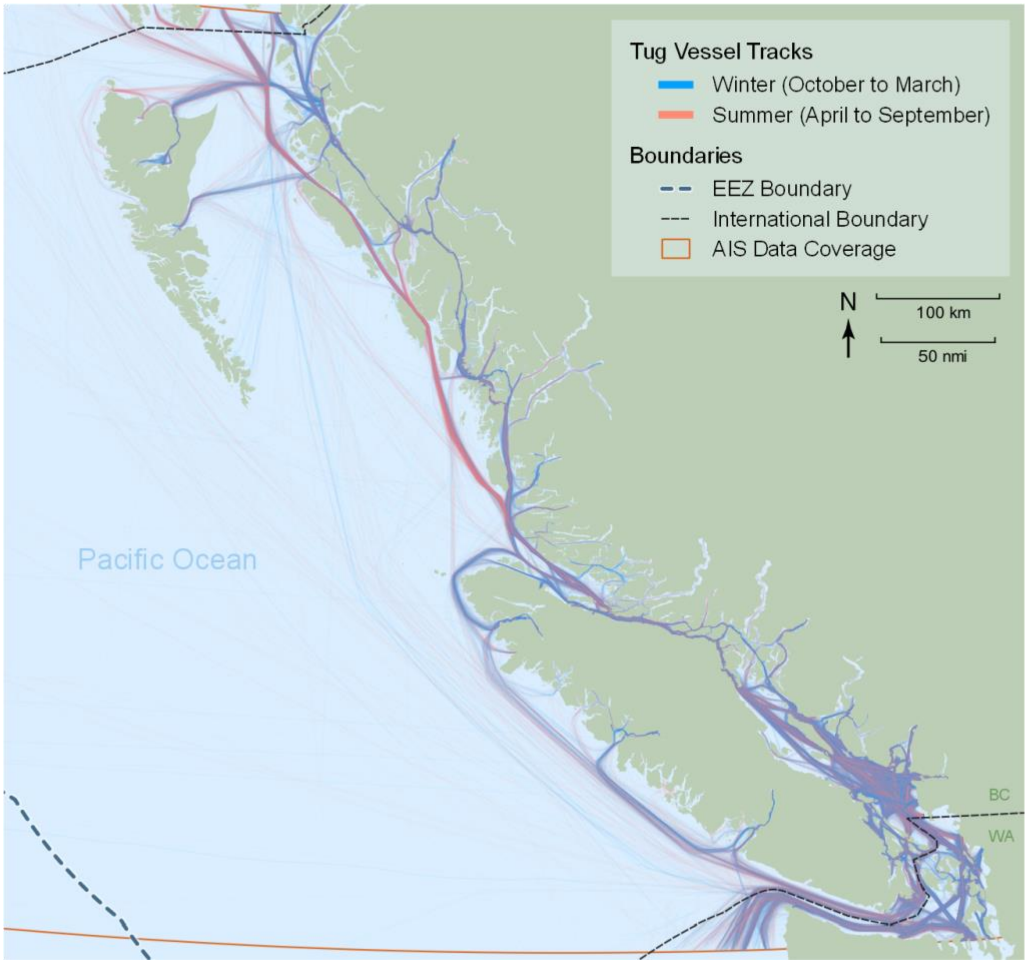


Tug and Non-Tug Traffic at Small Ports (2014-2016)

Canada's Waters Offer a Sheltered Marine Highway for Tugs and Their Cargo

The map of tug traffic patterns below illustrates that tugs have seasonal patterns of trade. In summer months, when the weather is calmer and storms are less likely, tugs travelling north along the coast tend to use a more direct and less sheltered route through Queen Charlotte Sound. In the winter months, when weather is harsher and less predictable, the sheltered Inside Passage through the north coast islands is the safer, preferred route.

Johnstone Strait and Discovery Passage between Vancouver Island and the mainland are used year-round, acting as a sheltered highway for tugs travelling along the coast. This highway is used by tugs travelling between Canadian ports, but also by tugs travelling between Alaska and the continental United States. This innocent passage of American tugs made up at least 45% of tug traffic through Queen Charlotte Strait during the study – nearly 600 tugs and barges per year.

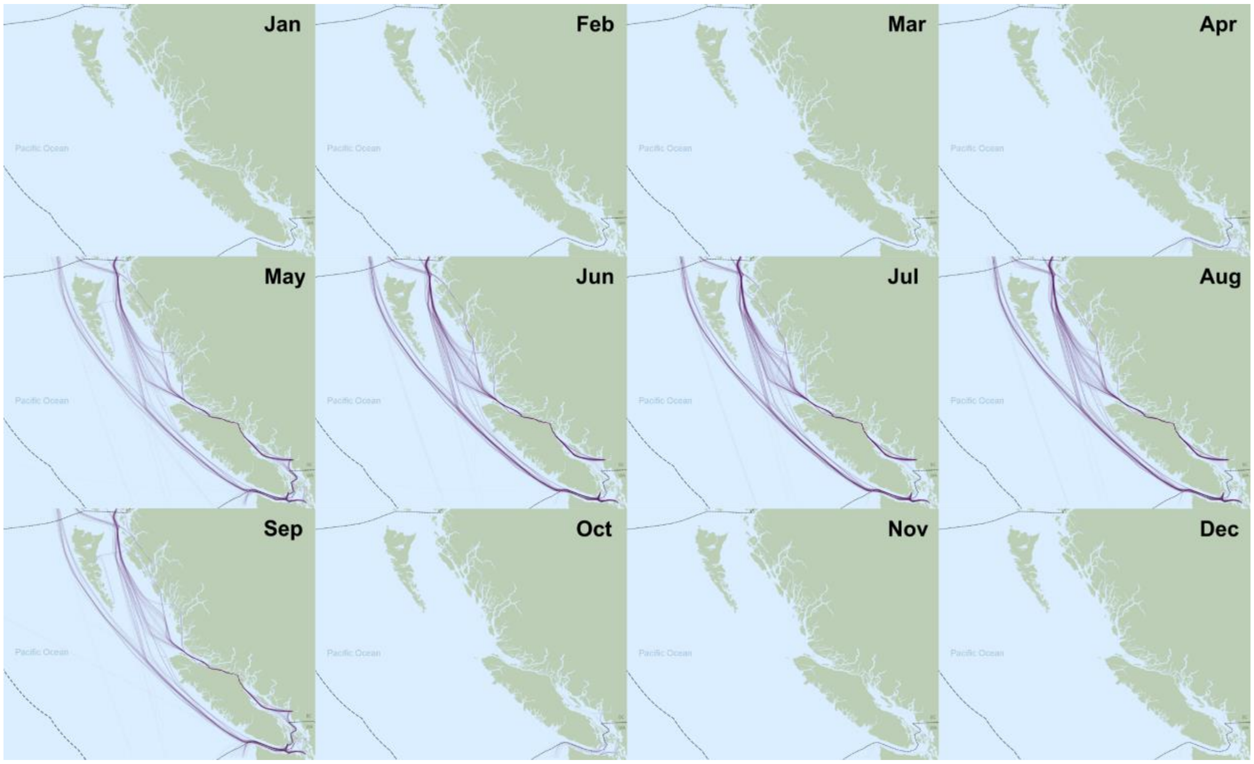


Winter and Summer Seasonal Variation of Tug Traffic Patterns

It's not just tugs that take advantage of Canada's sheltered waters. An examination of cargo ships passing through Canadian waters but not calling at a Canadian port, show that they tend to travel closer to shore during the winter, sometimes entering Queen Charlotte Sound and Dixon Entrance to pass to the east of Haida Gwaii en route to or from Asia, presumably to avoid heavy seas and storms found on the great circle routes.

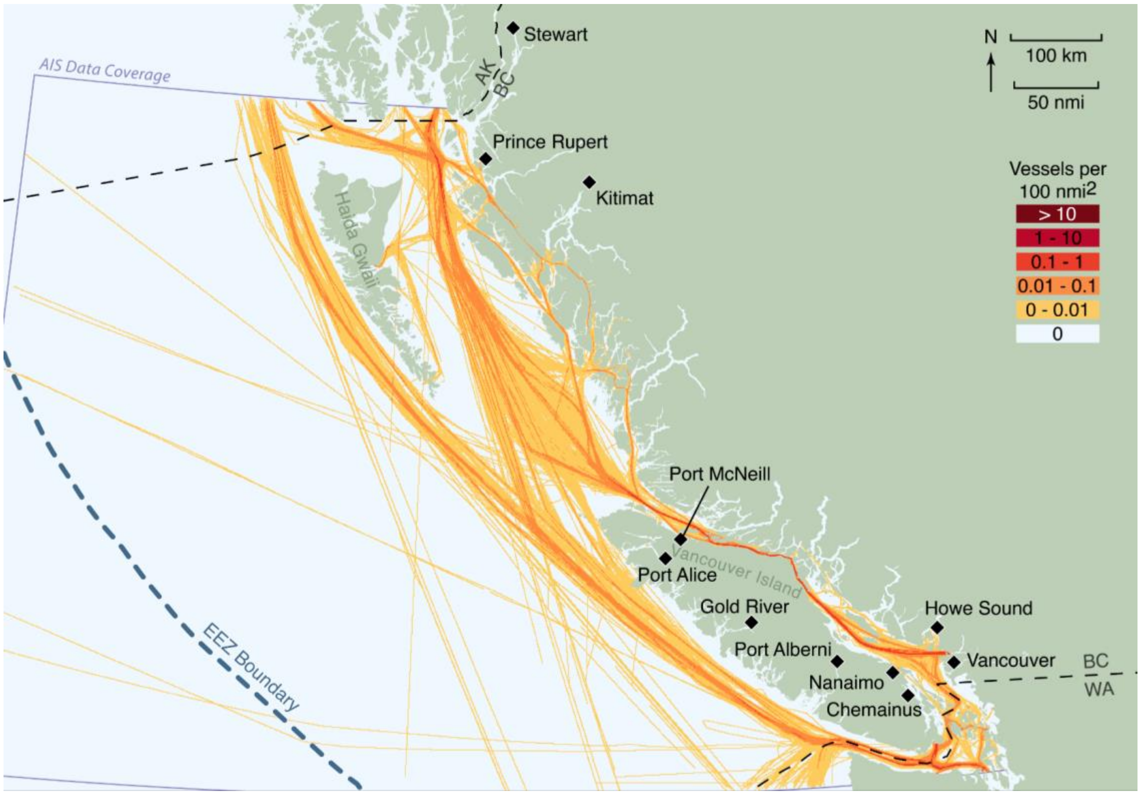
Cruise Traffic Brings Persistent Oil to Sensitive Areas During the Season

Cruise ships represent a small but very visible fraction of vessel traffic in Canada's Pacific waters. As cruise ships often call at small ports in remote places without deep-water berths or escort tugs, these vessels are designed to have excellent maneuvering characteristics, especially at low speed, such that they can safely navigate narrow waterways and confined areas. Their propulsion systems are designed with fail safes to mitigate the risk of an engine failure. But cruise ships very often also carry heavy fuel oil – a potential source of persistent oil spills. As demonstrated in the monthly map series below, cruise traffic is highly seasonal, with the first cruise ships usually travelling up the British Columbia coast in March and the last in early October. The season peaks through the summer and early fall with highest densities seen between May and September.



Monthly Variation of Cruise Ship Traffic Patterns (2014-2016)

The main destination for cruise traffic through Canadian waters is Alaska, with 380 cruise ships leaving the Salish Sea bound for Ketchikan, Juneau, and other tourist destinations in an average year. The map of cruise traffic density below illustrates the routes they take, with some passing west of Vancouver Island and Haida Gwaii, while others use the inshore route passing through Discovery Passage, Queen Charlotte Strait and Hecate Strait.



Vessel Density: Cruise Ships (2014-2016)

Going Forward with the Facts

The purpose of this study is to establish the facts and dispel some common misperceptions about vessel traffic in Canada's Pacific region.

Many of these misperceptions relate to oil tankers. It is natural that people are more sensitive to tankers than other types of large vessels, one just needs to look at their capacity to cause spills with huge repercussions for the people, wildlife, and waters of coastal regions – and their history of doing so. It is likely for this reason that tankers are often perceived as being relatively more common than other types of vessels. In contrast, this study's analysis shows that bulk carriers and container ships are by far the most numerous vessel types in the region and the fuel that these cargo ships carry is almost as large in aggregate as the quantity of oil carried by oil tankers.

In some cases, all large commercial vessels are perceived to be the same, without awareness of the distinct differences that dictate how they travel in regional waters and visit Canadian ports. This study illustrates the important differences in traffic flows for each ship type. While the dominant traffic type in the region is bulk carriers mainly bound for Vancouver, container ships treat the ports along the coastline as a complex, calling on multiple ports along their voyages. The distinctive-shaped vehicle carriers move in and out of the region, most often delivering cars to both U.S. and Canadian ports in the same voyage and sometimes collecting wood products for the return voyage. Tugs moving barges weave an intricate network of routes between small ports, industrial locations and coastal communities.

The marine industry is extraordinarily complex, and it naturally brings risks along with its many benefits. Day in and day out, year after year, a person looking seaward from Canada's Pacific shore sees many types of vessels and vessel movements. But it is difficult to understand the entire system from what can be observed. With three years of data tracking the individual movements of nearly 6,000 distinct vessels, this study provides a solid basis of facts. Individuals and organizations of ranging needs and interests are encouraged to apply these findings to individually and collectively determine how sustainable vessel traffic can, and should, evolve in Canada's Pacific region to the benefit of all.

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Acronyms and Abbreviations

AIS	Automatic Identification System
AIP	Alaska Inside Passage (Passage Line)
DE	Dixon Entrance (Passage Line)
DWT	Deadweight Tonnage
ECA	Emission Control Area
ESS	East Salish Sea (Passage Line)
EEZ	Exclusive Economic Zone
GT	Gross Tonnage
HS	Hecate Strait (Passage Line)
IMO	International Maritime Organization
LNG	Liquefied natural gas
LPG	Liquefied petroleum gas
LOA	Length Overall
MARPOL	International Convention for the Prevention of Pollution from Ships
MMSI	Maritime Mobile Service Identity
m	Metres
nmi	Nautical Mile
NPO	Non-Persistent Oil
OCIMF	Oil Companies International Marine Forum
PO	Persistent Oil
QCS	Queen Charlotte Strait (Passage Line)
SJDF	Strait of Juan de Fuca (Passage Line)
SSG	South Strait of Georgia
UNCLOS	United Nations Convention on the Law of the Sea

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Vessel Traffic Analysis for Canada's Pacific Region

1.0 Introduction

Nuka Research and Planning Group, LLC (Nuka Research) conducted the analysis for this report under contract to Clear Seas Centre for Responsible Marine Shipping (Clear Seas) as part of Clear Seas' larger Marine Transportation Corridors Initiative. This report characterizes the commercial vessel fleet and the movement of vessels and oil within Canada's Pacific region.

1.1 Purpose

The purpose of this report is to provide a clear picture of the commercial shipping vessels operating in Canada's Pacific region, their typical routes and behaviours, and the quantity and types of oil they carry. One use of this information is to help assess and understand risks associated with commercial shipping in these waters.

1.2 Scope

This report focuses on both deep draft ships and tugs engaged in commercial service. Many of these vessels are trading in Canada, but some are travelling through Canadian waters without calling at a Canadian port on their voyage. Figure 1 shows the study area used in the analysis. The area encompasses most of the marine waters in Canada's Pacific region including the Inside Passage and offshore waters to the outer boundary of Canada's Exclusive Economic Zone (EEZ), 200 nautical miles offshore. The ports that fall within the study area shown in Figure 1 are those at which commercial shipping vessels typically call. Section 2.2 provides a description of each of the ports included in the study.

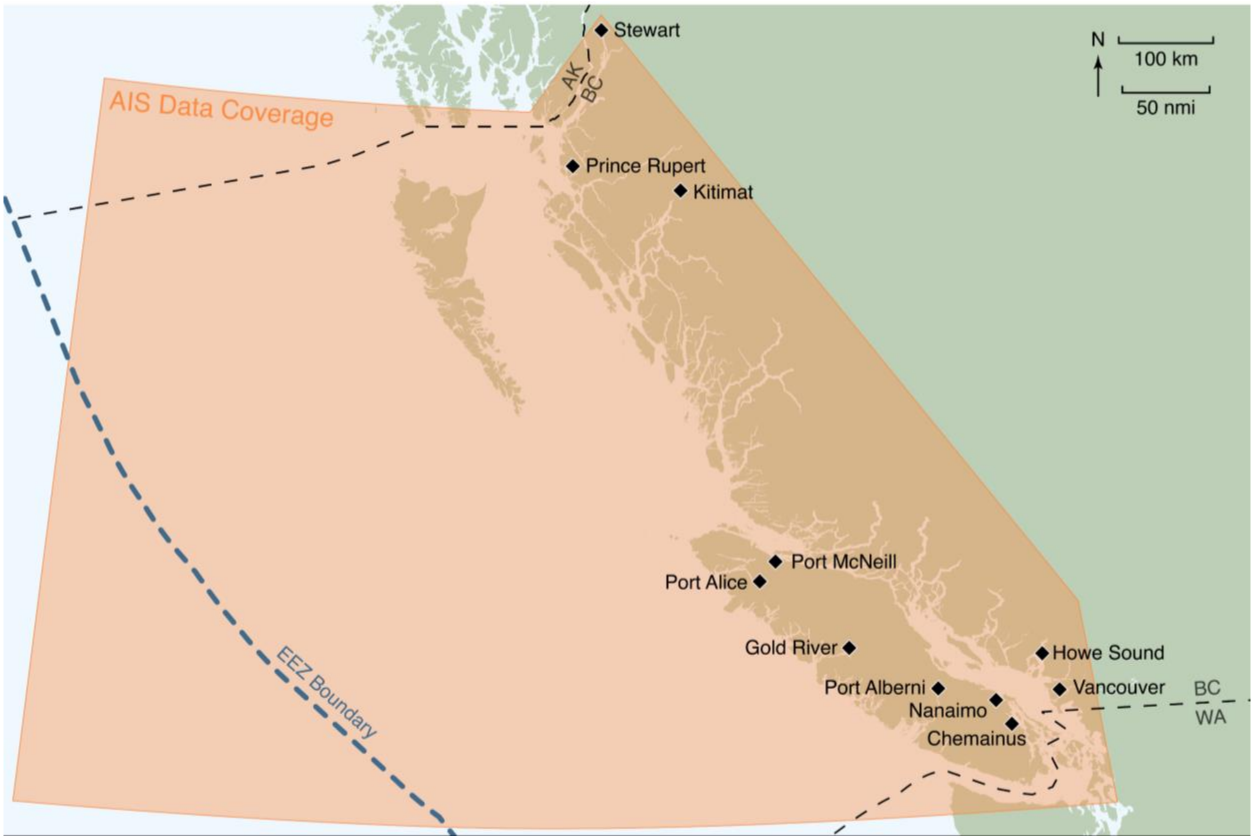


Figure 1. Map of the Study Area

1.3 Report Organization and Contents

The contents of this report are organized as follows:

Section 2: Background information used in the analysis, including: vessel types and sub-types, ports, oil types, definition of the term "Emission Control Area".

Section 3: Overview of the methodology used in the analysis, including: the processing of Automatic Identification System (AIS) data, vessel movement data, vessel attribution data, vessel voyages, presentation of results, data validation, and the study's limitations.

Section 4: Commercial vessel fleet characterization, of the different types and sub-types, in the following ways: size in both deadweight tonnage (DWT) and gross tonnage (GT), flag state, and age.

Section 5: Commercial vessel traffic characterizations as demonstrated by: typical routes, traffic density, port visits, passage line crossings, passage types, and an analysis of Strait of Juan de Fuca traffic.

Section 6: Oil movement characterizations as defined by: oil capacity of vessels, movement of persistent and non-persistent oils, and oil movements specifically in the Strait of Juan de Fuca.

2.0 Background Information

Many types of commercial vessels trade through Canada's Pacific waters, calling on both large and small ports. This section provides background on the types of vessels, ports, and some relevant policy issues applicable to the results of the analysis.

2.1 Vessel Types

This study focuses on large commercial vessels (greater than 300 GT) engaged in the movement of goods. These vessels are further broken down into four types and 10 sub-types as shown in Table 1 and illustrated in Figure 2. Tugs of greater than 15 m in length were included in the study in two sub-types because they are most commonly used to move barges. Cruise Ships are the only category of passenger vessel included in the study.

Table 1. Vessel Types and Sub-Types Used in the Analysis

Vessel Type	Vessel Sub-Type
Cargo	Bulk Carrier Container Ship Vehicle Carrier Other Cargo
Tanker	Small Tanker (<50k DWT) Large Tanker (>50k DWT) LNG / LPG Carrier
Tug	Articulated Tug Tug
Passenger	Cruise Ship

All of the above types are operated by licensed professional mariners and are subject to Canadian, United States (U.S.) and/or International Maritime Organization (IMO) regulations. Many of the vessels in the study are required to have Canadian marine pilots on board in designated areas (Clear Seas, 2017).

The two tanker sub-types referred to as "small tanker" (defined as having a weight of less than 50,000 DWT) and "large tanker" (defined as having a weight of greater than 50,000 DWT) were selected and defined to align with previous vessel traffic studies conducted by the British Columbia (B.C.) Ministry of Environment[3] and Pacific North Coast Integrated Management Area.[4] This alignment of sub-types with other previous vessel traffic studies allows comparison of traffic over multiple years and reports. The small tanker sub-group, also called a "coastal tanker" or "handysize tanker", are usually associated with the movement of refined products like diesel and gasoline along the coast in regional trade. Large

[3] West Coast Spill Response Study. Volume 2: Vessel Traffic Study. (2013).
[4] Atlas of the Pacific North Coast. Integrated Management Area. (2011).

tankers are typically involved in the transportation of unrefined products and are largely represented in the study region by the Aframax tanker (with about 120,000 DWT cargo capacity).

Specialized tankers carry liquefied natural gas (LNG) and liquefied petroleum gas (LPG) as cargo. If spilled, these substances will rapidly revert to a gas and do not mix with or pollute the marine environment. As such, their cargo is considered a non-oil cargo for the purposes of this study.

Fishing vessels (commercial and sport), ferries, government vessels (including military) and pleasure craft are excluded from this analysis, which reports only on commercial shipping vessels – vessels that transport goods and materials for commercial or trade purposes. While not commercial shipping vessels, Cruise Ships are an important and visible type of vessel found in the Pacific Region which often carry persistent oil as a fuel, and were thus included.

Figure 2. Vessels Included in the Study

2.2 Ports

A short description of each port included in the analysis is provided below in alphabetical order with their location illustrated on the map in Figure 3.

Figure 3. Ports Included in the Study

Chemainus – Chemainus, which includes the nearby port of Crofton, is a port located on Stuart Channel on the southeastern shore of Vancouver Island. Vessels calling at Chemainus/Crofton include bulk carriers, other cargo, and tugs. Forest products including logs and wood chips are chief products exported from Chemainus/Crofton. Non-persistent oil products are imported by tug and barge to an oil terminal on Bare Point.

Gold River – Gold River is a port at the head of Nootka Sound on the west side of Vancouver Island. Gold River hosts a ship berth and barge facilities. Vessels that call in Gold River include bulk carriers and tugs. The chief cargo at Gold River is forest products.

Howe Sound – Howe Sound is on the southern mainland of B.C. Howe Sound includes the ports of Port Mellon, which serves the Howe Sound Pulp and Paper Mill, and Squamish, which hosts break-bulk and barge terminal facilities. Squamish is tied to a rail head and a highway system allowing intermodal transportation (Squamish Terminals Ltd., 2012). The chief cargos are forest products, steel, and general cargo.

Kitimat – Kitimat is located at the head of Douglas Channel on the northern mainland of B.C. Kitimat has bulk, break-bulk, petroleum, and barge terminals. Export cargos include aluminum products (Kitimat Shipping, n.d.).

Nanaimo – Nanaimo is located on Georgia Strait on the eastern shore of Vancouver Island. Nanaimo hosts bulk, break-bulk, ro-ro, tug, and cruise ship terminals. Cargos at Nanaimo include forest products, intermodal containers, general cargo, vehicles, chemicals, and non-persistent petroleum products. (Nanaimo Port Authority, 2018)

Port Alberni – Port Alberni is located at the head of Barkley Sound on the western shore of Vancouver Island. Port Alberni has three break-bulk berths and a barge facility (Port Alberni Port Authority, 2018). Cargos are predominately forest products for export.

Port Alice – Port Alice is located at the head of Quatsino Sound on the western shore of Vancouver Island. There are no ship docks in Port Alice but ships regularly anchor and self-load floating logs. The chief cargos are forest products for export.

Port McNeill – Port McNeill is located on Queen Charlotte Strait on the northeastern shore of Vancouver Island. Port McNeill hosts a bulk terminal. Cargos include sand and gravel (Polaris Materials Corporation, 2018).

Prince Rupert – Prince Rupert is a port located on the northern mainland of B.C. at the eastern end of Dixon Entrance. Prince Rupert is the head of the CN Rail Line and is connected to the rail system throughout North America, making it an important transportation corridor to all of Canada and the U.S. Prince Rupert terminals include container, cruise ship, and bulk. A few tankers call in at Prince Rupert with cargos of slack wax, used to make paraffin, which is loaded on rail cars and shipped east. Commodities shipped to or from Prince Rupert include: intermodal containers, coal, grains, wood pellets, logs, slack wax, and general cargo (Prince Rupert Port Authority, 2017).

Stewart – Located at the head of Portland Canal, Stewart is the northernmost port in B.C. Stewart hosts a bulk terminal and barge terminal. Commodities shipped to or from Stewart include: mineral ore, forest products, and break-bulk cargo.

Vancouver – Canada's largest port, the Port of Vancouver, is located on the southern B.C. mainland. The port is connected to other modes of transportation by rail, highway, pipeline, and ferry. The Port of Vancouver has container, bulk, break-bulk, ro-ro, cruise ship, petroleum, tug and barge terminals. Deep draft ships can also anchor at established anchorages in English Bay and Burrard Inlet. Fuel bunkering services are available in the port and at anchorages. All vessel types included in this study, except LNG/LPG carriers, call in Vancouver. Commodities shipped through this port include: intermodal containers, bulk coal, bulk grain, bulk minerals, bulk fertilizer, bulk persistent and non-persistent oil, bulk animal/vegetable oils, bulk chemicals, project materials, forest products, machinery, and vehicles (EY, 2017).

The port includes the anchorages at English Bay; Burrard Inlet, which contains the North Shore Trade Area (North Vancouver) and the South Shore Trade Area (Vancouver, Burnaby and Port Moody); the Fraser River Trade Area, and Roberts Bank (including terminals in the South Georgia Strait between the Fraser River and the Canada/U.S. border). In some charts in this report, data for Vancouver are displayed in three segments – Burrard Inlet, Fraser River and Roberts Bank. This is done to facilitate presentation of results as the scale of the Port of Vancouver is significantly greater than all other ports in the analysis.

Other Ports - As mentioned, this study focuses on ports where the commercial vessels studied tend to call and is not intended as an exhaustive list of ports in the study area. Victoria is an example of a port not included in this analysis despite its service of some commercial ship traffic such as about 200 cruise ship visits per year; some escort tugs; bulk material via tug and barge; ship repair vessels, and maintenance and construction traffic at Victoria and Esquimalt. In the case of most of the deep draft vessels in the area of the Greater Victoria Harbour / Ogden Point – with the exception of some cruise ships – they are there to embark or disembark pilots rather than to conduct business at the port and therefore are not relevant to study purposes. It should also be noted that ferry services to Vancouver, Seattle and Port Angeles operate from Victoria and several government vessels are based at Victoria and Esquimalt. Tugs also call at many locations not included in the ports analyzed, including non-port locations such as logging camps or mines. Cowichan Bay bulk terminal was also not included due to limited overall marine traffic.

2.3 Oil Types

The movement of oil is included in the study to help inform risk assessment of oil spills by better understanding the total amount of oil being transported along the coast. There are many different types of oil, based on the product into which it is refined or where it was extracted. In this analysis, oils are categorized as non-persistent or persistent, based on how long spilled oil is likely to remain recognizable in the marine environment.

Persistent oils include crude (unrefined) oils and both intermediate and heavy fuel oils. Persistent oils last longer in the environment than non-persistent oils and are more likely to spread in a slick and strand on shore. They are also more likely to coat or smother wildlife than non-persistent oils.

Non-persistent oils include jet fuels, gasoline, diesel, marine diesel, marine gas oil, home heating oil, and some light crude oils. When spilled, non-persistent oils will evaporate or dissolve in the water.

Ships carry oil both as cargo (tankers) and as fuel for their own propulsion (referred to as bunker fuel). Conventional bunker fuel used by ocean-going ships is typically heavy fuel oil, a persistent oil.

2.4 Emission Control Area

Emission Control Areas (ECAs), or Sulphur Emission Control Areas (SECAs), are areas established by the IMO with stricter controls to minimize airborne sulphur emissions from ships in coastal areas (Regulations 13 and 14 of MARPOL Annex VI). The Pacific waters of Canada out to the EEZ boundary, as shown in Figure 1, are part of the North American ECA, which came into force internationally in August 2012. As of January 2015, ships operating in ECAs were required to use fuel with less than 0.1% sulphur (or to scrub exhaust to emit a maximum of 0.1% sulphur content). Vessels typically comply with the emissions limits by switching to a different ("lighter") fuel within the ECA than that which they use in the ocean areas outside the ECA. Outside of ECAs, ships were permitted to use fuels with sulphur content up to 3.5% up until January 2020 when a new 0.5% sulphur cap came into force.

3.0 Study Methods

This section describes the methodology applied to characterize vessel traffic by compiling and aligning information about vessel movements, or tracks, with a database of vessel particulars (type, size, etc.) associated with each track. Vessel traffic characterization is based on AIS data broadcast by ships travelling in the study area during the three-year period from 2014 to 2016. Clear Seas obtained the AIS data from exactEarth.

Nuka Research applied the following overall approach to compiling and processing vessel traffic data:

1. Process AIS data to remove bad data and reduce number of points
2. Develop Vessel Track Database from processed AIS data
3. Develop Vessel Attribute Database
4. Associate attribute data with track data
5. For some analyses, classify individual tracks
6. Develop vessel track and oil carriage density plots (heat maps)
7. Develop statistics for tracks that crossed passage lines or called at ports

3.1 Processing of AIS Data

When an AIS signal is transmitted from the vessel to a terrestrial or satellite receiver, a data point is logged identifying the position of the vessel. Each data point includes the vessel's identity, time, date, location, and limited vessel particulars. When the next signal is received, a track of the vessel's movement (vessel track) can be developed using interpolation between the data points. The vessel identification is then added to the project's vessel attribute database.

AIS transmissions may occur as frequently as every second. However, since a satellite is not always overhead, not every signal transmitted by a vessel is recorded. When a satellite is overhead, more data points are collected than are needed to accurately characterize where the vessel traveled. In this sampling, the data points for an individual ship have been separated by up to 45 minutes. In the case of this study, the initial dataset provided by exactEarth included 91 million individual points. Once processed to remove invalid or extraneous data, using the custom computer program described below, the database was reduced to 19 million points.

3.2 Collection of Vessel Movement Data

Using a custom computer program, Nuka Research developed a Vessel Track Database from sequential AIS points for each individual vessel within the study area. The program removed records that did not have valid vessel identification, transmitted time, or latitude or longitude position data. Only data transmitted by vessels with mandatory (Class A) AIS transmitters were kept.[5]

Data points were grouped by vessel and ordered chronologically. One or more tracks were then built for each vessel using the following method:

1. The first and last points are always kept.

2. Beginning with the first point chronologically, each succeeding point is compared to the previous point. The successive point is excluded if it is less than three minutes since, or closer than 0.2 nmi to, the previous point.

3. Tracks are then constructed from the remaining set of points for each vessel. A new track is started if one or more of the following cases occurs: a successive point is greater than 7 days or 50 nmi from the previous point; the designation information provided by the vessel in the AIS signal changes; or the vessel does not move for more than four hours.

4. Tracks are stored in a geo-spatial dataset and spreadsheet. Each track is identified with a specific vessel based on that vessel's Maritime Mobile Service Identity (MMSI) number and then detailed with vessel-specific attributes associated with that same number.

The computer code reduces the number of data points associated with each vessel track while retaining the information necessary to determine where the vessel traveled.

3.2.1 Passage Lines

Passage lines are used to capture additional information about vessels as they move in and out of selected key transit areas with high traffic volumes. They operate as "tripwires" in the analysis to identify each time a vessel in the dataset crosses one of the passage lines. This process of "geofencing" an area was used to develop both passage line data and port call data.

The passage lines used for this analysis are shown in Figure 4, with specific geographical references provided in Table 2. Study results show the number of movements that occur across a passage line. For example, if a vessel crosses the Dixon Entrance passage line on the way both to and from Kitimat, that vessel will count twice in totals for Dixon Entrance. That same vessel trip would count as one port call at Kitimat.

[5] Class B transmitters send a lower power signal and are voluntarily carried by vessels not required to transmit an AIS signal.

Table 2. Geographical References for Passage Lines Used in Analysis

Passage Line	Approximate End Points
Alaska Inside Passage	Cape Muzon to Tree Point
Dixon Entrance	Cape Muzon to Cape Knox
Hecate Strait	Rose Spit to Chell Point
Queen Charlotte Sound	Cape Scott to Cape Saint James
Queen Charlotte Strait	Duval Island to Stuart Point
North Strait of Georgia	Qualicum Beach to Halfmoon Bay
South Strait of Georgia [Canadian Vessel Traffic]	Crofton to Point Roberts
Strait of Juan de Fuca	Bonilla Point to Neah Bay
East Salish Sea [US Vessel Traffic]	Kwomais Point to Dungeness Spit

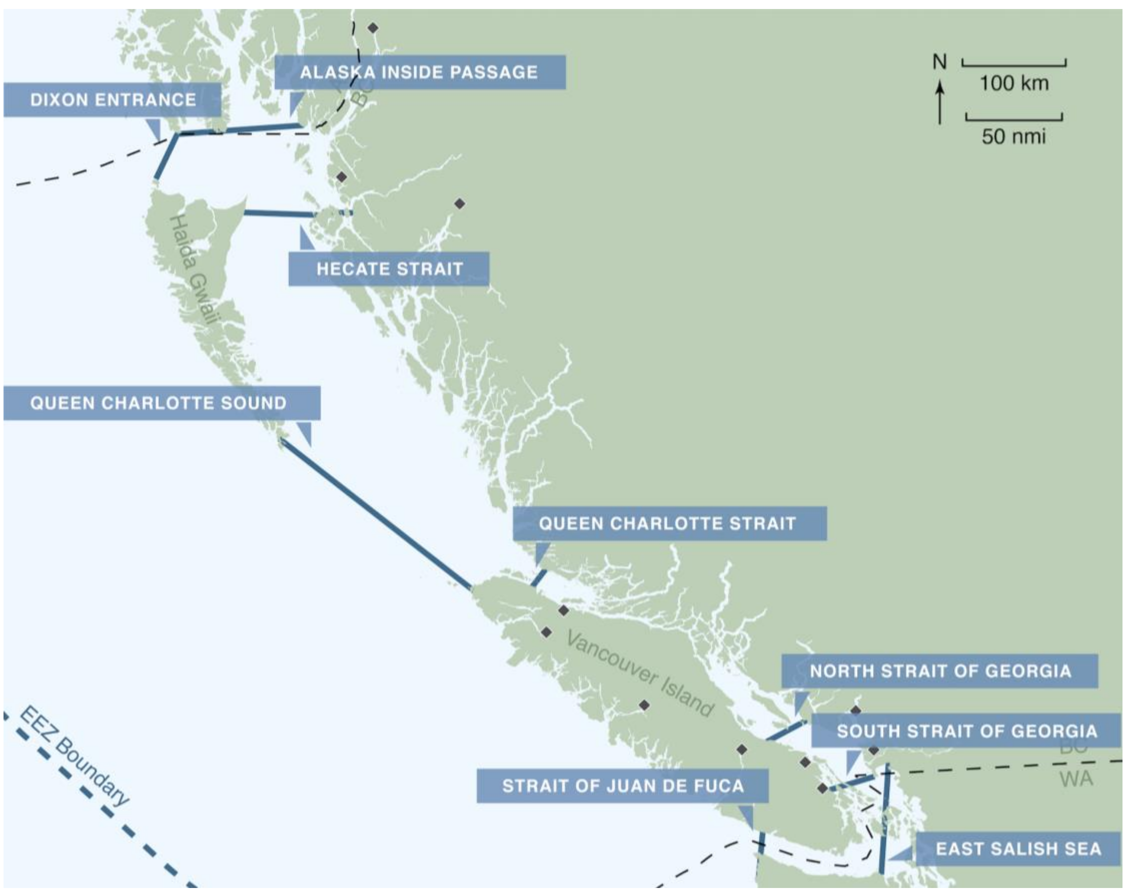


Figure 4. Passage Lines Used in the Analysis

3.2.2 Passage Types

A sub-set of vessel tracks was analyzed to determine whether those tracks were associated with a voyage that was engaged in Canadian trade, i.e. calling at a port in B.C., or passing through Canadian waters in innocent passage. Vessels in innocent passage were further broken down into those trading between the U.S. states of Washington and Alaska, and those travelling between U.S. ports and Asia. Almost 12,000 tracks occurring in January, March, June, and September 2016 were examined individually and assigned to one of these three categories based on the vessel's behaviour. See section 5.5 for additional details.[6]

3.3 Assignation of Vessel Attribute Data

The AIS dataset acquired from exactEarth comprised more than 7,500 unique vessels transmitting Class A signals as required by the IMO under Regulation 19 of SOLAS Chapter 'V'. The project developed a separate Vessel Attribute dataset with vessel-specific information for each of the unique vessels included in the study. Attributes include information on the size, age, flag state and oil capacities for each vessel. Attributes were then associated with each vessel track.

Some missing vessel information, such as fuel volume, could be estimated, as explained in Section 3.3.2. Other fields, such as flag state or year of construction, remained incomplete if that information was not obtainable through one of the methods described above, causing the total number of vessels to vary somewhat throughout the results. For example, the year of construction was only known for 210 of the 382 conventional tugs in the dataset.

The Vessel Attribute Database was assembled from multiple data sources to provide the most accurate information about each vessel. Some vessel attributes are provided with the AIS data. However, past experience shows that this self-disclosed information is not always accurate. For the most accurate results, additional data were collected from vessel registries and other sources as described in this section.

The project purchased vessel attribute data for 5,511 individual vessels from the worldwide vessel registry maintained by IHS.[7] Nuka Research also maintains a database of vessels encountered in other studies (Nuka Research and Planning Group, 2013; 2016). Where information was still missing, an attempt was made to collect information from other public sources, such as U.S. government databases and online ship identification sources. In some cases, information about a particular vessel attribute was not available and had to be estimated based on the attributes of similar vessels using a best-fit regression analysis.

Best-fit regression analysis was performed in the following manner. Within a vessel sub-type, two attributes would be correlated for all vessels with known values using linear, exponential, logarithmic, polynomial, and power regression models. Other pairs of attributes would then be explored to

[6] Because this is a time-intensive process (requiring the examination of each track), activity for only four months was analyzed. These four months were chosen to capture potential seasonal variations.
[7] Maritime Portal Desktop

determine the best predictor for a missing attribute. The model with the best fit, as determined by the R-squared statistic, would be utilized to estimate attributes for other vessels within the same sub-type. For example, after exploring length and gross tonnage as variables to predict deadweight tonnage for container ships, it was determined that a power regression of gross tonnage (yielding an R-square of .95) provided the best method to estimate deadweight tonnage for this vessel sub-type.

IHS data was considered the primary source. If a vessel's data was missing from IHS, Nuka Research assigned values based on the following order of priority:

- Data extracted from the AIS data
- Nuka Research vessel attribute data
- Researched data
- Regression model values

As an outcome of this process, Table 3 provides the primary attributes associated with each vessel and sources used.

Once the Vessel Attribute Dataset was completed, the vessels further excluded from the analysis included:

- Vessels less than 300 gross tonnes, except for tugs
- Tugs less than 15 m
- Fishing vessels, ferries, government vessels and pleasure craft
- Vessels for which no vessel type could be identified

Table 3. Vessel Attributes and Sources

Attribute	Characteristic and Units	Source
MMSI	MMSI from AIS data associated with a track	AIS data
IMO Number	IMO registration number	Vessel registry / AIS / Subject Matter Expert Research
Name	Vessel name	
Flag State	Country where vessel is registered	
Year Constructed	Year vessel was constructed	
Vessel Type	Vessel type assigned for this study	
Length	Overall length in metres	
Width	Maximum width in metres	
Draft	Maximum draft in metres	
Gross Tonnage	Volume of all internal spaces of the ship; not a measure of mass but a measure of the internal volume.	IHS/research or regression based on vessel type/length
Deadweight Tonnage	Weight of cargo, fuel, fresh water, ballast water, provisions, passengers, and crew.	IHS/research or regression based on vessel type/length or gross tonnage
Fuel Capacity (Non-Persistent Oil)	Estimated maximum volume of non-persistent fuel carried on board in cubic metres	IHS/research or regression based on vessel type/length or tonnage (either DWT or GT see Table 4)
Fuel Capacity (Persistent Oil)	Estimated maximum volume of persistent fuel carried on board in cubic metres	
Cargo Capacity (Non-Persistent Oil)	Estimated maximum volume of non-persistent oil cargo carried on board in cubic metres, for tankers only	IHS/research or regression based on deadweight tonnage
Cargo Capacity (Persistent Oil)	Estimated maximum volume of persistent oil cargo carried on board in cubic metres, for tankers only	
Excluded	Vessels marked to be excluded from the analysis	Nuka Research

3.3.1 Vessel Types and Sub-types

For the purpose of this project, commercial vessels were assigned to one of four types: cargo, passenger, tanker, or tug. Type categories were selected to be consistent with, though not identical to, the Canadian Coast Guard Marine Communications and Traffic Services database and a previous vessel traffic study for the British Columbia Ministry of the Environment (B.C. MOE - Nuka Research, 2013). The notable differences between the vessel types across the various reports are the size of vessel used in the analysis and the different types of vessels. This report focuses on vessels which are >300 GT compared with the 2013 BC MOE report that used vessels >400 GT. Also, the latter report included government vessels, fishing boats, and ferries, all of which are excluded from this report.

As the analysis is based on AIS data from vessels required to carry transmitters (Class A),[8] all vessels over 300 GT are included regardless of type, and all tanker ships are included regardless of size. Tugs

[8] International Convention for the Safety of Life at Sea (Regulation 19, Chapter V).

engaged in commercial service were captured regardless of size. Appendix A provides examples of the kinds of vessels included in each type and sub-type and additional discussion of each is included in Section 4.1.

Barges are not required to have AIS transmitters; to track oil movement by barge it was necessary to identify tugs that tow or push an oil barge, and determine the capacity of the barge. Interviews and research of company websites provided information regarding which tugs were associated with oil barges in 2016. Interviews were conducted with personnel from Canadian and U.S. companies operating tugs transporting oil barges through the study area.[9] In some cases, a tug-barge combination was associated throughout the entire year of 2016. In other cases, an oil barge was moved by several different tugs. This information was recorded on an individual track level to estimate the amount and movement of oil carried by tug/barges in the study area during that year.

3.3.2 Oil Type and Capacity

All commercial shipping vessels carry oil as fuel and tankers and tugs moving oil barges carry oil as cargo. Due to the amount of time required to associate each individual AIS track with the appropriate fuel types and quantities, estimates of oil carriage were derived from a single year of vessel movements (2016). Oil carriage for 2016 was estimated by assessing the type and amount that each vessel was capable of carrying and then applying a standardized assumption for that vessel type, as described below.

Oil types were assigned in two categories: persistent and non-persistent. For cases where oil types and quantities could not be obtained from primary data sources (discussed in Section 3.3), it was assumed that the fuel type was the same as other known vessels within the same vessel sub-type and tonnage.

Oil capacities refer to the volume of either persistent or non-persistent oil that a ship can carry, whether for its own propulsion or as cargo (tankers and tugs/barges only). Table 4 shows the methods used to estimate oil capacity for different vessel types when the actual data was not available from the primary or secondary sources listed at Table 3.

[9] Interviews were conducted with representatives of the following companies with the understanding that specific tug/barges or oil movements would not be identified: (1) Foss Maritime, (2) Island Tug and Barge Ltd., (3) Kirby Corporation, (4) North Arm Transportation, (5) Olympic Tug and Barge, and (6) Seaspan ULC.

Table 4. Methods Used to Estimate Non-Persistent and Persistent Oil Capacities

Vessel Sub-type	Method for Estimating NON-PERSISTENT Oil Capacity	Method for Estimating PERSISTENT Oil Capacity
Cargo - Bulk	Regression analysis based on gross tonnage	Regression based on gross tonnage
Cargo - Container Ship	Regression analysis based on gross tonnage	Regression based on length
Cargo - Vehicles Carrier	Regression analysis based on length	For vessels with a non-persistent fuel capacity greater than 2,400 m^3, persistent fuel capacity was estimated to be zero.[10] For vessels with a non-persistent capacity less than 2,400 m^3, regression analysis based on length was used to estimate persistent fuel capacity.[11]
Cargo - Other	Regression analysis calculated based on vessel type and length	Regression analysis calculated based on vessel type and length
Small Tanker (<50k DWT)	Regression analysis based on gross tonnage	Regression analysis based on length
Large Tanker (>50k DWT)	Regression analysis based on gross tonnage	Regression analysis based on length
LNG/LPG Tanker	Regression analysis based on gross tonnage	n/a
Tug	Regression analysis based on length	n/a
Tug (Articulated)	Regression analysis based on gross tonnage	n/a
Passenger - Cruise Ship	Regression analysis based on deadweight tonnage	Regression analysis based on gross tonnage

Estimating oil type for tanker cargo is challenging because tankers can carry different types of oil cargo on different voyages. In some cases, oil type can be determined by the trade in which a vessel engages. For example, tankers travelling between Valdez, Alaska, and refineries in Washington are known to carry crude oil (a persistent oil) and tankers travelling to Prince Rupert are known to carry a constituent of paraffin called slack wax (also a persistent oil). In cases where cargo type could not be determined based on typical trade patterns, the type of oil cargo was estimated based on the following rules:

- Small tankers were assumed to be carrying non-persistent oil as cargo;
- Large tankers were assumed to be carrying persistent oil as cargo; and,

[10] This applied to Canadian flagged vehicle carriers operating between Vancouver and Vancouver Island.

[11] This applied to foreign flagged vehicle carriers.

- All oil barges were assumed to be carrying non-persistent oil, with the exception for known barge movements that carried persistent oil from a refinery in Washington to the Port of Vancouver for fuelling ships.

The amount of oil as fuel carried is calculated by assuming that fuel tanks are 70% full. This was found to be a reasonable assumption in other studies (DNV & ERM-West, Inc., 2010).

The total amount of oil actually carried as cargo is estimated by assuming that cargo tanks are 50% full. This standard assumption is based on the fact that most tankers and oil barges usually carry oil one way to a port and return empty. There are limitations to this assumption in that barges, ATBs and smaller product tankers may be more complex, as these tank vessels may have multiple parcels of different refined product, stored in different tanks, waiting for delivery to a terminal or vessel.

3.4 Vessel Voyages via the Strait of Juan de Fuca

The Strait of Juan de Fuca (SJDF) is the primary gateway for ships entering or exiting the Salish Sea, which spans the Canadian and U.S. waters from the Strait of Georgia in the north to Puget Sound to the south. Round trip voyages through the SJDF were analyzed, using the passage lines shown in Figure 5, to determine the number and type of vessels calling in Canada, the U.S., or both countries during the 2014-2016 period, and the amount of oil carried by the vessels in each of these categories in 2016 only. The South Strait of Georgia line was used to determine vessel traffic to Canadian ports and the East Salish Sea line was used to determine vessel traffic to U.S. ports.

Individual vessels were identified that entered the SJDF from the west and traveled across either the East Salish Sea passage line into U.S. ports in the State of Washington, or the South Strait of Georgia passage line into ports in Canada, and then exited the SJDF within 45 days of entry.[12] The analysis did not consider vessels that entered and exited the SJDF without crossing a second passage line as such vessels tended to be calling at Victoria or Cowichan Bay in Canada, Port Angeles in the U.S., or picking up a pilot to call at a port on the west coast of Vancouver Island. For vessels calling at ports in both countries, no distinction was made between vessels that called in Canada first, the U.S. first, or vessels that made multiple calls in one or both countries. This analysis assumed that a tanker's cargo would be full on one leg of the journey and empty on the other, except on some occasions when refined oil products are shipped from Anacortes and Ferndale in the State of Washington.

[12] This duration was chosen based on the frequency distribution of time between entering and exiting the SJDF, to capture the longest likely length of time a vessel could be in the project area on a single voyage.

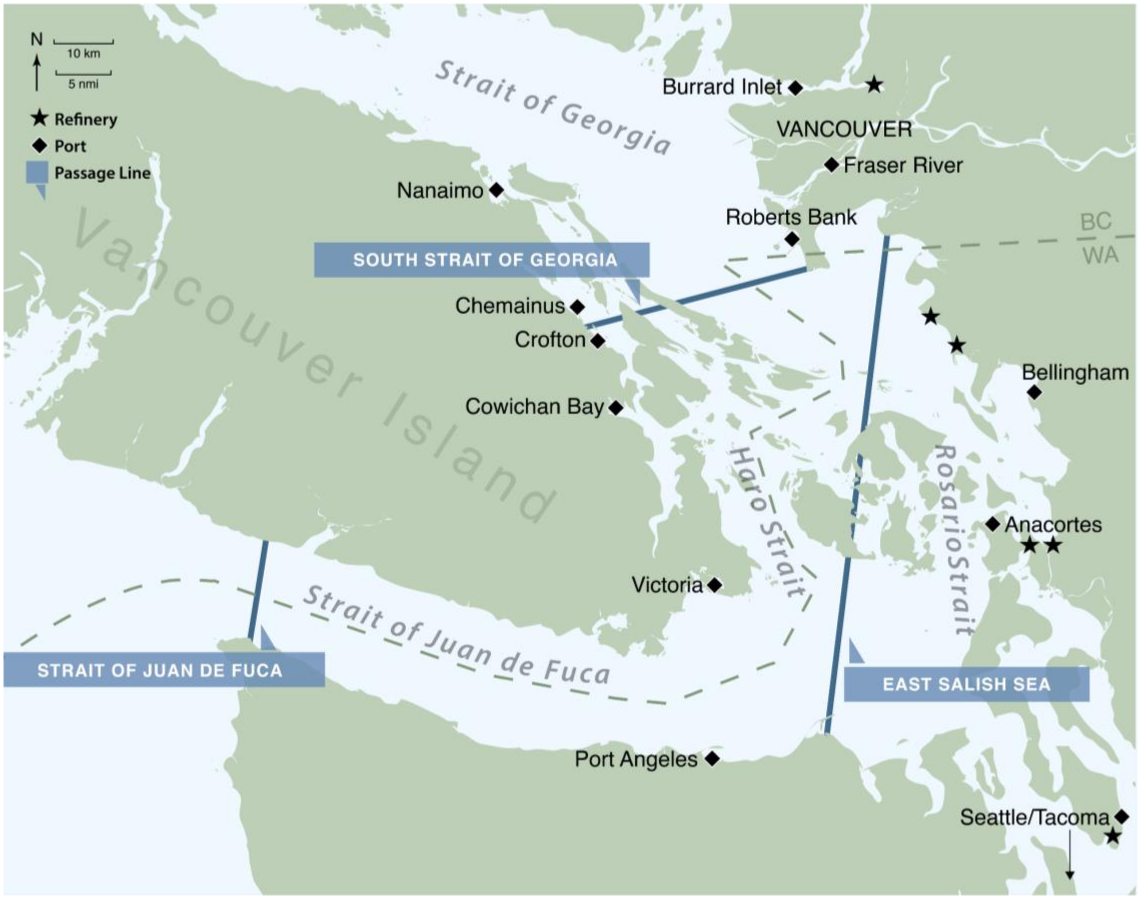


Figure 5. Passage Lines and Ports Applicable to Strait of San Juan de Fuca Analysis.

3.5 Presentation of Results

The results of this report are presented in maps and statistics as described below.

The maps produced show actual tracks for all selected vessel types and sub-types that fall within the study scope. These maps are useful for identifying and studying the routes of individual vessels.

Density (Heat) Maps – These maps are useful for showing the aggregated information from many tracks. Two types of density maps (or heat maps) were developed with the datasets constructed for this project. A gridded density map where each grid cell contains a value calculated from the intersection and accumulation of all selected vessel tracks that crossed the cell. The values in the cell are grouped into categories and a colour is associated with each category. A map is produced that shows the accumulated information or density for every grid cell using the associated colour.

Vessel Count – This presents the number (at any given instant) of vessels in a grid cell, averaged over the entire study period. Values are expressed as the number of vessels per square nautical mile (nmi^2). Grid cells are coloured to show the density of vessel traffic.

Oil Exposure – This statistic indicates the oil exposure associated with each grid cell. It is an estimate based on the oil carriage estimated for each vessel that occupied the grid cell.

Summary Statistics – Tables and bar graphs complement the maps and are used to present the total numbers of vessels of different types and sizes moving across passage lines or calling on a port, for example. For readability, numerals referenced in text are usually rounded.

Quartile Plots (Box-and-Whisker) – This analysis method is useful for showing data distributions for certain statistics that are presented in this report. Data are divided into quartiles, each representing 25% of the values in the dataset. The plot is a box divided with a light shaded line and two whiskers, one coming from the top of the box and one coming from the bottom. The top and bottom of the whiskers represent the maximum and minimum values found in the data. The top and bottom of the box represent the 75th and 25th percentiles, while the light shaded line represents the 50th percentile or median of the data. Figure 6 shows a box and whisker plot for a standard bell curve distribution (on the left) and one (on the right) that is skewed such that most of the values are lower on the vertical scale.

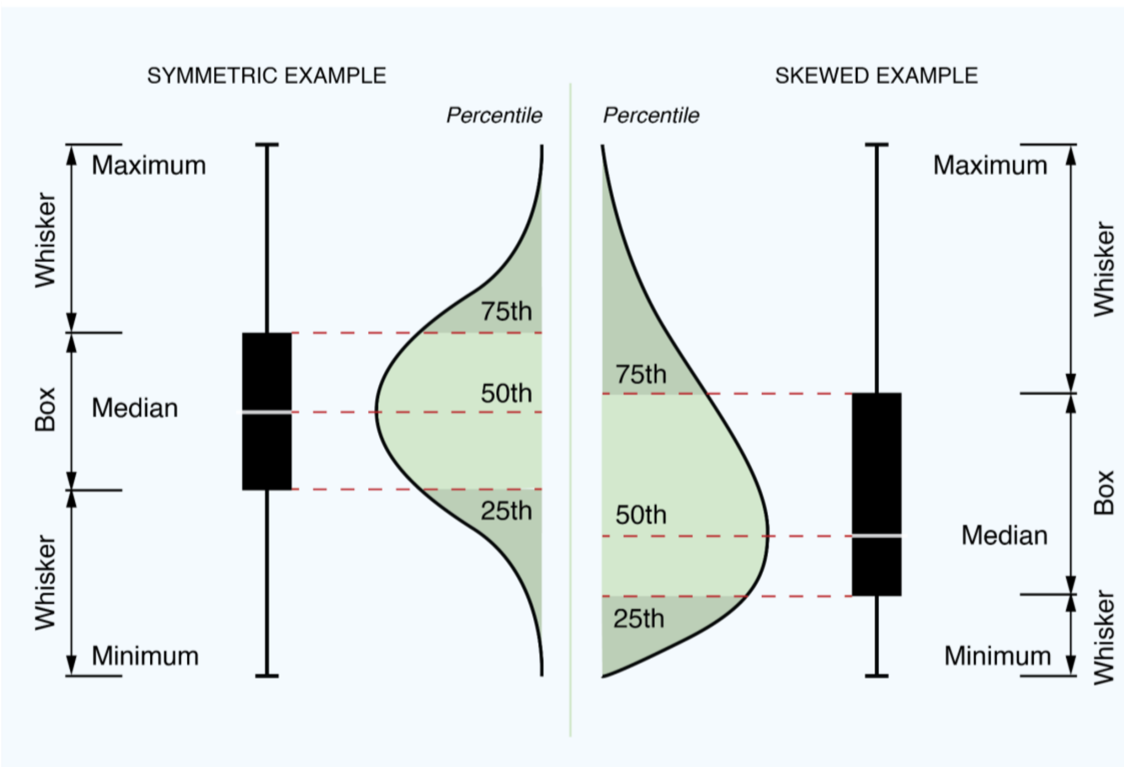


Figure 6. Example of Quartile Plots for a Standard Distribution (Left) and Skewed Distribution (Right)

3.6 Validation of Data and Estimates

Data employed in this analysis range from quantifiable observations to estimates based on statistical analysis. It also uses assumptions based on professional experience and best judgement. Examples of quantifiable data include AIS reports of vessel position and known specifications for vessels based on a ship registry. However, even some of these data can be inaccurate. Examples of estimates derived through statistical methods include vessel specifications, such as fuel capacity, based on regression analysis of known vessels of the same type. An example of an assumption based on professional judgement is the type of oil carried by a tanker based on its size and designation.

This range of data sources introduces varying degrees of uncertainty associated with the estimates made in this report, so the results were validated with external data sources wherever possible. Estimates of vessel tonnage typically have small levels of uncertainty associated with them, while estimates of persistent oil versus non-persistent oil as cargos involve greater levels of uncertainty, because these estimates are made based on informed assumptions (based on interviews, experience and professional knowledge) regarding what type of cargo is carried at any given time.

The estimates in this report are precise in that they have all been made using the same methods and assumptions, so they are repeatable and readily comparable to one another, and readily comparable to other investigations using the same methods.

The accuracy of estimates was gauged by comparing the results of this analysis to known quantities reported elsewhere. Port call estimates made by counting vessels crossing a passage line around a port, as in this study, were compared with reports of port calls published by the Port of Prince Rupert and the Port of Vancouver. The finding was a low variability between the estimated values and the actual values reported for the two ports. The estimated port calls in this study varied from plus or minus 7% across the vessel types reported for the two ports, with the estimates being generally higher than reported numbers. One reason for this is likely because a vessel may enter and exit a port area more than once if anchoring outside the port area.

Oil cargo movement estimates were compared with the annual report of the Port of Vancouver. Estimates of oil movement in this study were about 6% higher than reported by the Port, based on the number of tanker calls. As discussed, this analysis applied a general assumption that all tankers or oil barges are loaded to capacity on one leg of their voyage and empty on the return, so the assumed carriage is set at 50% of capacity.

3.7 Limitations of Data and Estimates

This study is subject to the following limitations:

- The time between position points in vessel tracks can be longer than desired due to gaps in satellite coverage. Tracks with long times between points may appear to cross over land, because the position of the vessel was not accurately characterized between points. Still the track is fit for the purpose of determining where the vessel travels and its general route to get there.

- A small amount of AIS position data is properly formed but inaccurate. Tracks with a bad position point appear to jump a long distance from an otherwise normal course. The computer code filters most of the bad position data, but some cannot be distinguished by the code. This bad data can show up on density maps as broken lines that do not appear to coincide with other tracks. They have minimal effect on the analysis and can be ignored on the density maps.

- Barges are not required to carry AIS transmitters, so to understand oil movements by barges, tracks for tugs towing a barge must be identified and assigned the type and volume of oil being carried in the barge.

- Oil types for tanker cargos are not always known and must be assumed based on the characteristics and trade of the tanker.

- Some vessel characteristics, such as fuel or cargo capacity, are not known and must be estimated from other vessels of similar type and size.

- A small minority of passage line crossings or port calls are missed because the vessel track breaks on one side of the line and begins anew on the other side of the line.

- Track type characteristics, such as determining if a vessel was involved in domestic trade or in innocent passage, are based on an assessment of track behaviour.

4.0 Commercial Vessel Fleet Characterization

This section presents the number of vessels of different types and sub-types included in the final dataset, describes each type/sub-type, and characterizes vessel size (in deadweight tonnage and gross tonnage), flag state, and age.

4.1 Dataset Representation of Vessel Types and Sub-Types

There were 5,921 individual vessels in the final dataset representing three years of vessel traffic in the study area. Table 5 and Figure 7 show how these totals break down among the vessel sub-types. There were far more bulk carriers (59% of all vessels) than any other sub-type of vessel in the study. Container ships (11%), other cargo (8%), tugs (7%), vehicle carriers (6%), small tankers (5%), large tankers (3%), cruise ships (1%), and articulated tugs (0.3%) follow in order.

Table 5. Number of Unique Vessels by Sub-Type (2014-2016)

Vessel Type	Count of Unique Vessels
Cargo	4,958
Bulk Carrier	3,472
Container Ship	664
Vehicle Carrier	360
Other Cargo	462
Tanker	503
Small Tanker (<50k)	288
Large Tanker (>50k)	195
LNG/LPG Carrier	20
Tug	402
Articulated Tug	20
Tug	382
Passenger	56
Cruise Ship	56
Total	5,919

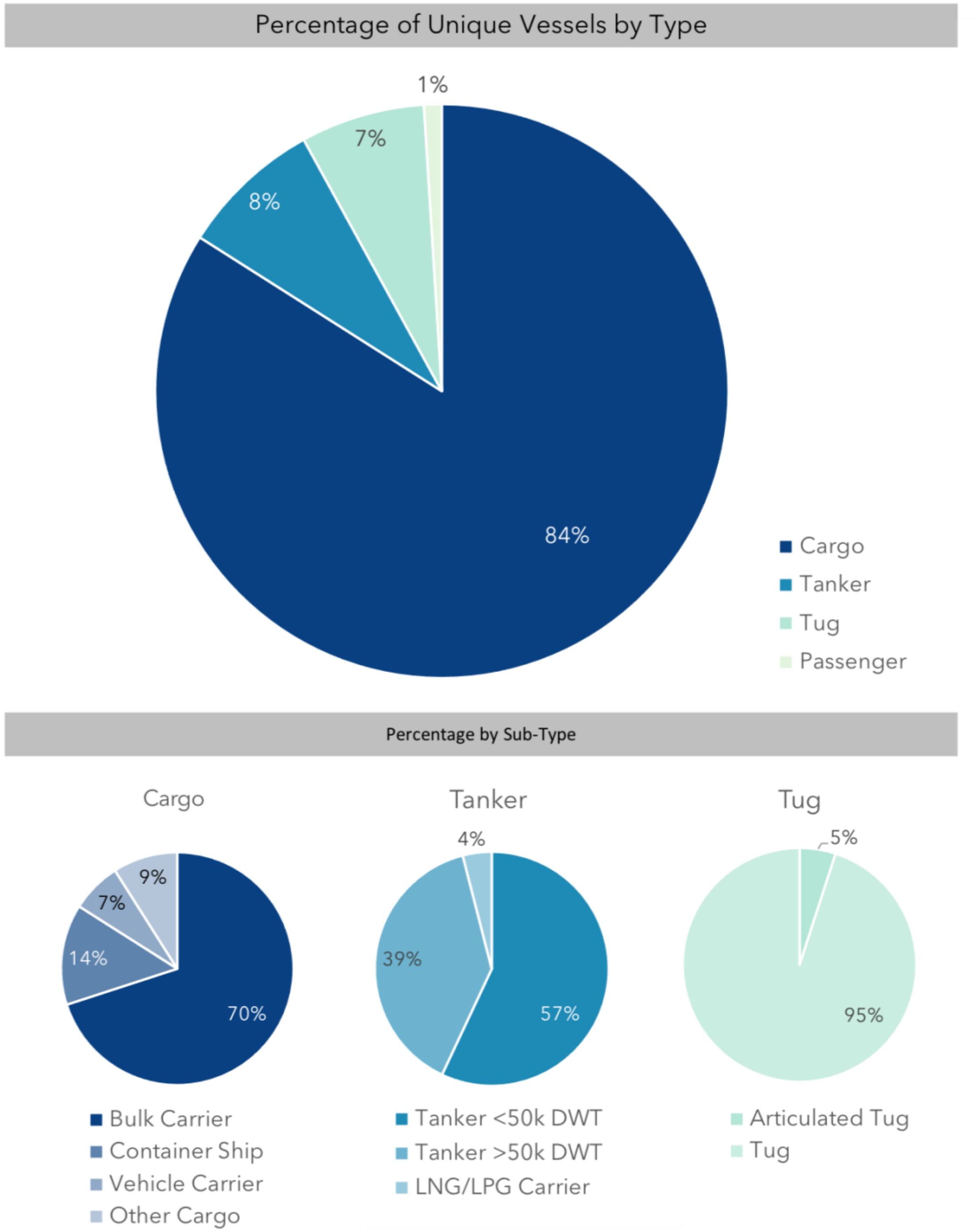


Figure 7. Percentage of Unique Vessels by Type and Sub-type in 2014-2016 Dataset

4.2 Vessel Profiles

This section provides profiles for each of the vessel sub-types analysed in the study. More detailed analysis of the size, age and flag state for each vessel type follow in Section 4.3 – 4.5. The oil capacity is analysed in detail in Section 6.1.

4.2.1 Cargo Vessels

Bulk Carrier - As the name implies, these ships carry unpackaged mass cargo in large holds. Typically spot chartered to carry a single load from one port to another (rarely trading back and forth between the same ports), bulk carriers are primarily used to export mineral, forest, or agricultural products to foreign markets. They call at every major port in B.C. and some bulk carriers pass through Canadian waters in innocent passage to and from U.S. ports. They typically travel in similar tracks or corridors, but occasionally deviate to avoid storms or for other unknown reasons. They take a long time to load and offload and are not bound to a rigid schedule. Bulk carriers generally travel in outside (open ocean) waters except when approaching the coast to enter a port.

The estimated average persistent oil capacity for bulk carriers in 2016 was 2,400 m^3 and the maximum was 6,200 m^3. All bulk carriers operating in the area during the study period were registered in foreign countries.

Container Ship - Container ships carry cargo in standard-sized intermodal containers that can be quickly loaded and unloaded by cranes at special terminal facilities and further transported by truck or rail. Container ships move commodities in both directions - importing and exporting consumer goods in a vast network of world trade. Container ships call at three ports in B.C. including Prince Rupert, Vancouver, and Nanaimo. Container ships calling at U.S. ports regularly travel through Canadian waters in innocent passage. These large ships call on a regular schedule and often follow a route that brings them back to a port on a regular basis. Container ships generally travel in outside waters except when entering a port.

The estimated average persistent oil capacity for container ships in 2016 was 8,600 m^3 and the maximum was 15,000 m^3. All container ships operating in the area during the study period were registered in foreign countries.

Vehicle Carrier[13] - Ships that are configured to allow vehicles to drive on board are known as "roll-on/roll-off" or ro-ro. One type of ro-ro is a vehicle carrier, which are designed to transport cars and small trucks to market. Since many more vehicles are imported than exported in North America, most vehicle carriers are carrying vehicles to Canadian ports. Vehicle carriers calling at U.S. ports also travel through Canadian waters in innocent passage. In B.C., large deep draft vehicle carriers currently call at the Port of Vancouver to off-load, as well as the Port of Nanaimo, which expanded to include a vehicle processing centre in 2019. They are also known to visit Nanaimo to backload logs and other forest products after delivering their cargo of vehicles. Vehicle carriers are dispatched on an as-needed basis and may revisit

[13] Two vessels providing commercial truck and trailer ferry service between the Fraser River and Vancouver Island were inadvertently included in the Vehicle Carrier traffic.

a port, but do not necessarily follow a regular scheduled route. Vehicle carriers generally travel in outside waters except when entering the Strait of Juan de Fuca (SJDF) to come into port.

The estimated average persistent oil capacity for vehicle carriers in 2016 was 3,200 m^3 and the maximum was 6,500 m^3. All of the vehicle carriers operating in Canada's Pacific region during the study period were registered in foreign countries.

Other Cargo - All other cargo ships are included in this sub-type. These include: ro-ro ships that carry trailers or rail cars, general cargo ships carrying loads that may be packaged but are not necessarily in standard intermodal containers (allowing them to call at terminals that do not have specialized cranes), log carriers that haul forest products from production to mills, heavy lift ships that carry specialty loads including other ships, and offshore supply vessels that service offshore drilling or oil production operations. This diverse category varies greatly in its characteristics, and some vessels captured here may be similar to other subcategories of cargo vessels. Many are engaged in domestic trade, but some are only passing through Canadian waters. Some follow regular routes and schedules while others only call on an as-needed basis. Other cargo vessels travel though both open ocean and inside waters.

The estimated average persistent oil capacity for other cargo ships in 2016 was 2,000 m^3 and the maximum was 4,800 m^3. All other cargo vessels operating in Canada's Pacific region during the study period were registered in foreign countries.

4.2.2 Tanker Vessels

Tanker (Large and Small) - These ships that carry refined oil, crude oil, and liquid chemicals as cargo fall into two sub-types: small tankers (<50k DWT) and large tankers (>50k DWT). Small tankers generally carry non-persistent, refined oil products or chemicals, and large tankers generally carry persistent, unrefined crude oil. Large tankers typically move oil east from Alaska to U.S. refineries in Washington State, and tankers heading into Vancouver are en-route to pick up oil products for export. Small tankers call in several U.S. and Canadian ports. They frequently call at Vancouver, Prince Rupert, Kitimat, and, in some years, Nanaimo and Chemainus as well. Some tankers consistently trade on a regular basis between two or more ports and others are chartered to carry single loads of cargo to a particular terminal. Tankers travel in outside waters except when approaching a port.

Considering the cargo and fuel capacities combined, the average non-persistent oil capacity for small tankers in 2016 was 40,000 m^3 and the maximum was 58,000 m^3. The average persistent oil capacity for large tankers in 2016 was 125,000 m^3 and the maximum was 216,000 m^3. All tankers operating in Canada's Pacific region during the study period were registered in foreign countries.

LNG/LPG Carrier – LNG/LPG carriers are a special sub-type of tankers that transport compressed or cooled gaseous products. Currently, no LNG/LPG carriers call at Canada's Pacific ports but some travel through Canadian waters to deliver to ports in Washington State. These LNG/LPG carriers do not operate in a regular trade but are chartered to move cargo on an as-needed basis. LNG/LPG carriers travel in outside waters except when approaching a port. Most LNG/LPG carriers are fuelled by burning offgassed cargo, but also carry non-persistent oil to burn as fuel when necessary. All the LNG/LPG carriers operating in the area during the study period were registered in foreign countries.

4.2.3 Tug Vessels

Tugs are capable of a variety of tasks, such as assisting large ships to dock, moving logs floating in the water, handling anchors, or towing barges. This study is primarily interested in tugs that tow barges and are thus employed in commercial shipping. While they are generally much smaller than the ships, they often tow barges with large amounts of cargo, including bulk minerals or forest products, oil cargo, containerized cargo, and even ro-ro cargos of vehicles, trailers, or rail cars. Tugs are further broken into two sub-types: articulated tugs whose bows are rigidly connected to the stern of a barge to push the barge through the water; and conventional tugs that either tie alongside the barge or tow it on wires behind the tug. Tug/barge combinations call at every B.C. port and in other places not considered ports such as logging camps or mines. They provide a critical source of supply to isolated coastal communities not connected to the road system. Also, they transport forest and mineral products from their source to larger ports where they can be processed, shipped, or exported. Both types of tugs also transit through Canadian waters between ports in the States of Washington and Alaska. Some tugs operate in a regular trade between ports and others operate on an as-needed basis.

All tugs burn diesel fuel. The average fuel capacity for all tug types in 2016 is 190 m^3 and a maximum of 800 m^3. Oil barges associated with articulated tugs have an average cargo capacity of 26,000 m^3 and a maximum of 31,000 m^3. Oil barges associated with conventional tugs have an average cargo capacity of 7,000 m^3 and a maximum of 10,000 m^3. Most tugs operating on Canada's Pacific coast are flagged to Canada or the U.S.

4.2.4 Passenger Vessels

Cruise ships are the only sub-type of passenger vessel included in the study. Ferries were excluded because they are generally operated by the governmental organizations and travel consistent routes on a regular schedule.

Cruise Ship – Cruise ships carry tourists on vacation and are distinguished from ferries that carry passengers (and sometimes cars) as a mode of transportation. Cruise ships generally fall into two categories: deep draft vessels greater than 60 m in length that carry anywhere from several hundred to several thousand passengers on regular scheduled tours, and light draft vessels less than 60 m that carry fewer than 100 passengers on more customized cruises. Cruise ships make port calls in B.C. at Vancouver, Victoria, Nanaimo, and Prince Rupert while others pass through Canadian waters travelling between ports in Washington State and Alaska. Typically, cruise ships departing from Vancouver head north through the Inside Passage while cruise ships departing U.S. ports in Puget Sound head west through the SJDF, with many also calling at Victoria. Since the purpose of their trade is to show visitors the natural beauty of the coast, most cruise ships follow regular routes that are close to shore and in inside waters. Cruise ships generally operate from April to October, with a peak season of May to September.

The estimated average persistent oil capacity for cruise ships in 2016 was 2,400 m^3 and the maximum was 3,500 m^3. All of the cruise ships operating in Canada's Pacific region during the study period were registered in foreign countries.

4.3 Vessel Sizes

Vessel size can be expressed in multiple metrics including length, draft, width, and tonnage. This report uses two types of tonnage to characterize vessel size: deadweight tonnage (DWT) and gross tonnage (GT). DWT is a measurement of total mass of the contents of the vessel including the cargo, ballast, fuel, provisions, passengers, and crew. GT is a measure of the volume of the internal spaces that can hold the vessel's cargo.

4.3.1 Deadweight Tonnage

Table 6 presents the distribution of DWT across vessel sub-types with the exception of articulated tugs and conventional tugs, which often do not have a registered DWT because they do not generally carry cargo on board – they push or pull it.

At almost 270,000 DWT, the vessel capable of carrying the greatest weight is a bulk carrier. Overall, bulk carriers, large tankers (>50k DWT), and container ships have the greatest DWT of the vessels in the study with median values between 60,000 and 90,000 metric tonnes. LNG/LPG carriers, smaller tankers (<50k DWT) and other cargo vessels have median DWT values between 30,000 and 60,000 metric tonnes. Vehicle carriers and cruise ships have median DWT values of less than 20,000 metric tonnes.

Table 6. Comparison of Deadweight Tonnage Across Vessel Sub-Types (Excluding Tugs)

Vessel Type	Minimum	25th Percentile	50th Percentile (Median)	75th Percentile	Maximum	Number of Vessels
Bulk Carrier	6,077	48,724	62,803	81,119	266,651	3,472
Container Ship	5,945	63,216	73,674	103,647	185,070	664
Vehicle Carrier	8,546	16,578	18,795	21,066	48,988	36
Other Cargo	294	12,722	30,418	41,832	179,016	462
Tanker <50K DWT	4,999	22,180	40,727	47,149	49,999	288
Tanker >50K DWT	50,083	57,484	84,073	115,672	193,049	195
LNG/LPG Carrier	44,822	52,467	54,152	54,730	58,691	20
Cruise Ship	78	1,441	7,294	9,547	13,294	56

4.3.2 Gross Tonnage

Table 7 presents the distribution of GT across vessel sub-types. The greatest volume or GT of all the vessels in the study was a container ship with almost 180,000 GT. In contrast to DWT, the vessel types with the highest median values for GT are container ships and cruise ships with median values over

60,000 GT. Vehicle carriers, large tankers, LNG/LPG carriers, and bulk carriers in the study have median values between 30,000 and 60,000 GT. Other cargo and small tanker vessel types have median values less than 30,000 GT.

Table 7. Comparison of Gross Tonnage Across Vessel Sub-Types (Excluding Tugs)

Vessel Type	Minimum	25th Percentile	50th Percentile (Median)	75th Percentile	Maximum	Number of Vessels
Bulk Carrier	4,061	28,799	35,832	43,840	149,017	3,472
Container Ship	4,090	53,453	68,888	91,921	178,228	664
Vehicle Carrier	34,960	50,309	58,767	60,347	75,283	360
Other Cargo	349	9,627	21,344	29,729	92,924	462
Tanker <50K DWT	3,201	13,899	24,651	29,285	46,186	288
Tanker >50K DWT	28,465	31,285	49,974	62,331	110,693	196
LNG/LPG Carrier	35,012	46,021	46,973	48,042	48,963	20
Cruise Ship	94	10,980	65,803	90,303	138,194	56

4.4 Vessel Flag State Analysis

Commercial vessels in the study area during 2014-2016 were flagged to 65 different countries. More than a quarter of the vessels, primarily cargo ships, were flagged to Panama, which is by far the most common flag seen in the dataset as shown in Figure 8. Other common flag states include the Marshall Islands (673), Hong Kong (583), Liberia (516), and U.S. (389). Most of the Canadian-flagged vessels in the study are tugs (118). Only four non-tug cargo vessels in the study are flagged to Canada. Most of the U.S.-flagged vessels are also tugs (273). The presence of U.S.-flagged tankers, cargo ships, and passenger vessels in the study area is largely due to the U.S. requirement for vessels trading between U.S. ports to be constructed in and registered in the U.S.

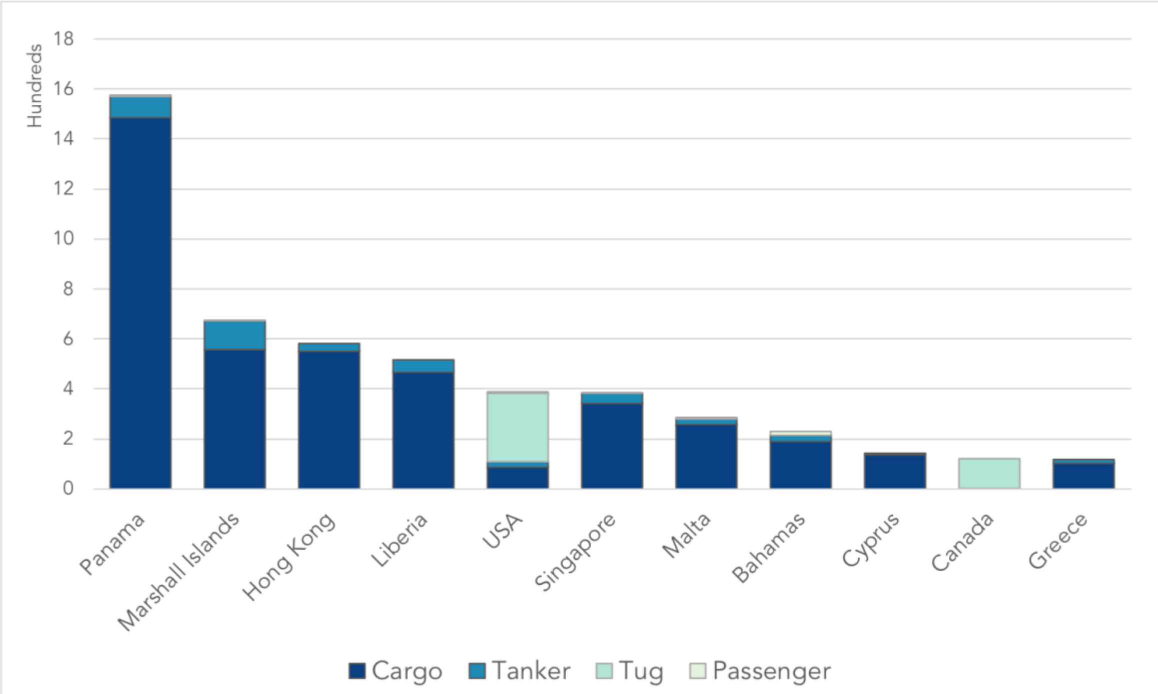


Figure 8. Flag State by Vessel Type (2014-2016) for countries with >100 vessels

4.5 Vessel Age Analysis

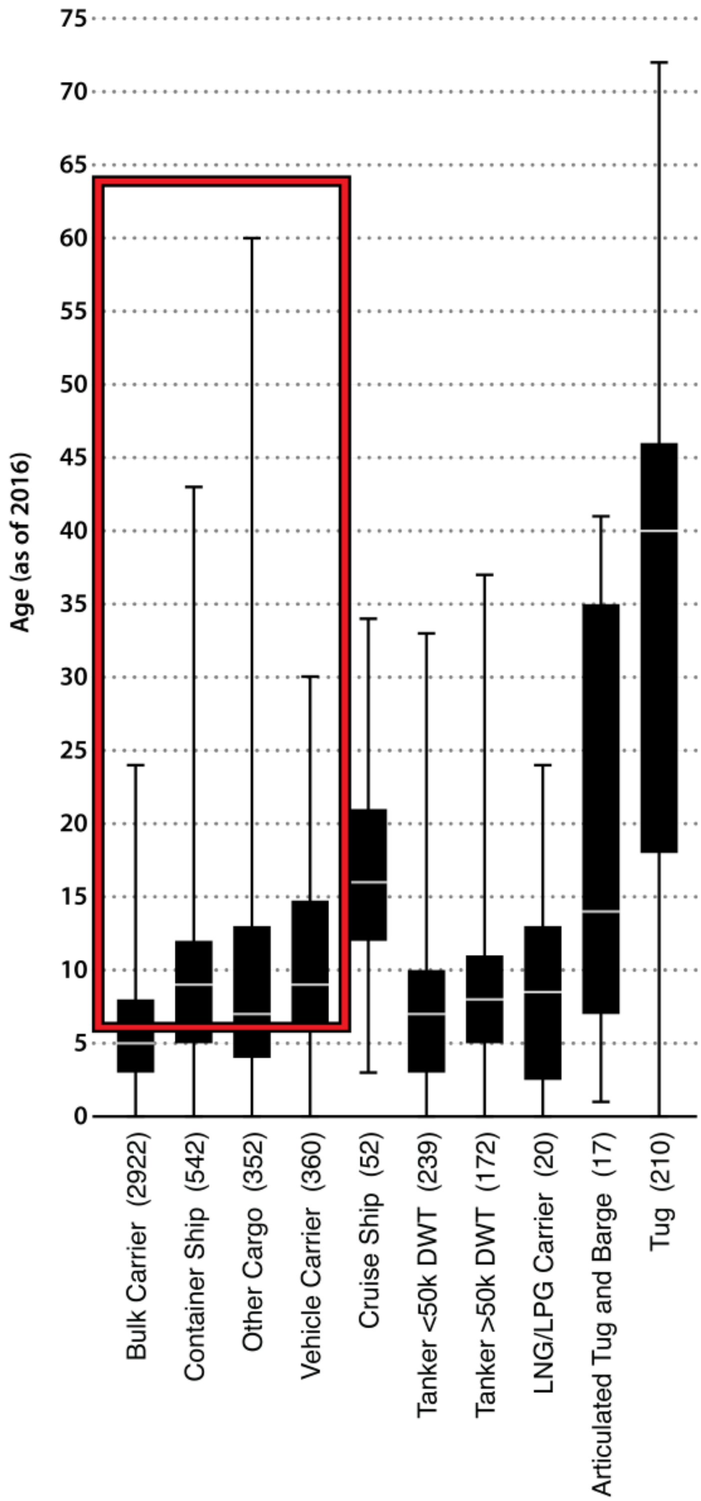
Vessel age was calculated as of 2016. Most vessels in the study have a median age well under 20 years, and all sub-types of cargo vessels and tankers had a median age under 10 years. Half of the conventional tugs, on the other hand, are at least 40 years old including some ranging from 50 to 70 years old. See Figure 9 and Table 8Table 8.

In the process of phasing in environmental and safety requirements, the IMO (and coastal state regulators) has linked many requirements to the dates after which ships are constructed. In particular, the IMO requires that ships with 600 m^3 fuel capacity and delivered after August 1, 2010 must have a double wall of protection around their fuel tanks (MARPOL Annex 1 regulation 12A). This applies to all ships, but since tankers were already required to have double hulls as of 2010, Regulation 12A is particularly relevant to cargo vessels.

Since Figure 9 below shows age as of 2016, the fuel tank requirement will apply to vessels six years old or less in this table. The figure does not show actual date of delivery, only year, so there are likely some vessels delivered before August in 2010 to which the fuel tank protection requirement would not apply. Bulk carriers stand out here because, based on their relative “newness”, more than half of them would be required to have the fuel tank protection. Otherwise, based on age only, a small percentage of non-tanker ships are currently required to have double hulled fuel tanks.

Table 8. Comparison of Vessel Age Across Vessel Sub-Types

Vessel Type	Minimum	25th Percentile	50th Percentile (Median)	75th Percentile	Maximum	Number of Vessels
Bulk Carrier	-	3	5	8	24	2,922
Container Ship	-	5	9	12	43	542
Vehicle Carrier	-	6	9	14	30	360
Other Cargo	-	4	7	13	60	352
Tanker <50K DWT	-	3	7	10	33	239
Tanker >50K DWT	-	5	8	11	37	172
LNG/LPG Carrier	-	3	9	13	24	20
Articulated Tug	1	7	14	35	41	17
Tug	-	18	40	46	72	210
Cruise Ship	3	12	16	21	34	52



Vessels within the 'red box' are affected by the 2010 IMO fuel tank regulations.

IMO Regulation: Vessels with 600 m^3 fuel capacity that appear below the red line are required to meet MARPOL Annex 1 regulation 12A to have double-walled fuel tanks. Vessels appearing above the red line are not required to have double-walled fuel tanks.

This regulation for increased safety applies to many of the vessels trading along Canada's Pacific Coast as approximately half of the bulk carriers (the sub-type containing the majority of ships) are less than six years old.

Figure 9. Comparison of Vessel Age Across Vessel Sub-Types

5.0 Commercial Vessel Traffic Characterization

5.1 Overview of Typical Routes

The typical routes taken by ships transiting Canada's Pacific region are depicted in Figure 10 and are described in this section. The majority of deep draft commercial vessels travelling through Canada's Pacific waters are heading to and from ports in the Salish Sea and thus transit through the Strait of Juan de Fuca. Many deep draft commercial vessels calling at Canadian ports are trading to and from Asia, typically following a great circle route as the shortest distance from Asia to North America. Some vessels will head along such a route shortly after clearing the coast, while others will proceed directly west or even southwest in some cases - the shortest distance out of the ECA - before turning on their route to Asia.

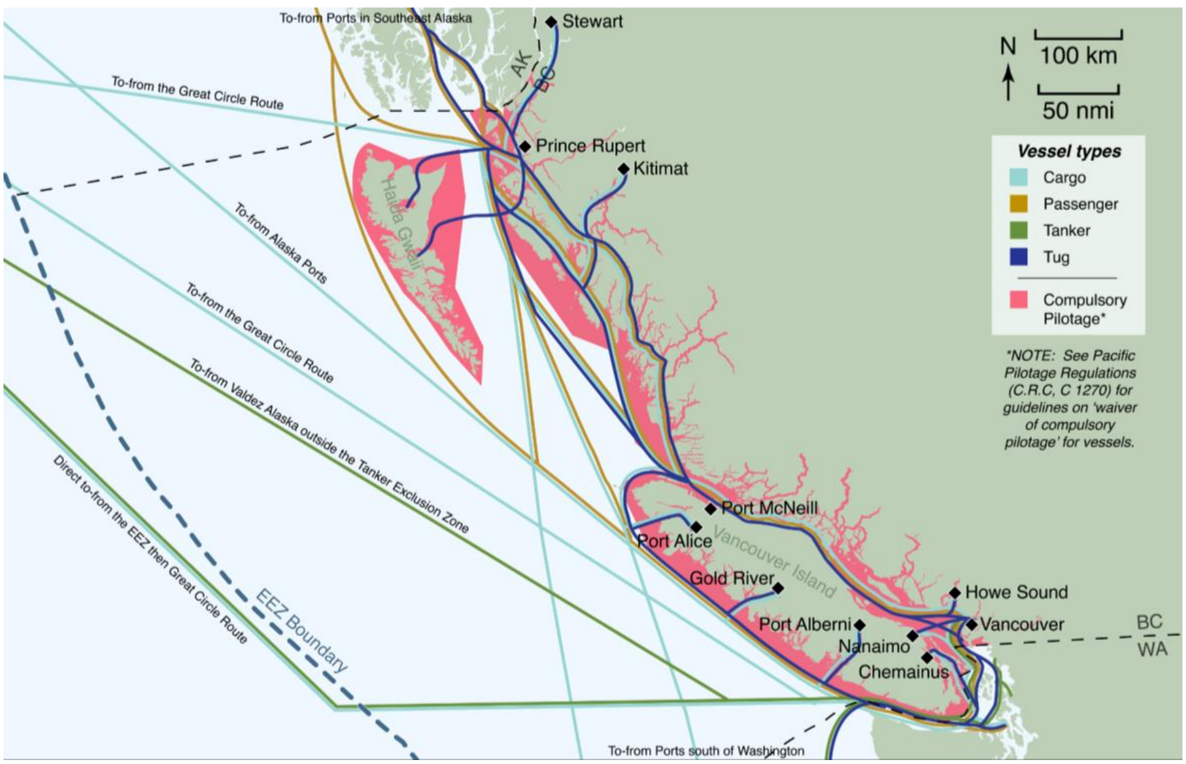


Figure 10. Typical Vessel Routes

Another typical route is followed by crude oil tankers trading from Valdez, Alaska to refineries in western Washington State and those involved in the export of Canadian crude. The typical tanker involved in both of these routes is the large Aframax tanker. Tankers entering or leaving SJDF typically stay outside the voluntary Tanker Exclusion Zone when coming to and from Prince William Sound. Tankers returning from Alaska follow a reciprocal course. Other deep draft vessels travelling to Alaskan ports in Prince William Sound, Cook Inlet, or Kodiak Island will take a more direct route across the North Pacific and Gulf of Alaska. Of these large tankers entering and exiting the SJDF, approximately 83% are destined for U.S. refineries and 15% are headed to pick up oil for export from the Port of Vancouver.

Approximately 2% travel to both Canada and U.S. ports. See Section 5.8 (and Table 11) for additional details and discussion on analysis specific to the SJDF.

Deep draft vessels calling at Prince Rupert or Kitimat also follow the great circle routes from Asia but make landfall at Dixon Entrance. Ships travelling south from Prince Rupert or Kitimat will often transit Hecate Strait and Queen Charlotte Sound and either follow the coast to enter the SJDF or go offshore to reach ports in the U.S. or the Panama Canal.

The Inside Passage is a typical route for tugs, cruise ships, and smaller cargo vessels. Many tugs and cruise ships travelling from Washington State to Alaska take the Inside Passage. Likewise, many vessels trading between Canadian Pacific ports utilize the Inside Passage for its protection from weather and seas. There are several variations of these of international and domestic trade routes.

Some ships use the Direct to/from the EEZ from Great Circle Route to minimise the time spent in Canada’s ECA. The number of ships using this route increased in 2015 with the implementation of a 0.1% cap on the level of sulphur in fuel to be burnt within the ECA. Using this alternative route minimises the amount of expensive ultra-low sulphur fuel the ships have to burn. The route also takes vessels on a longer route, further from shore.

5.2 Vessel Traffic Density

Vessel density maps are useful for understanding where – and in what numbers – vessels transit. The maps are coloured in a scale that indicates the amount of traffic that transited through each point on the map from 2014-2016. Figure 11 depicts the vessel density resulting from all vessels tracked in the study for the three-year period. Figure 12 through Figure 21 on the following pages show the vessel traffic density for each sub-type of vessel in the study. The density scale used in these figures is the average number of vessels in a grid cell at any given time, i.e. the average number of vessels that occupy a 100 square nautical miles, 10 nautical miles by 10 nautical miles, at any point in time. The darker the color, the higher the density.

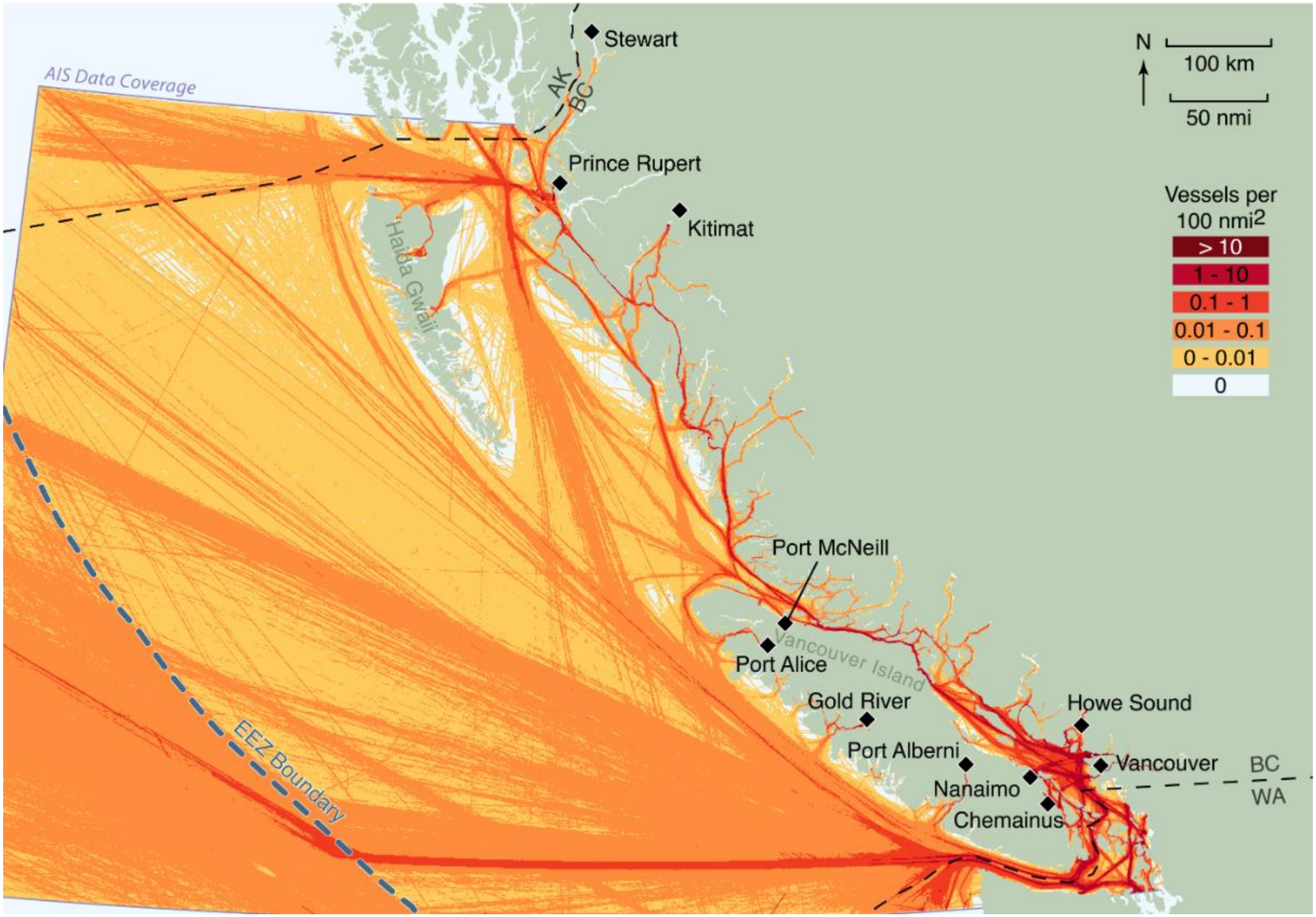


Figure 11. Vessel Traffic Density Map – All Vessels (2014 – 2016)

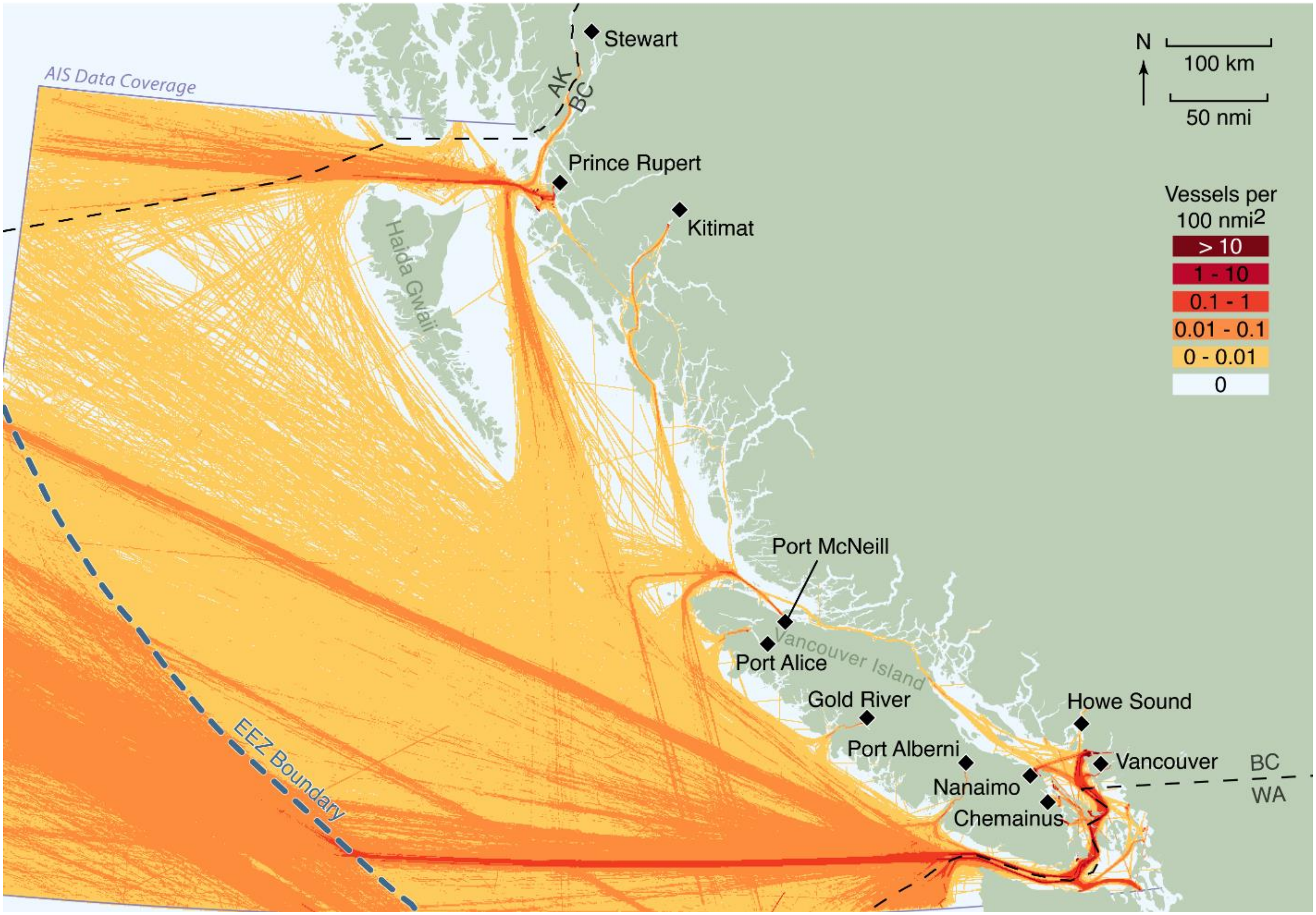


Figure 12. Vessel Traffic Density Map – Bulk Carrier (2014-2016)

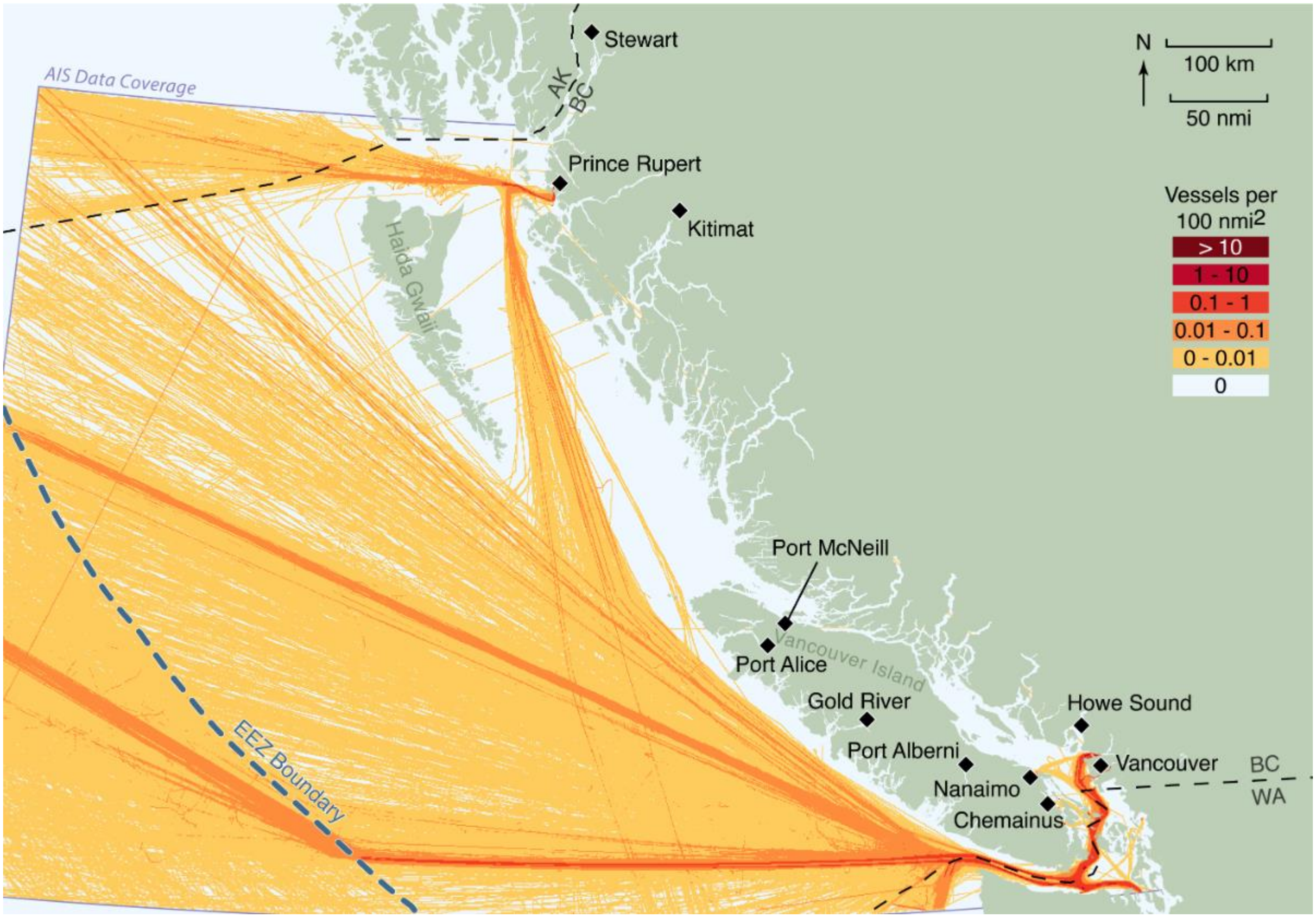


Figure 13. Vessel Traffic Density Map – Container Ship (2014-2016)

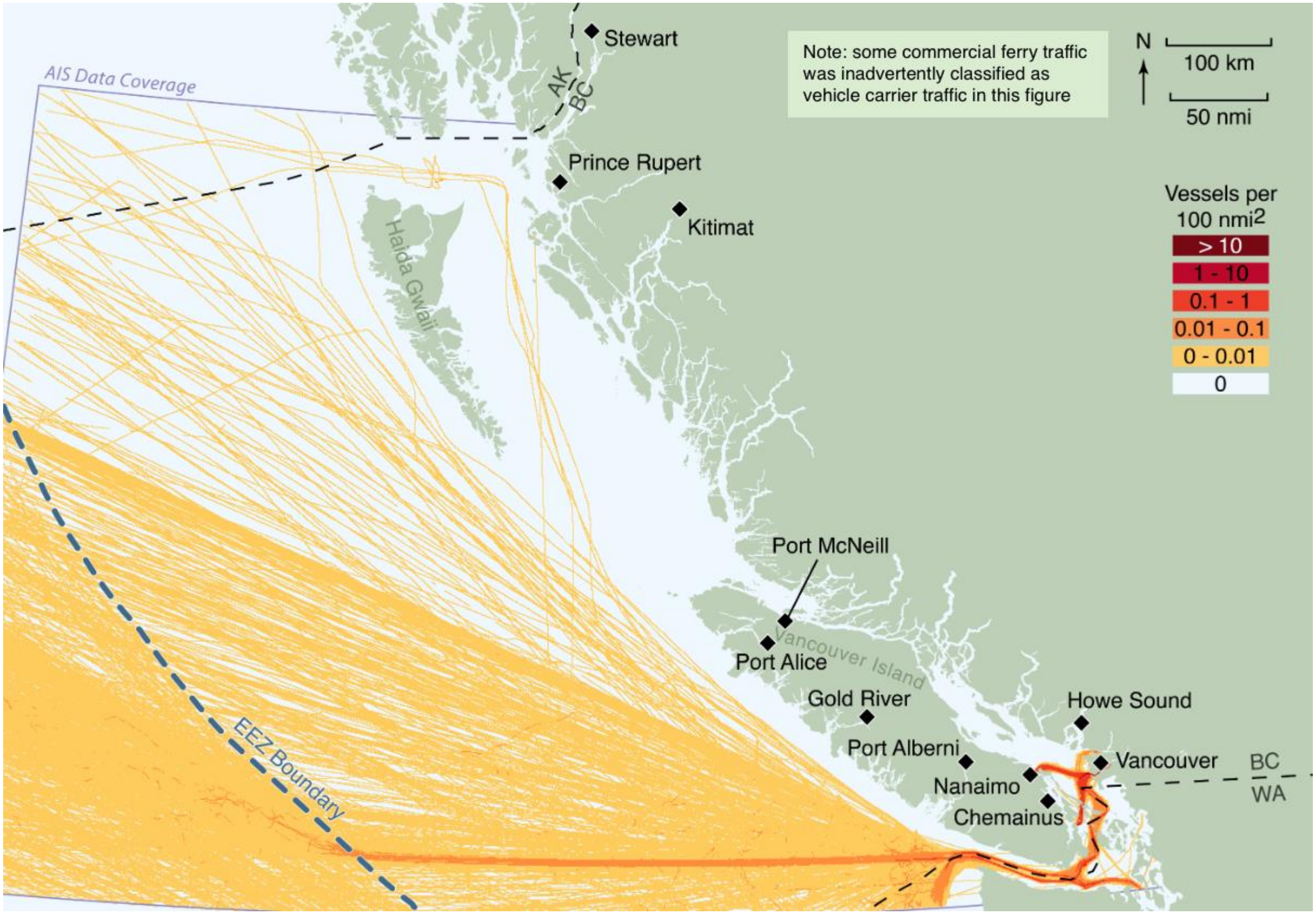


Figure 14. Vessel Traffic Density Map – Vehicle Carrier (2014-2016)

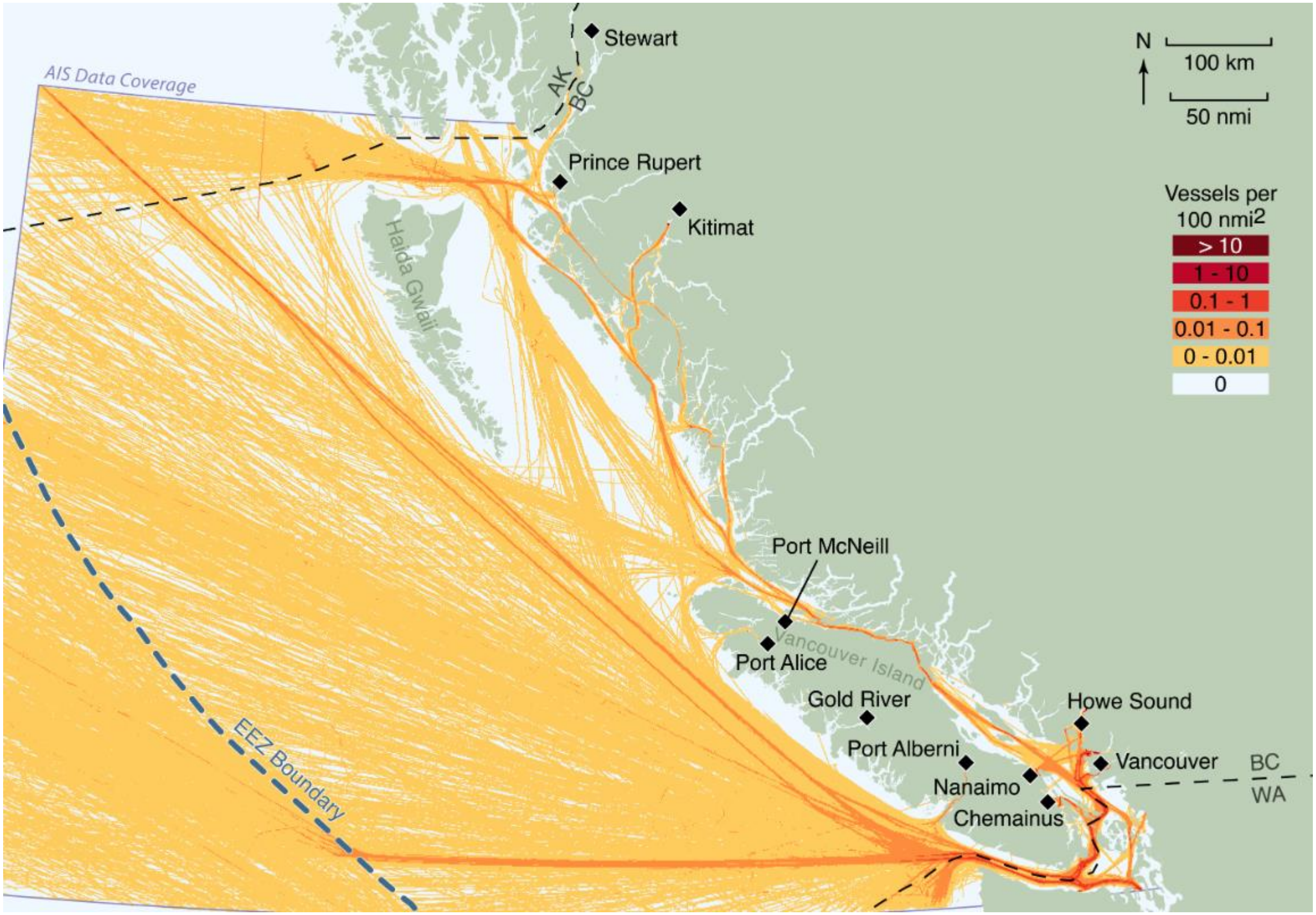


Figure 15. Vessel Traffic Density Map – Other Cargo (2014-2016)

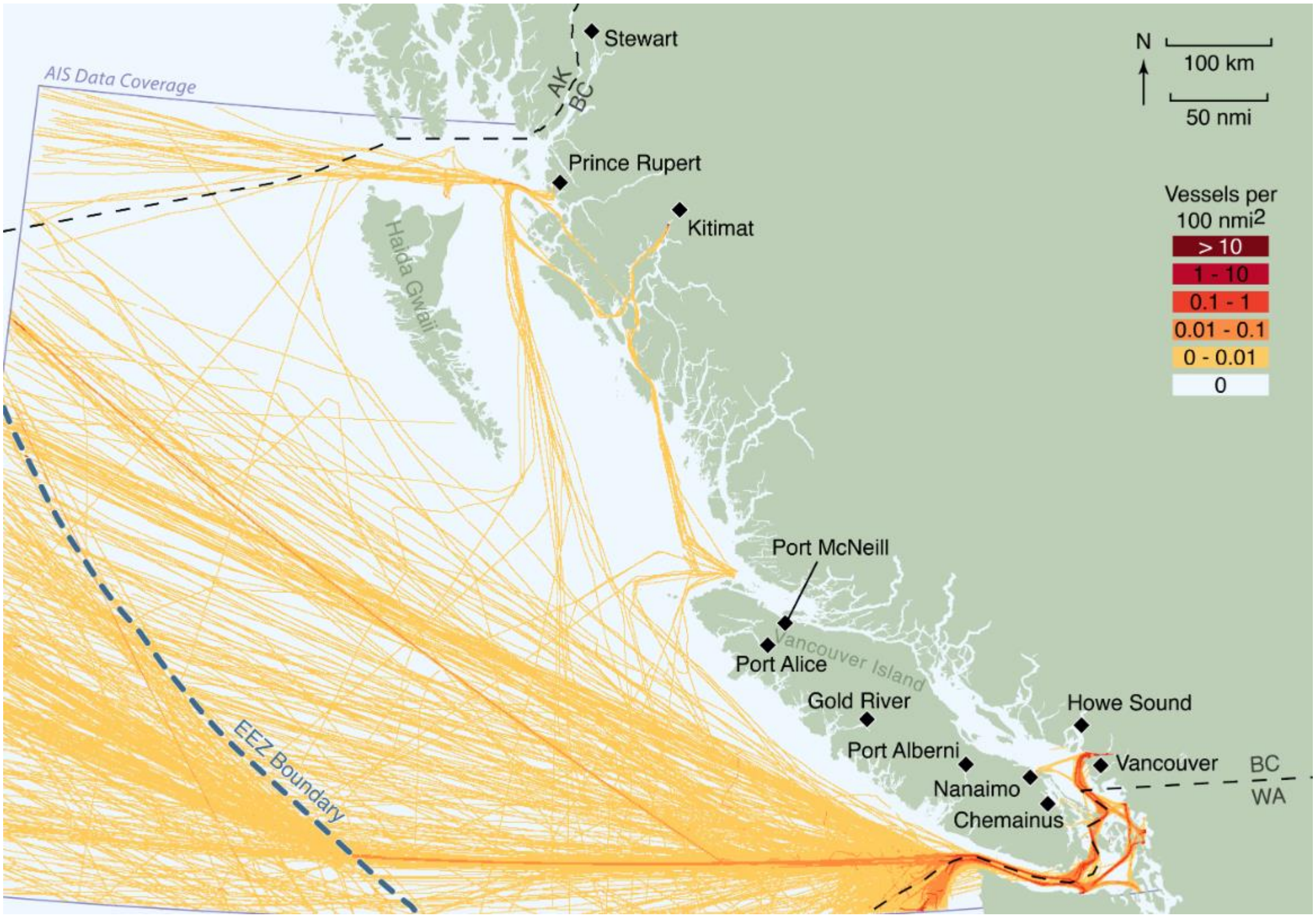


Figure 16. Vessel Traffic Density Map – Tanker <50k DWT (2014-2016)

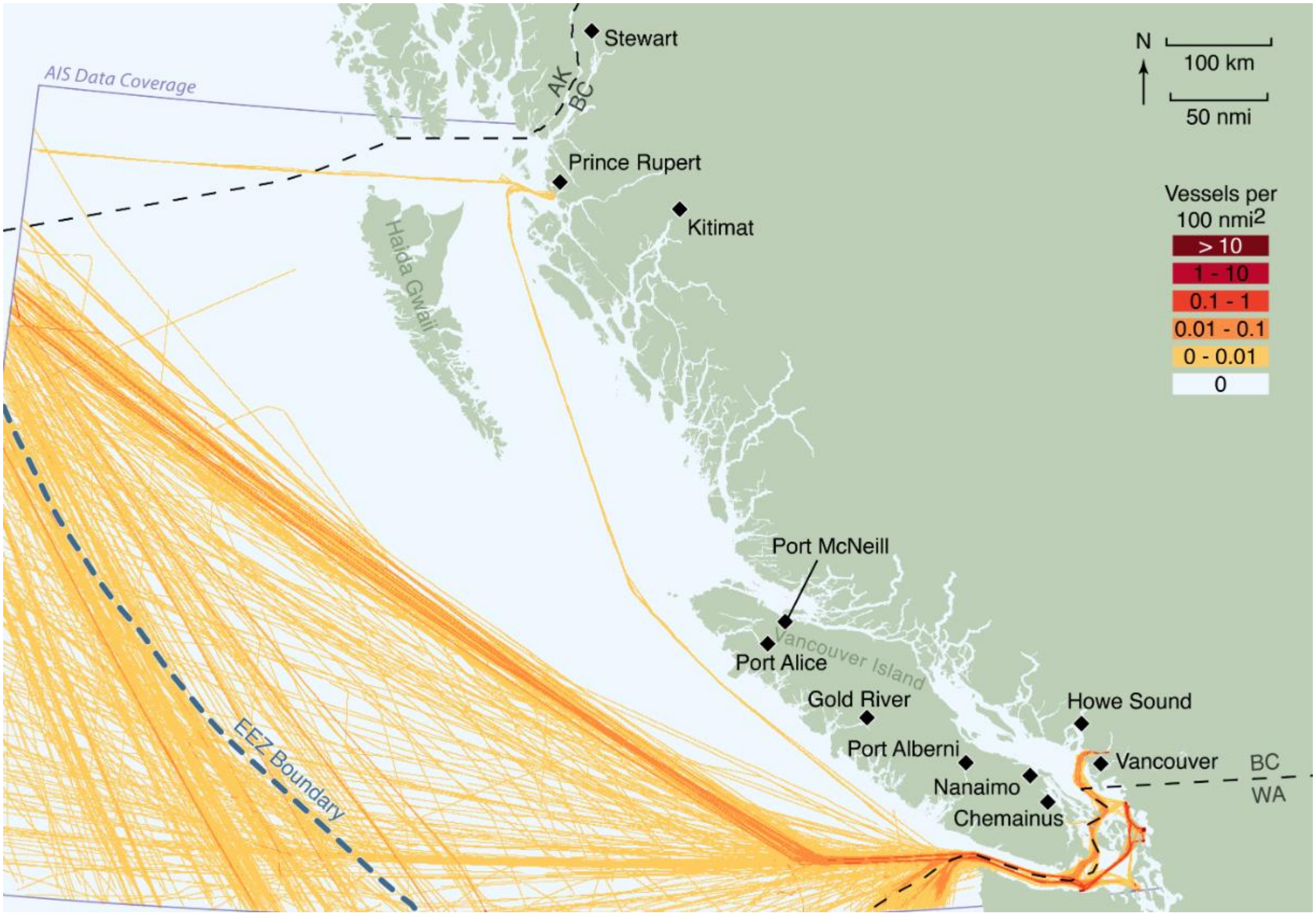


Figure 17. Vessel Traffic Density Map – Tanker >50k DWT (2014-2016)

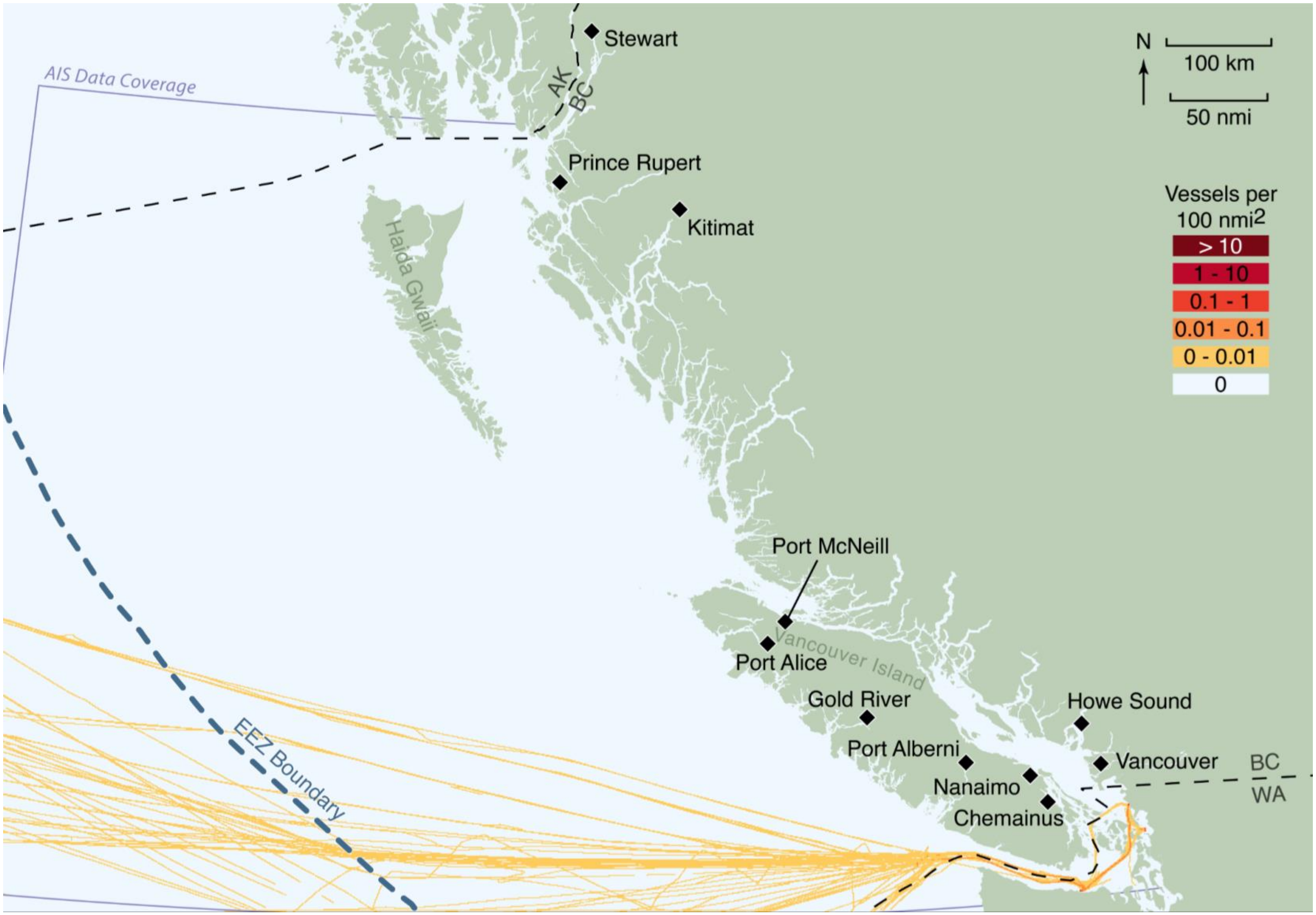


Figure 18. Vessel Traffic Density Map – LNG/LPG Carriers (2014-2016)

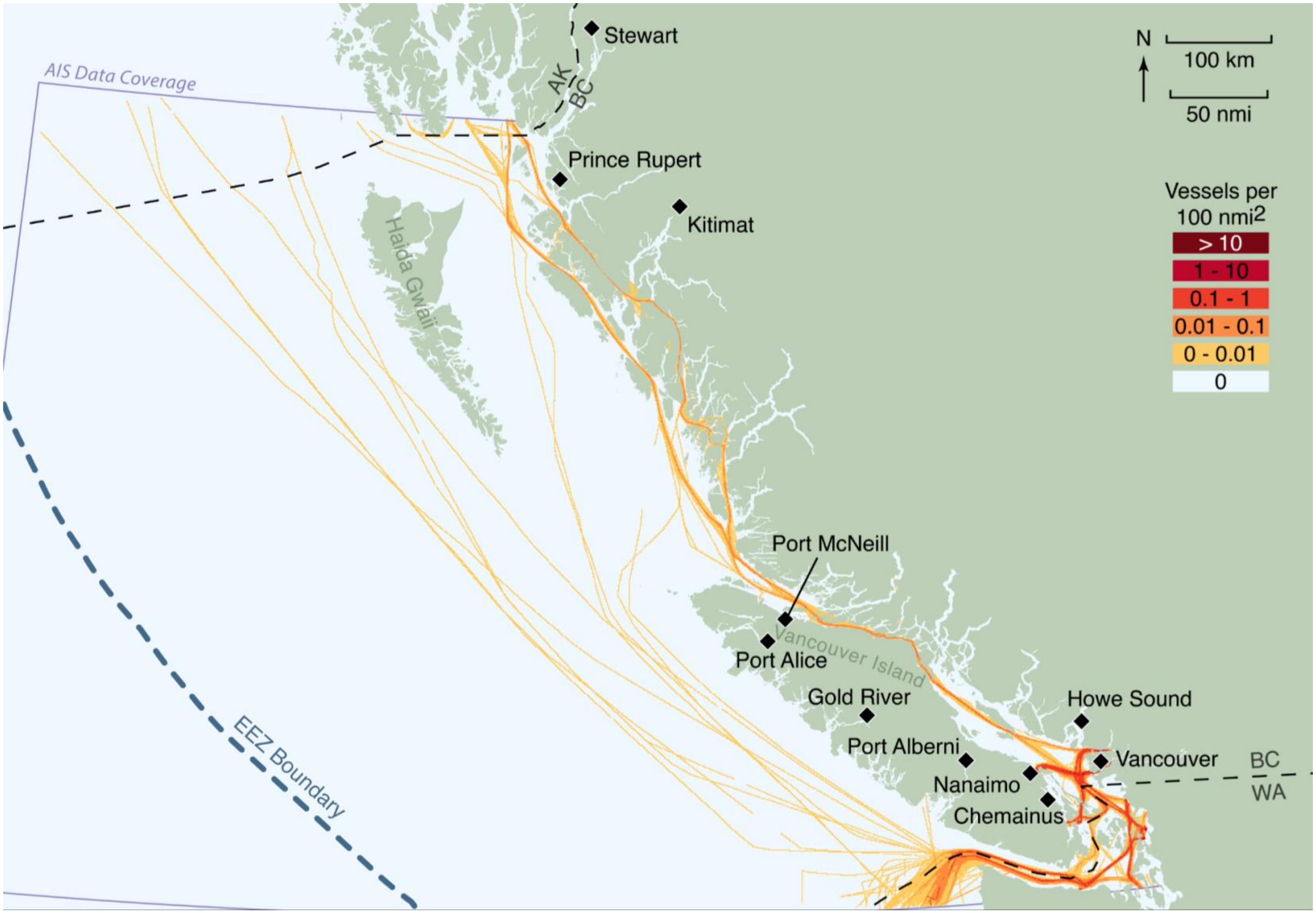


Figure 19. Vessel Traffic Density Map – Articulated Tug (2014-2016)

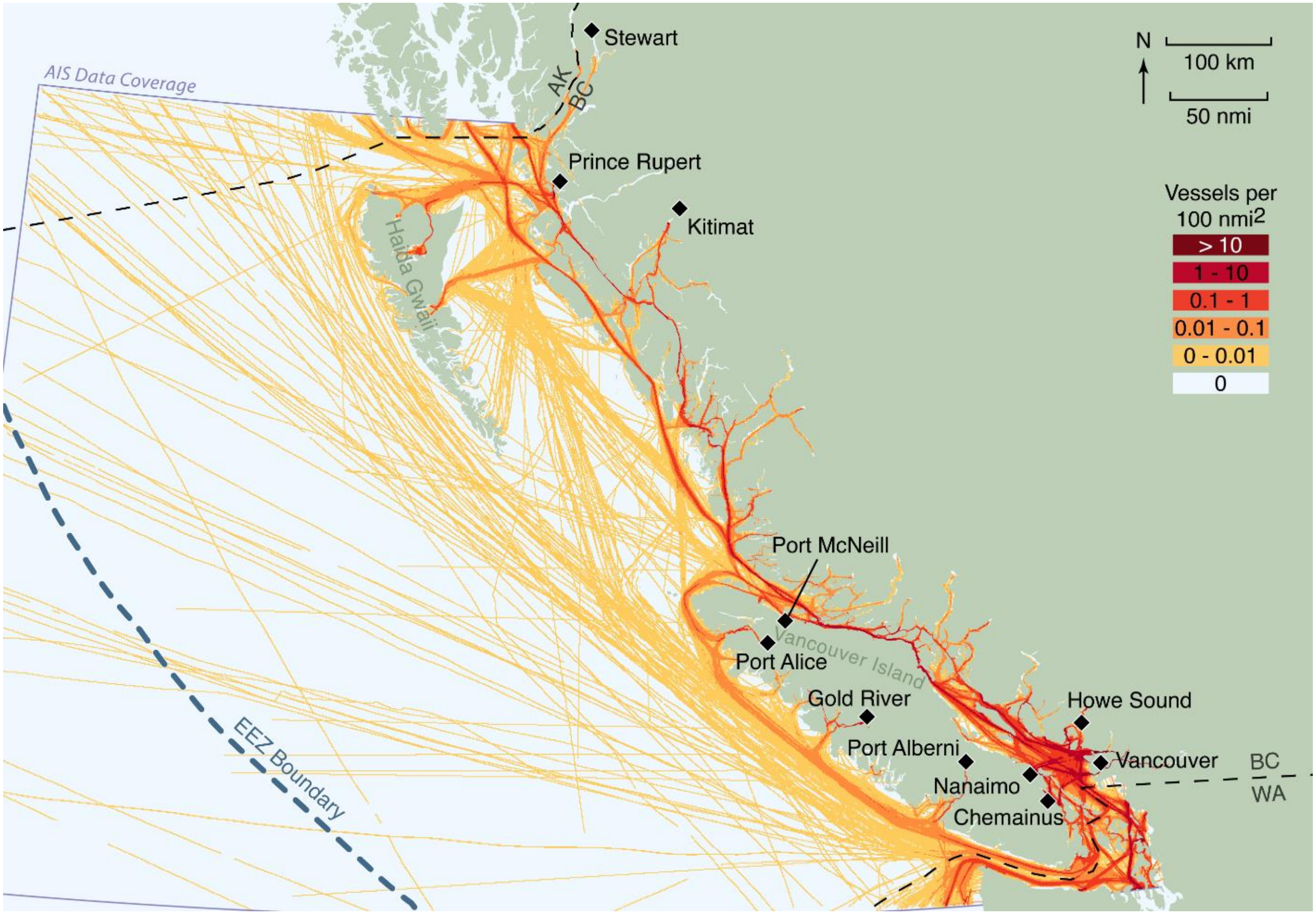


Figure 20. Vessel Traffic Density Map – Tug (2014-2016)

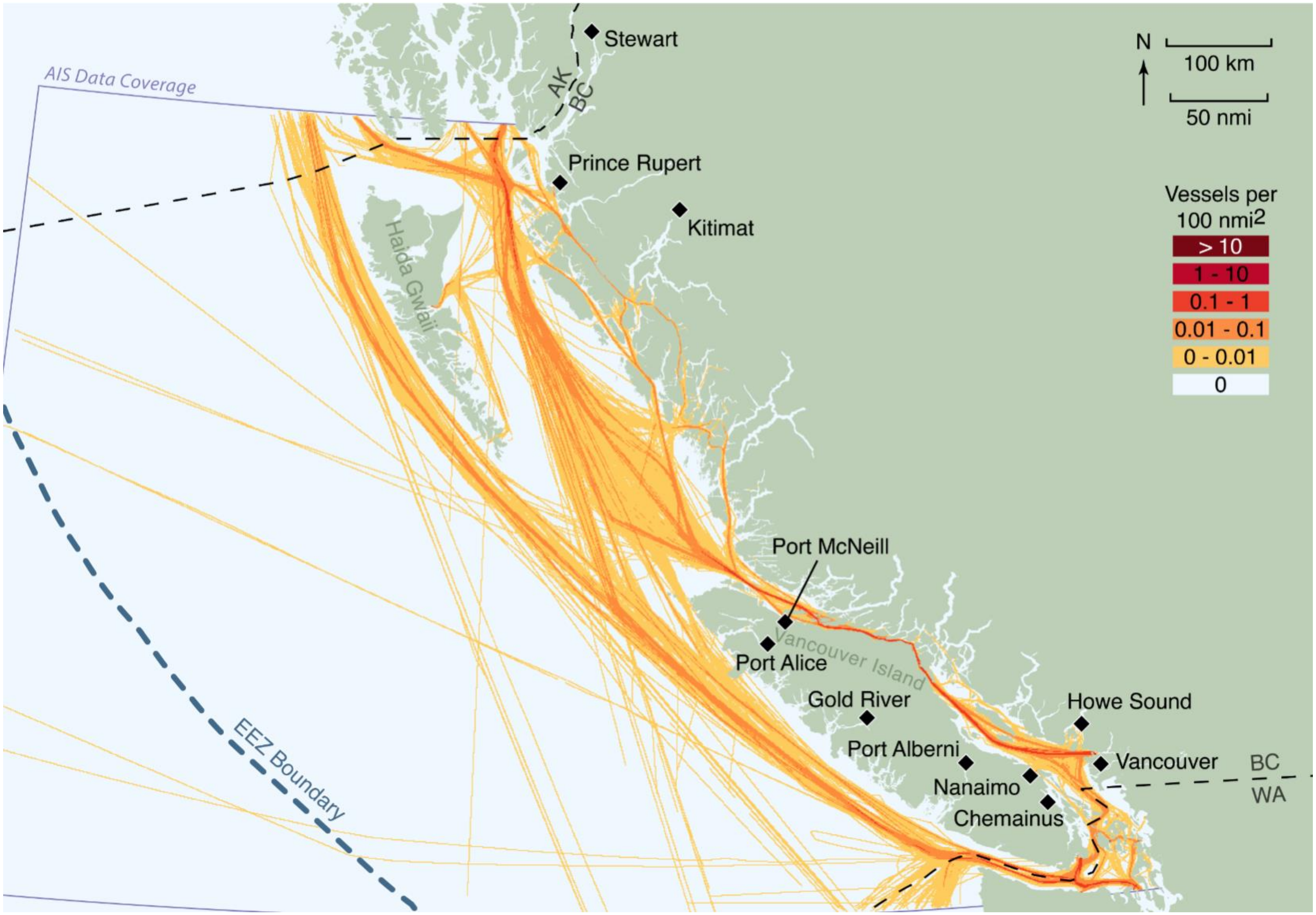


Figure 21. Vessel Traffic Density Map – Cruise Ship (2014-2016)

5.3 Ports Activity

Figure 22 and Table 9 show the average annual number of port calls by vessel type for each of the principal ports. The Port of Vancouver accounts for 65% of the total port calls of all vessels in the study. In terms of number of calls, the Port of Vancouver had an average of 12,042 port calls while the other ten ports combined had 6,438. Port calls by year and sub-type for each port are additionally shown in Appendix B. The most common vessel types that call on the Port of Vancouver are tugs (estimated annual average of 8,889) and cargo ships (estimated annual average of 2,697).

Nanaimo ranks second among ports overall for port calls and vessel activity when tugs are included; however, Prince Rupert handles significant container and cargo volumes, second only to the Port of Vancouver in these areas. Chemainus, Howe Sound, and Prince Rupert come in third, fourth, and fifth respectively overall for port calls. Howe Sound and Chemainus are dominated by tugs calls (1,060 and 1,090 respectively) while Prince Rupert receives almost half of its port calls from deep draft vessels.

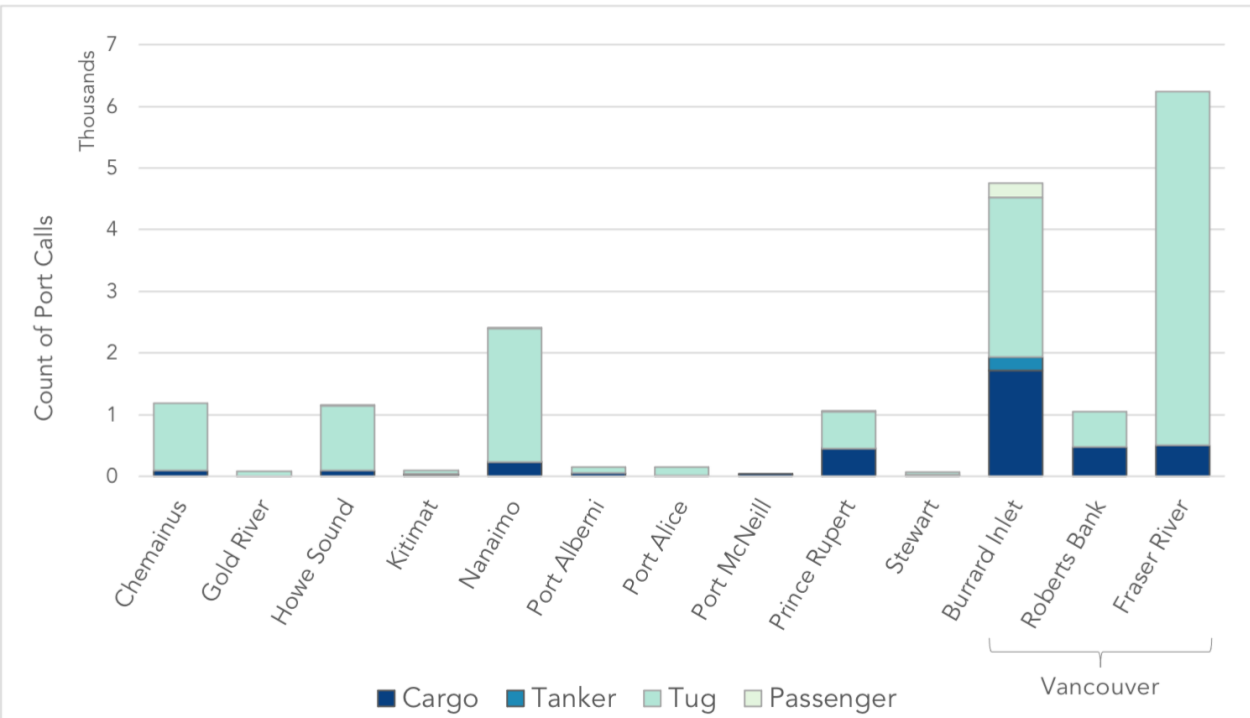


Figure 22. Average Annual Port Calls for All Vessels at Ports Included in Analysis (2014-2016)

Table 9. Average Port Calls for All Vessels at Ports Included in Analysis (2014-2016)

Ports	Average Annual Port Calls (2014-2016)				
	Cargo	Passenger	Tanker	Tug	All Vessels
Chemainus	101	-	-	1,090	1,191
Gold River	10	-	-	82	93
Howe Sound	95	2	-	1,060	1,157
Kitimat	36	-	5	56	97
Nanaimo	230	6	2	2,165	2,403
Port Alberni	63	-	-	97	160
Port Alice	15	-	-	139	154
Port McNeill	43	-	-	-	43
Prince Rupert	450	11	6	595	1,062
Stewart	31	-	-	48	79
Vancouver	2,697	229	228	8,889	12,042
Burrard Inlet	1,714	229	228	2,582	4,753
Roberts Bank	478	-	-	569	1,047
Fraser River	505	-	-	5,738	6,243

5.4 Passage Line Crossings

Passage line crossings for the three years in the study range from more than 12,000/year at the South Strait of Georgia (SSG) to fewer than 1,000/year at Dixon Entrance. The numbers for each passage line presented in Figure 23 reflect crossings in both directions cumulatively.

To better understand vessel traffic in the heavily trafficked Southern region of the project area (passage lines: SJDF, SSG, and ESS) the annual vessel traffic patterns were analyzed. The SJDF had 8,109 vessel transits (in either direction) by deep draft ships (excluding tugs), while the SSG had 7,014 vessel transits, and the East Salish Sea (ESS) 4,736 vessel transits.

Tugs are the dominant vessel type crossing the passage lines across the Inside Passage. On average, 5,572 tug one-way transits cross the South Strait of Georgia annually; an average of 4,213 vessels cross the North Strait of Georgia; on average, 1,530 vessels cross Queen Charlotte Strait; 1,094 cross Hecate Strait (including the Northern Inside Passage), and more than 733 cross the Alaska Inside Passage line. Many of the 733 tugs that cross to and from Alaska continue through Canadian waters to the State of Washington or vice versa. The remainder of the tugs crossing these passage lines are presumed to be trading in Canadian ports.

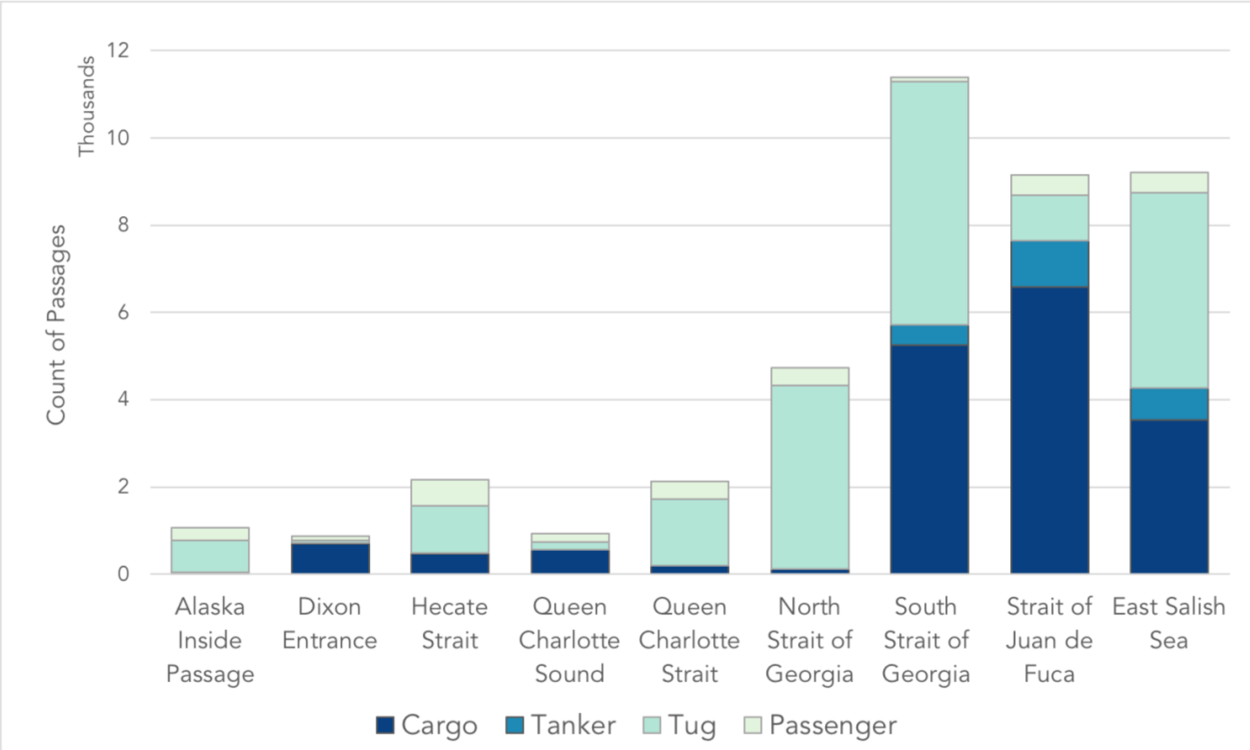


Figure 23. Average Annual Passage Line Crossings (2014-2016)

Table 10. Average Annual Passages of All Vessel Types (2014-2016)

Passage Line	Average Annual Passages (2014-2016)				
	Cargo	Passenger	Tanker	Tug	All
Alaska Inside Passage	35	295	-	733	1,062
Dixon Entrance	696	109	13	60	879
Hecate Strait	466	583	12	1,094	2,155
Queen Charlotte Sound	557	195	11	158	921
Queen Charlotte Strait	193	401	-	1,530	2,124
North Strait of Georgia	121	404	-	4,213	4,738
South Strait of Georgia	5,259	105	455	5,572	11,390
Strait of Juan de Fuca	6,576	458	1,074	1,039	9,148
East Salish Sea	3,537	467	731	4472	9,208

5.5 Analysis of U.S. Traffic Passing Through Canadian Waters

Individual tracks were examined for four specific months in 2016 representing different seasons to provide a deeper understanding of the patterns of traffic for vessels originating or terminating at U.S. ports that pass through Canadian waters. Traffic was split into two categories:

- U.S. Alaska traffic (between Alaska and Washington) – labeled as **US – AK** in the diagrams below
- Other U.S. traffic (primarily between U.S. and Asia) – Labeled as **Innocent Passage** in the diagrams below

These categories were analysed for the four major vessel types: Cargo, Tanker, Tug and Passenger.

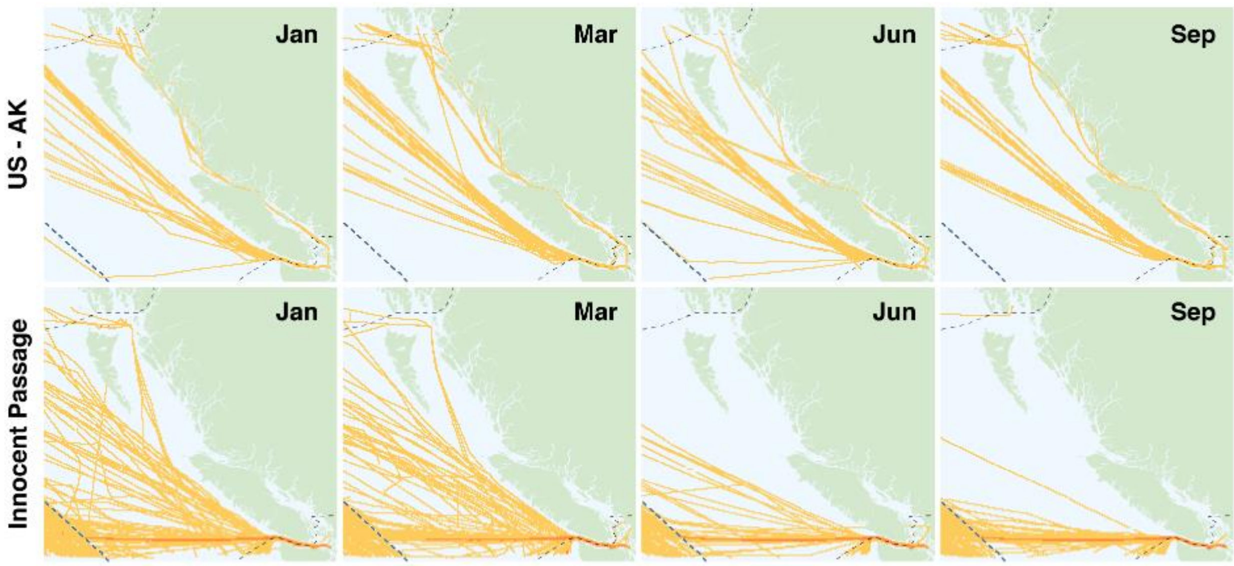


Figure 24. U.S. Traffic for January, March, June, and September 2016 – Cargo Vessels

In all four months sampled, some Alaska-bound cargo vessels used the route east of Vancouver Island via Johnstone Strait and Discovery Passage to reach their destinations while others followed the offshore route as shown in Figure 24.

Interestingly, U.S. Asia traffic exhibits stronger seasonal variation. Some vessels appear to take a more northerly track and sometimes use Hecate Strait and Dixon Entrance in the winter and spring months, possibly for storm avoidance. In the summer and fall they generally proceed directly to the EEZ before turning towards Asia.

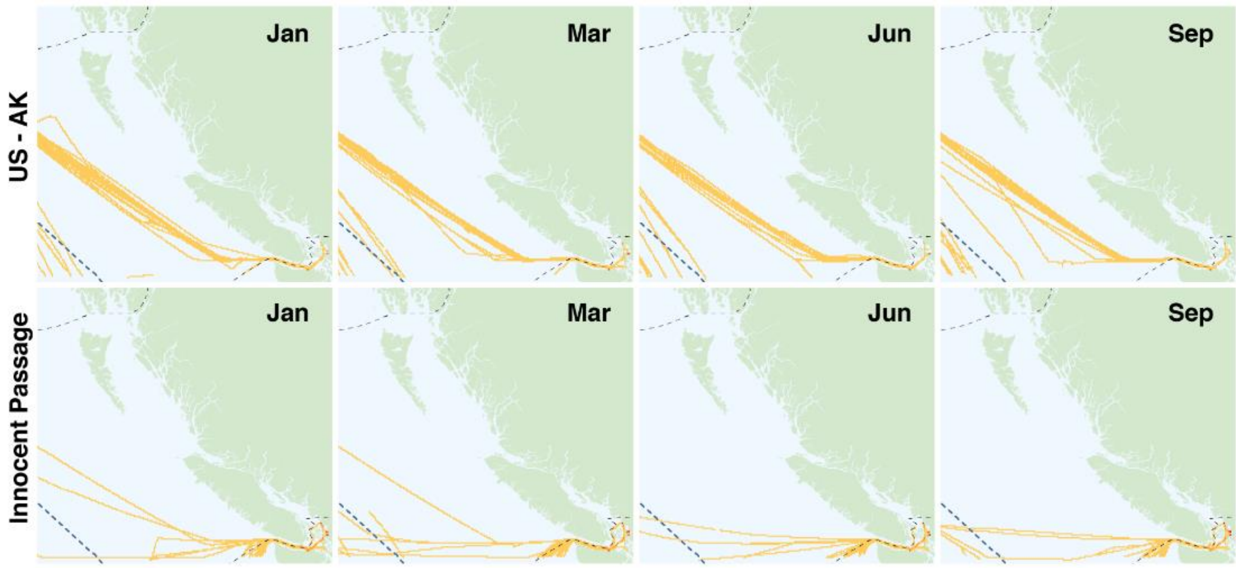


Figure 25. U.S. Traffic for January, March, June, and September 2016 – Tankers

Tankers, as shown in Figure 25, do not show much variation seasonally. Tankers moving to or from Alaska through Canadian waters stay outside of the voluntary Tanker Exclusion Zone. Most of the other tankers en route to Asia on a great circle route move directly to the edge of the EEZ before turning north on their way to Asia. In a few cases, a tanker stayed within Canadian waters longer.

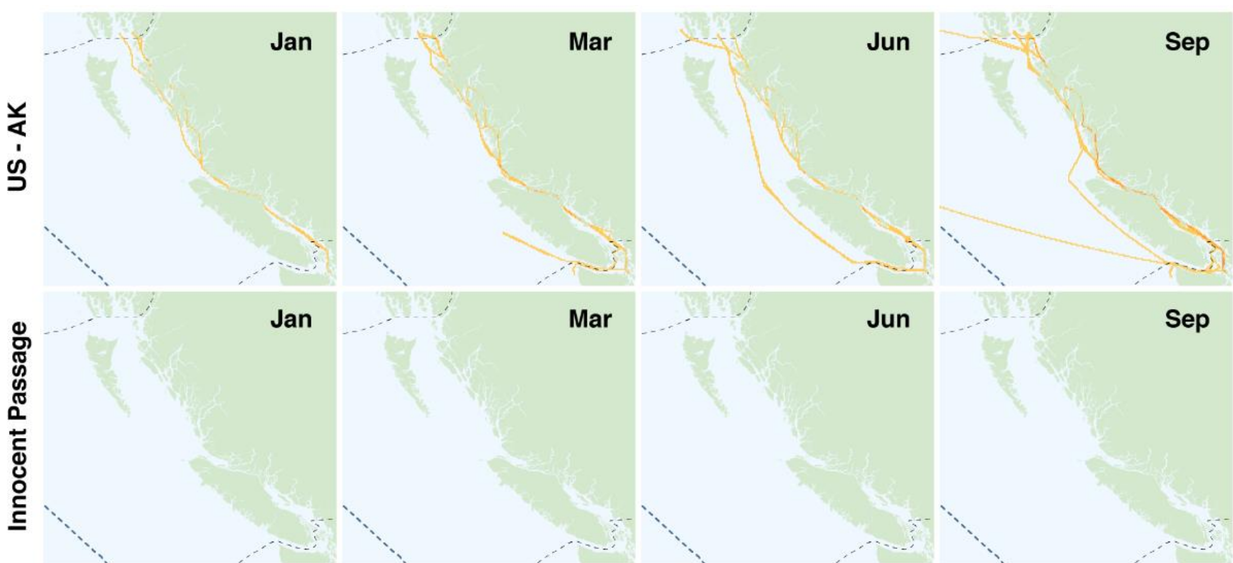


Figure 26. U.S. Traffic for January, March, June, and September 2016 – Tugs

Tugs that move to and from Alaska in innocent passage use both inside and offshore waters, tending to stay in the more protected waters in the winter months as shown in Figure 26. No tugs are engaged in U.S. Asia trade.

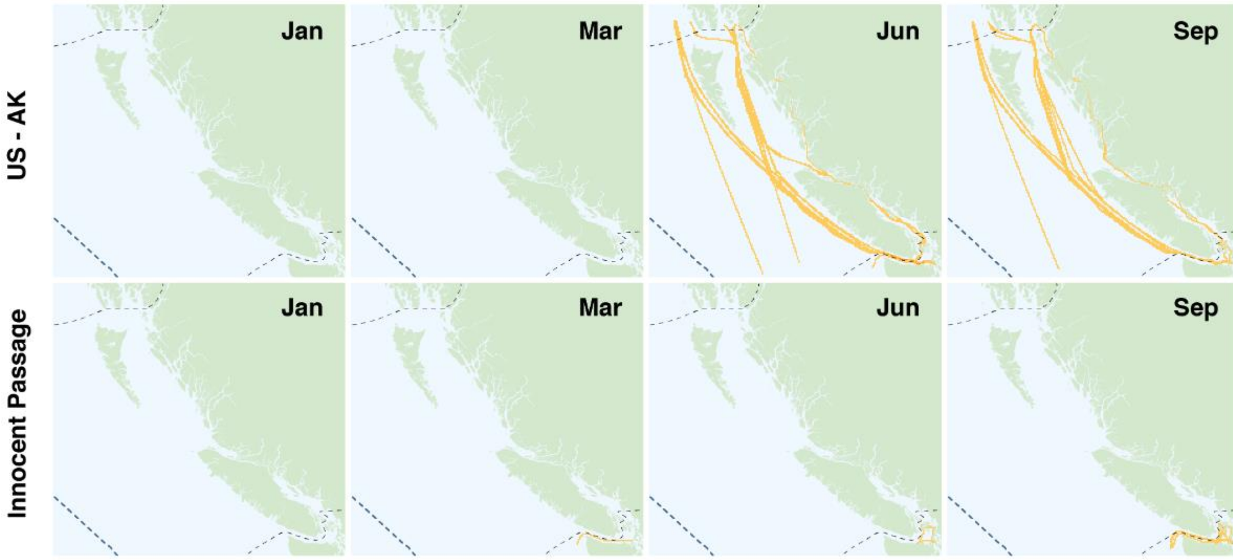


Figure 27. U.S. Traffic for January, March, June and September 2016 – Cruise Ships

Cruise ships are only active during the cruising season of the summer and early fall as can be seen from Figure 27.

5.6 Variations by Year

Figure 28 shows vessel traffic density by vessel type for each of the three years in the study period. Overall patterns appear similar across the three years for the passenger (cruise ship), tanker, and tug vessel types.

Cargo vessel movements changed in 2015. In contrast to 2014, cargo vessels moving in and out of the Strait of Juan de Fuca in 2015 and 2016 became more likely to use a direct route between the EEZ and the entrance to the SJDF. As mentioned in Section 5.1, this is likely due to the IMO-designated ECA (MARPOL Annex VI). It appears likely that those vessels on trans-Pacific routes (not going straight north to Alaska) became more likely to take the most direct route out of the ECA beginning in 2015 as compared to 2014.

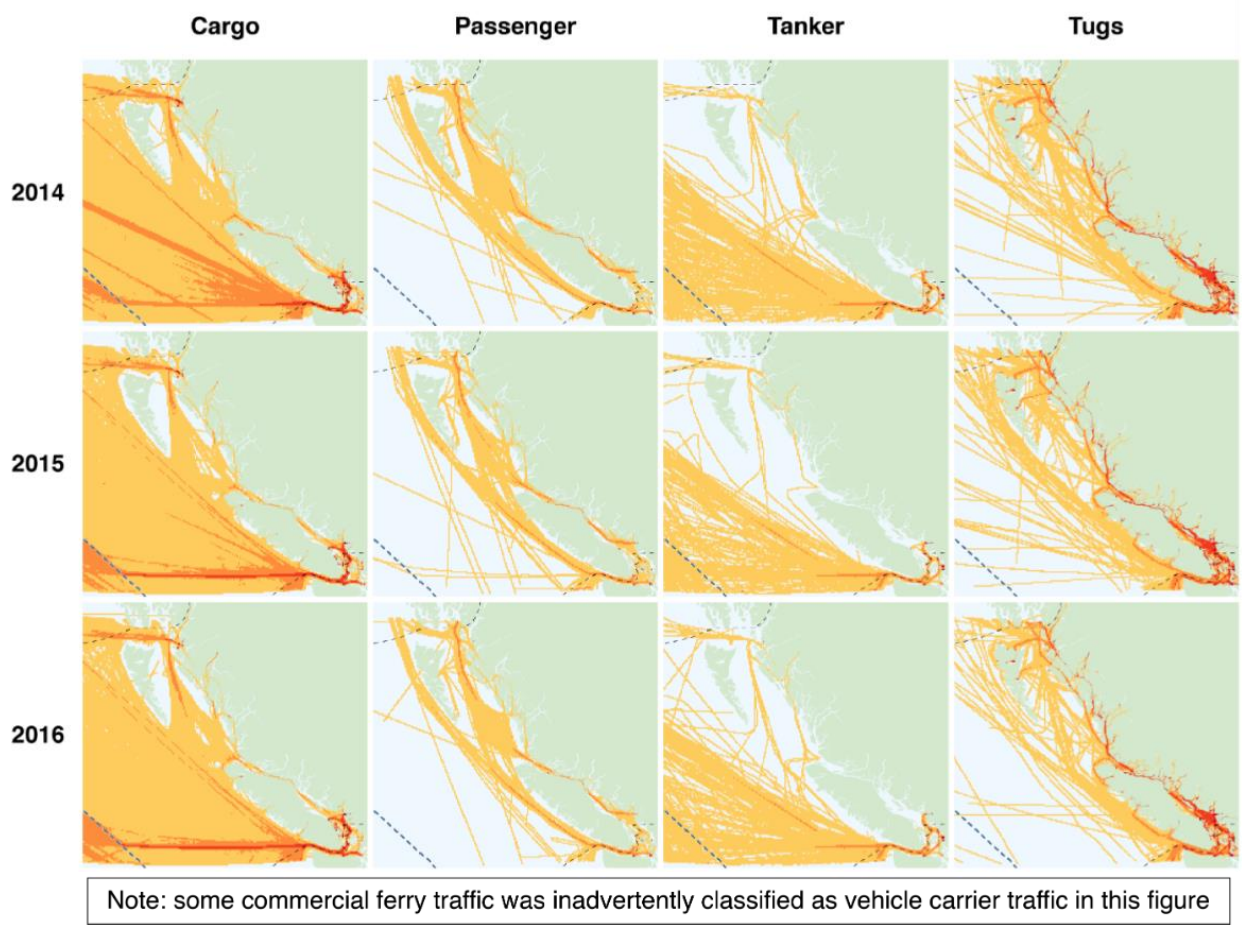


Figure 28. Vessel Density by Vessel Type and Year (2014-2016)

5.7 Variations by Month

Vessel movements by month are shown for each vessel type in Figure 29 through Figure 32. Most commercial vessels in the study area do not change their behaviour throughout the year. The exception is that tugs are more likely to travel offshore in the summer months as compared to winter (Figure 31). Another seasonal change is the presence of cruise ships up and down the coast and offshore from May through September, compared with little or no cruise ship activity during the rest of the year (Figure 32).

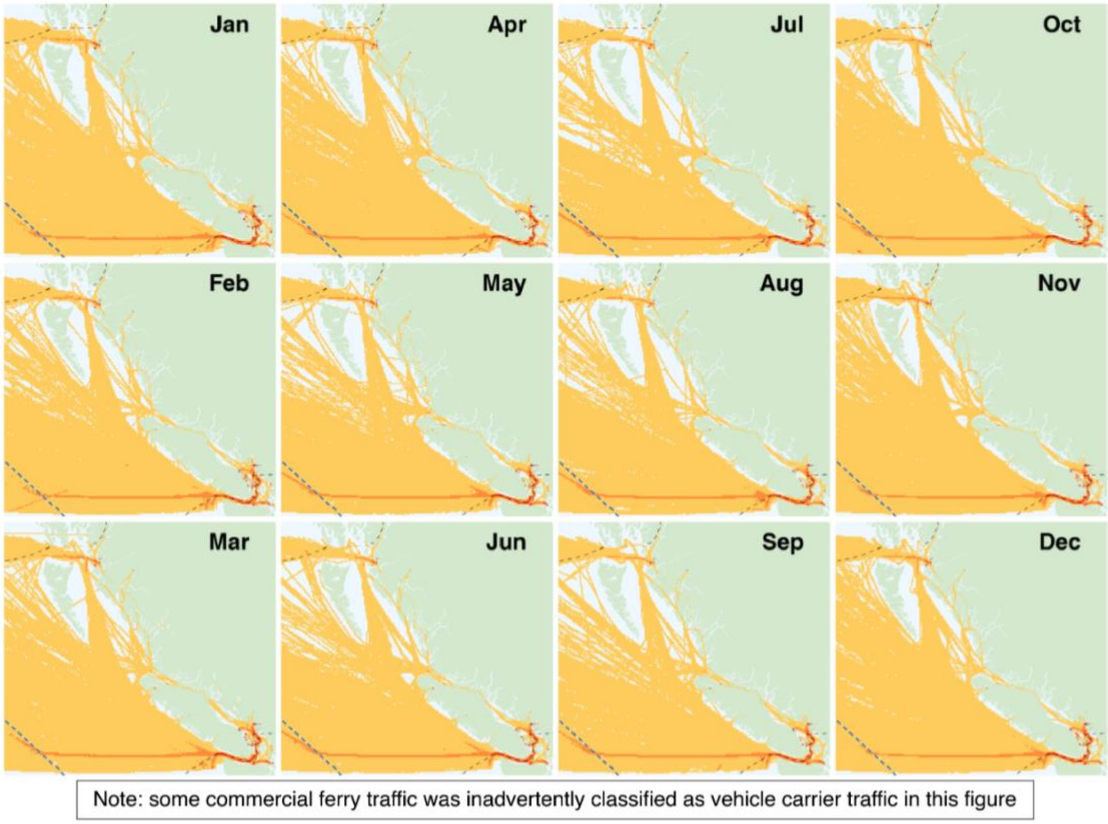


Figure 29. Vessel Density by Month – Cargo

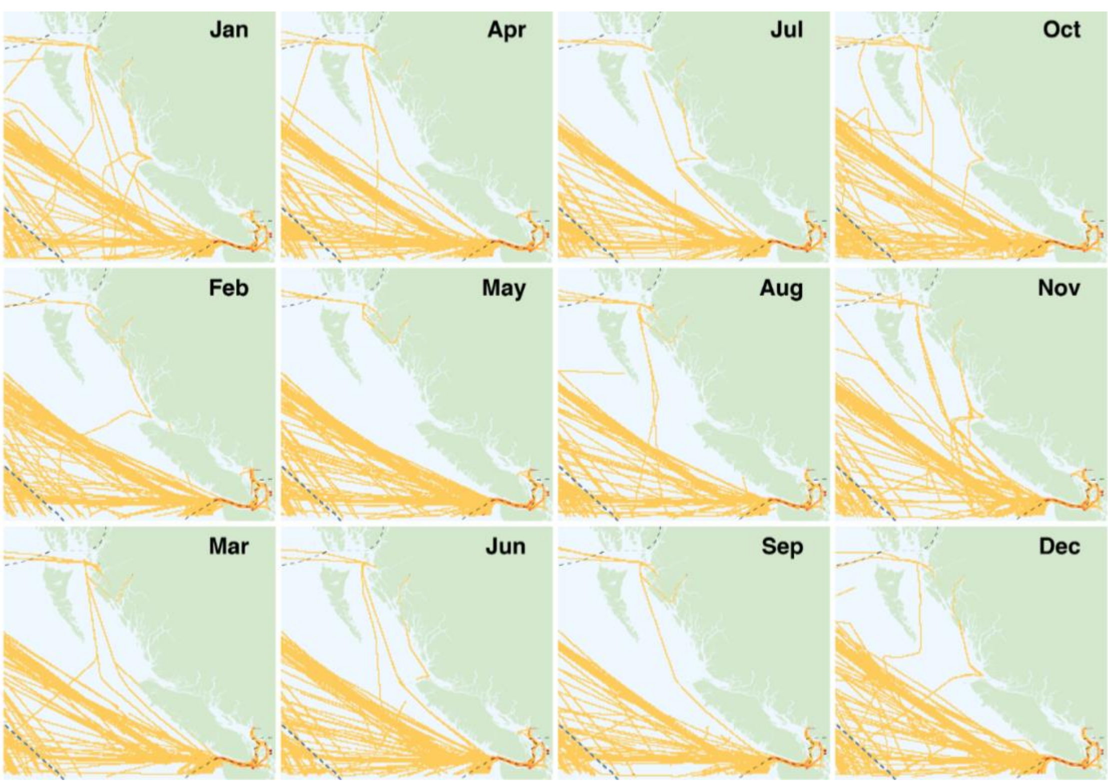


Figure 30. Vessel Density by Month - Tanker

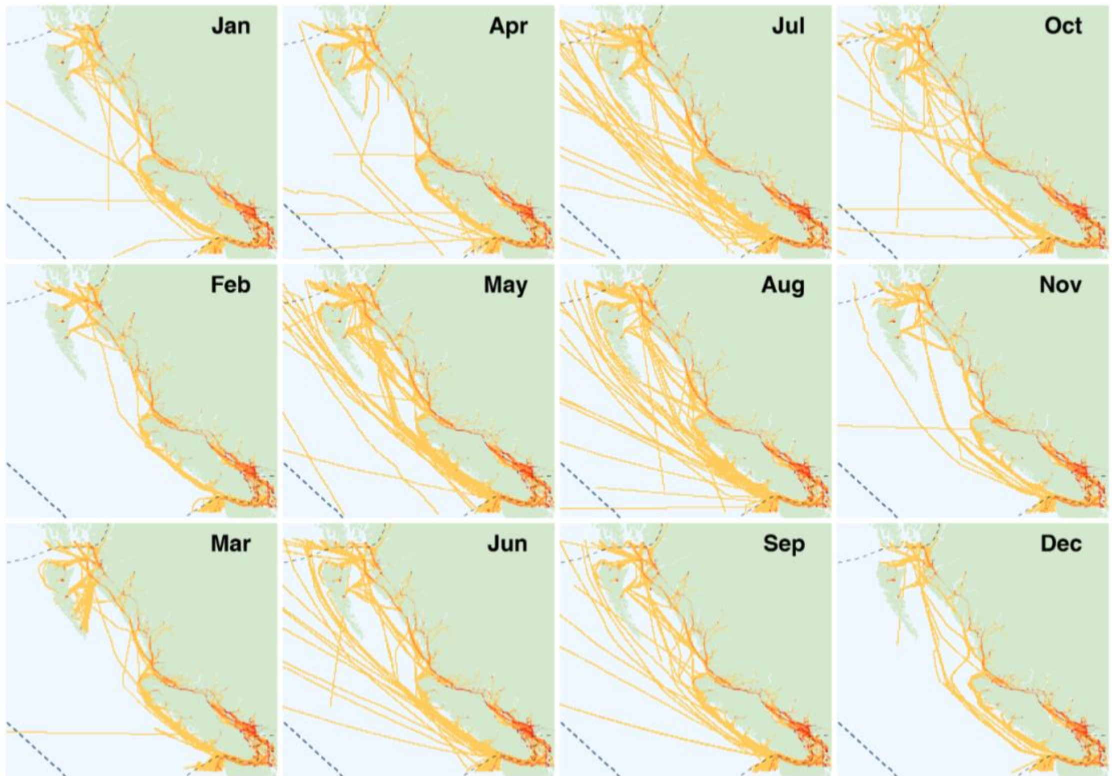


Figure 31. Vessel Density by Month – Tug

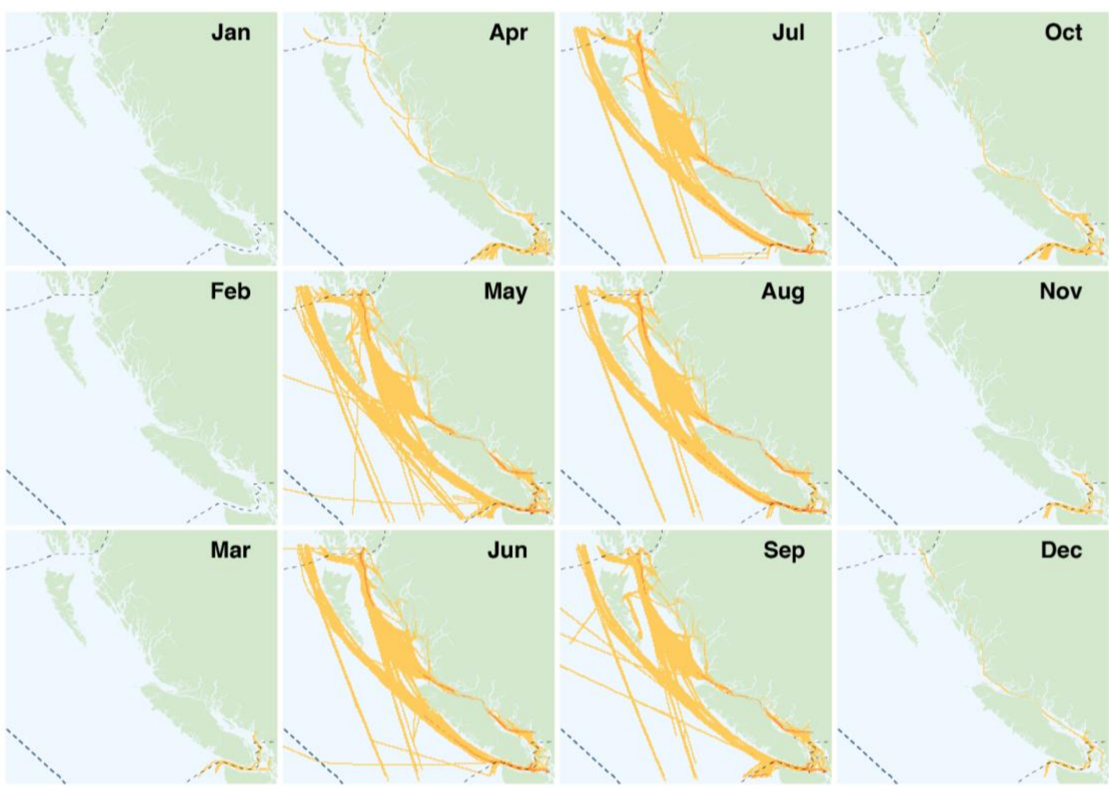


Figure 32. Vessel Density by Month – Cruise Ship

5.8 Strait of Juan de Fuca Analysis

A special analysis of the traffic transiting the Strait of Juan de Fuca was conducted in order to provide more detail on this important maritime gateway to both Canadian and U.S. ports. A total of 9,148 transits through the SJDF were identified from 2014 to 2016, with vessels calling at Canadian ports, U.S. ports, or ports in both countries. Given that the data were very consistent across the three years, annual averages are presented in this section of the report. Figure 33 shows the annual average number of round-trip transits for each port call category by vessel type. Table 11 shows the annual average number of round-trip transits for each port call category by vessel type and sub-type. The breakdown by vessel sub-type, port call category, and year are presented in Appendix D.

Overall, more SJDF round-trip transits were associated with vessels calling at Canadian ports (about 1,800 per year) compared to U.S. ports (about 1,400 per year). An annual average of about 1,000 round-trip transits were associated with port calls in both countries. Canada-bound traffic passing through the SJDF is dominated by bulk carriers carrying export products (about 1,200 per year, and 29% of all transits). U.S.-bound traffic passing through is more varied, with the main sub-types of vessels being container ships (about 300 per year), bulk carriers (about 200 per year), and large tankers (about 200 per year) bringing crude oil to refineries in the Washington State. Vessels that called in both countries were predominately container ships (about 600 per year). The vast majority of cruise ships and tugs making round trip transits through the SJDF were bound for U.S. ports. Slightly more of the smaller tankers entering were bound for Canada than the U.S. Most vehicle carriers call at ports in both countries. All LNG/LPG carriers were headed for U.S. ports.

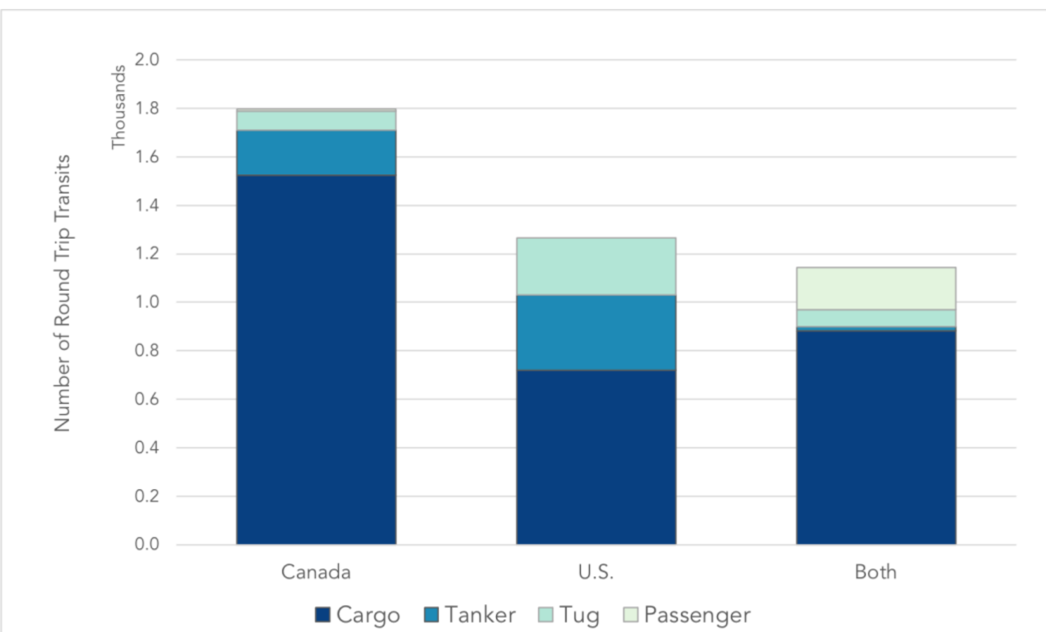


Figure 33. Number of Round-Trip Transits Through the Strait of Juan de Fuca by Type and Country of Destination (Annual Average 2014 - 2016)

Table 11. Number of Round-trip Transits Through the Strait of Juan de Fuca by Type and Country of Destination (Annual Average)

Type	Three Year Average			
Sub-type	Canada	U.S.	Both	Total
Cargo	1,523	720	882	3,126
Bulk Carrier	1,221	209	61	1,491
Container Ship	44	283	630	956
Vehicle Carrier	81	82	122	286
Other Cargo	177	147	69	393
Tanker	185	310	17	512
Small Tanker (<50k DWT)	154	119	13	285
Large Tanker (>50k DWT)	32	178	4	214
LNG/LPG Carrier	-	13	-	13
Tug	80	234	70	383
Articulated Tug	1	121	27	149
Tug	79	113	42	234
Passenger	10	0	176	187
Cruise Ship	10	0	176	187
Total	1,798	1,264	1,145	4,208

6.0 Oil Movement Characterization

Oil is moved by commercial shipping vessels as both fuel and cargo. Two forms of oil are considered: non-persistent oil (such as diesel fuel) and persistent oil (such as crude oil, heavy fuel oil, or diluted bitumen). This section first considers the oil capacity of individual vessels then presents the amount of oil moved through Pacific region waters by commercial shipping vessel fleets. The results of the oil movement analysis were generated using 2016 AIS data only.

6.1 Oil Capacities of Vessel Types

In general, vessels carrying oil as cargo have the greatest oil capacity. Large tankers carrying crude oil, principally from Valdez, Alaska to refineries in Washington State, carry the greatest quantity of persistent oil on board and thus represent the largest potential spill volume on a per-ship basis. The largest oil tankers in the Strait of Juan de Fuca are limited to carrying 125,000 DWT by the state of Washington,[14] which equates to about 136,000 m^3 of oil. Aframax tankers calling in Canada at Westridge Terminal are limited to about 105,000 m^3 of oil by a draft restriction set by the Port of Vancouver, although typical loads do not exceed 93,000 m^3. The capacity of Aframax tankers is about 120,000 m^3.

Small tankers generally carry non-persistent distilled oil or chemicals, however some carry persistent oil such as crude oil or slack wax. The largest of these vessels have a maximum capacity of 58,000 m^3 and an average of 48,000 m^3.

Tugs associated with oil barges (principally articulated tugs) also carry non-persistent oil in significant quantities. The maximum oil capacity associated with tug barges in the study is 32,000 m^3, and the average is 16,000 m^3, about one-twelfth the capacity of the average Aframax tanker.

Figure 34 and Figure 35 present the oil capacities of different vessel types for persistent oil and non-persistent oil, respectively. Table 12 shows the estimated maximum and average total oil capacities for each vessel type. Additionally, Appendix C contains tables of fuel and cargo capacities for each vessel type.

In 2016, deep draft ships typically carried persistent heavy oil as fuel, along with a smaller amount of non-persistent oil to burn within the ECA, unless the ship is equipped with an exhaust gas cleaning system also known as a scrubber. Cargo ships, principally container ships, typically carry the greatest quantity of persistent oil as bunker fuel. The maximum estimated capacity for a cargo ship in the study is 15,000 m^3 and the average is 3,400 m^3.

Cruise ships also carry both persistent and non-persistent oil as fuel. The maximum estimated persistent oil capacity for a cruise ship is 3,500 m^3 and the average is 2,900 m^3. As with other vessels, cruise ships are subject to sulphur restrictions while in the ECA, achieved by the consumption of lighter non-

[14] Puget Sound and Adjacent Waters, WA - Regulated Navigation Area. 33 CFR 165.1303

persistent fuel or the operation of a scrubber. Upon exiting the ECA they switch to a cheaper persistent fuel. Cruise ships typically spend their whole season, March to October, within the ECA.

The maximum capacity of non-persistent fuel oil on board cargo ships, cruise ships, and tugs (those not towing oil barges) ranges from 3,600 m^3 for vehicle carriers to 805 m^3 for tugs. The average capacity of non-persistent fuel oil on board these same vessels ranges from 1,000 m^3 for vehicle carriers to 200 m^3 for tugs.

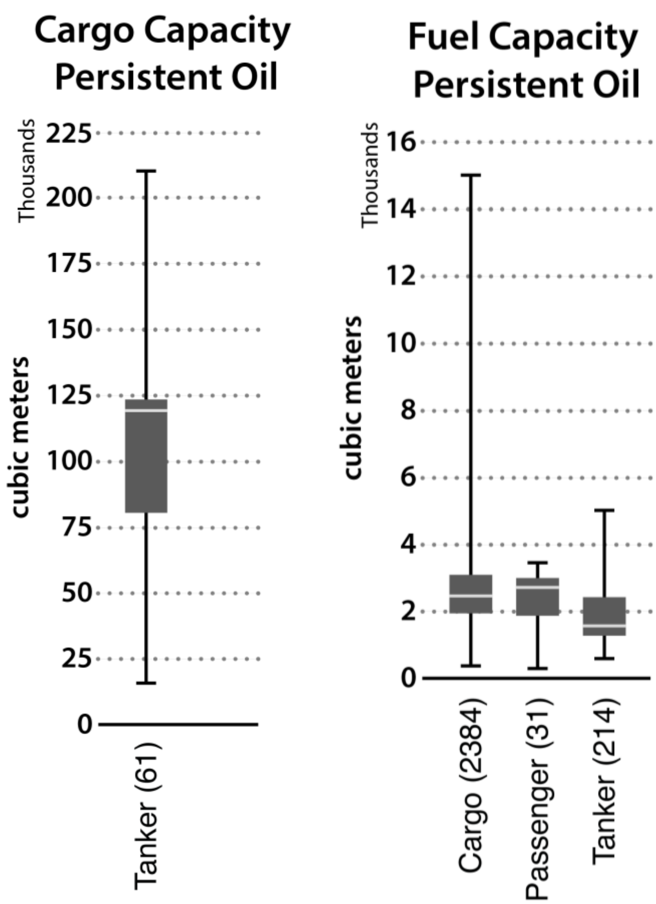


Figure 34. Oil Cargo and Fuel Tank Capacity by Vessel Sub-Type – Persistent Oil

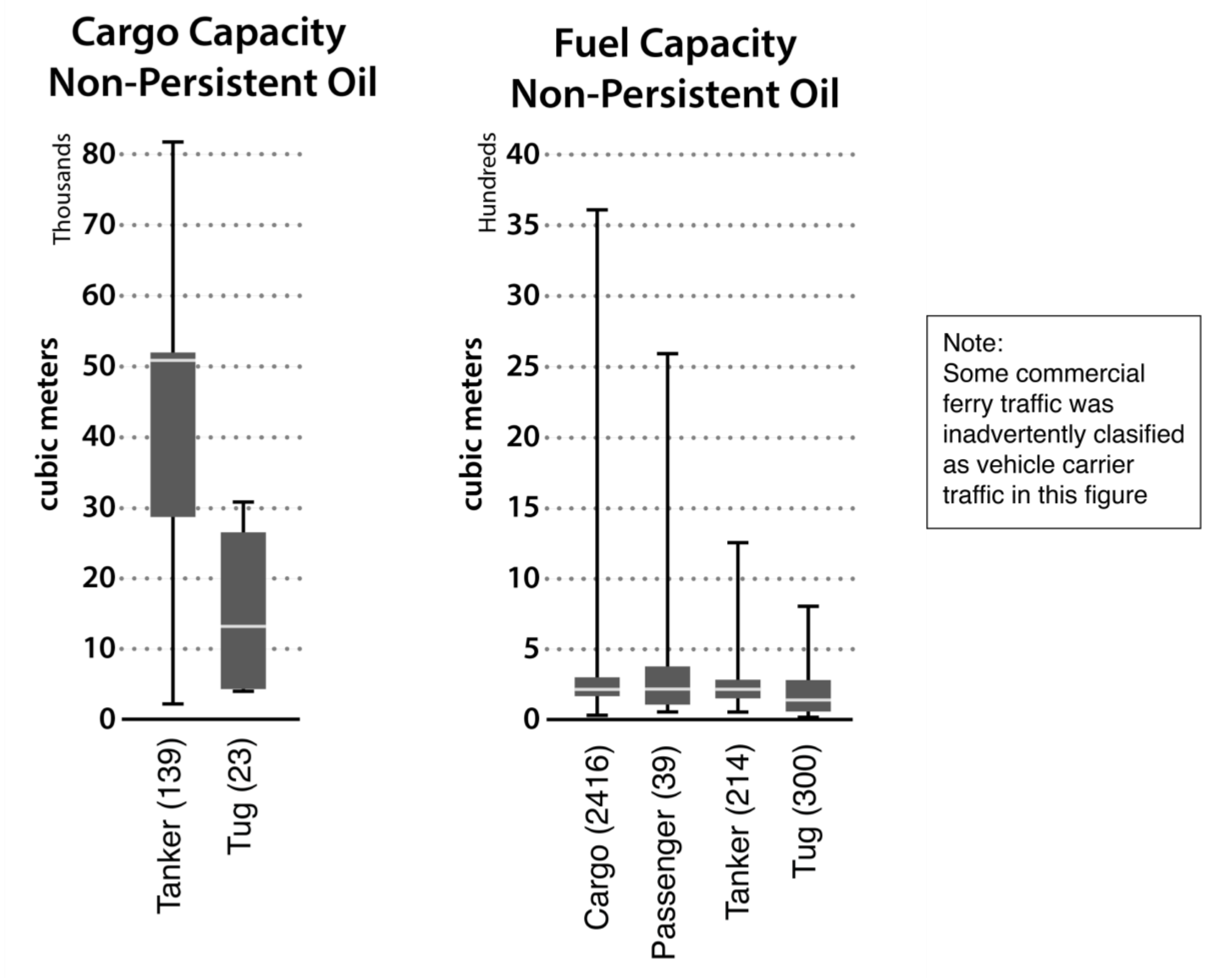


Figure 35. Oil Cargo and Fuel Tank Capacity by Vessel Sub-Type – Non-Persistent Oil

Table 12. Maximum and Average Oil Capacities for Vessels in Dataset (2016)

Total Oil Capacity (Cargo + Fuel) m^3				
Vessel Type	Non-persistent		Persistent	
Sub-type	Max.	Average	Max.	Average
Cargo	3,622	325	15,071	3,364
Bulk Carrier	2,710	214	6,204	2,378
Container Ship	1,192	477	15,071	8,620
Vehicle Carrier	3,622	961	6,526	3,218
Other Cargo	2,010	227	4,830	1,998
Tanker	83,315	42,616	215,990	109,425
Small Tanker (<50k DWT)	57,898	39,955	57,134	42,496
Large Tanker (>50k DWT)	83,315	57,130	215,990	124,473
LNG/LPG Carrier	380	282	3,400	2,853
Tug	31,673	13,542	30,869	10,352
Articulated Tug	31,637	21,332	30,869	26,374
Tug	12,172	4,253	10,248	6,792
Passenger	2,600	347	3,462	2,395
Cruise Ship	2,600	347	3,462	2,395
All Vessels	83,315	37,607	215,990	96,506

6.2 Regional Oil Movement Analysis

This section presents the estimated oil movements in Pacific region waters, by density maps and across passage lines. Additionally, maps in Appendix C show the density of oil movements by vessel type for both persistent and non-persistent oil and the amount of oil estimated to have moved in and out of each port during 2016.

6.2.1 Persistent Oil Movements (All Vessels)

The movement of persistent oil as fuel and cargo by all vessels through the study area in 2016 is depicted on a map in Figure 36, and the estimated amount of oil carriage is shown in Figure 37 and Table 13. As in the density maps of vessel movements, the darker colours on the oil density map represent more oil being moved through that recorded point for the entire year. Areas of high oil densities correspond to vessel routes where tankers and deep draft cargo ships travel. The routes regularly traveled by cruise ships also stand out.

Figure 37 and Table 13 show that the highest estimated volume of persistent oil (53 million m^3) in 2016 was moved through the Strait of Juan de Fuca, principally by crude oil tankers (34 million m^3) and cargo ships (18 million m^3). The passage line at the East Salish Sea, gauging U.S. ports, had the second highest volume of persistent oil movement (45 million m^3), principally by tankers (31 million m^3) and cargo ships

(13 million m^3). The passage line at the South Strait of Georgia had the third highest volume of persistent oil movement (17 million m^3), principally by cargo ships (14 million m^3) and tankers (2 million m^3). A smaller amount of persistent oil was carried across the South Strait of Georgia passage line primarily by tugs towing barges (0.5 million m^3) that contain heavy fuel oil to refuel ships in Vancouver.

Other passage line estimates for persistent oil carriage were far smaller with the persistent oil carriage estimates at the Hecate Strait, Dixon Entrance, and Queen Charlotte Sound all being less than 2.5 million m^3 annually, principally driven by cargo ships and cruise ships. The persistent oil carriage estimates for Queen Charlotte Strait, North Strait of Georgia and the Alaska Inside Passage were each less than 800,000 m^3 annually, also driven by cargo ships and cruise ships.

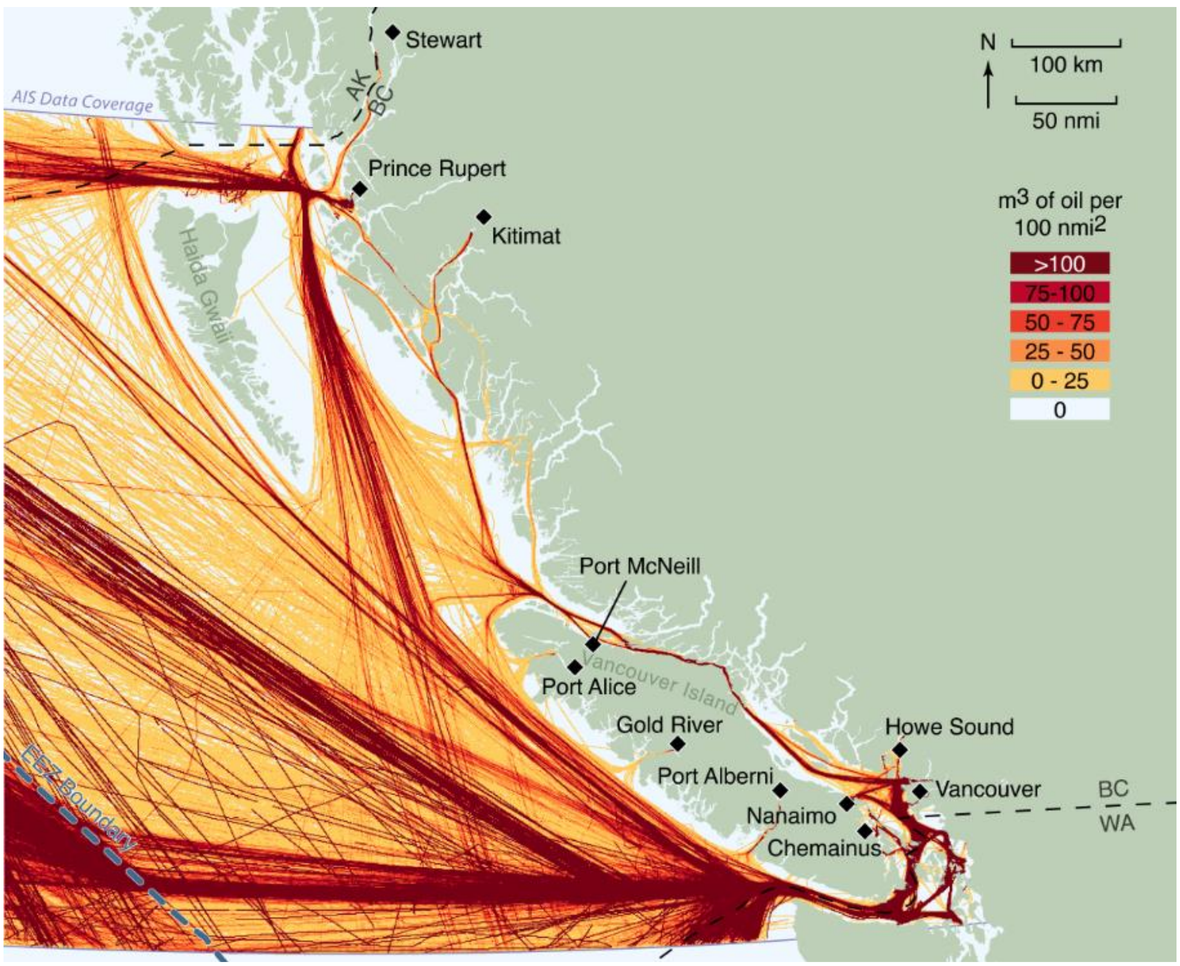


Figure 36. Persistent Oil Movement Density in 2016, All Vessels

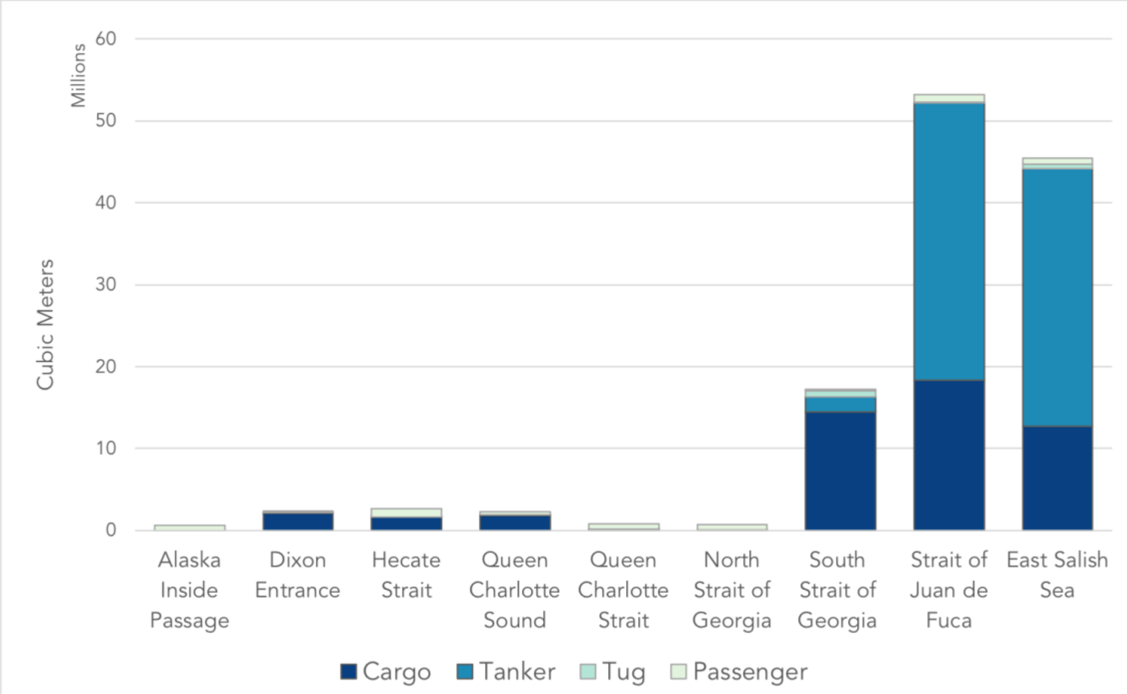


Figure 37. Estimated Persistent Oil Carriage by Vessel Type, Each Passage Line (2016)

Table 13. Estimated Persistent Oil Carriage by Vessel Type for Each Passage Line (2016)

Passage Line	Persistent Oil Carriage (million cubic metres)				
	Cargo	Tanker	Tug	Passenger	All
Alaska Inside Passage	0.02	-	-	0.59	0.61
Dixon Entrance	2.09	0.09	-	0.19	2.37
Hecate Strait	16.17	0.33	-	9.74	26.24
North Strait of Georgia	0.06	-	0.01	0.67	0.73
Queen Charlotte Sound	1.86	0.04	-	0.39	2.29
Queen Charlotte Strait	0.18	0.00	-	0.65	0.83
South Strait of Georgia	14.47	1.89	0.68	0.18	17.21
Strait of Juan de Fuca	18.30	33.91	0.10	0.92	53.23
East Salish Sea	12.73	31.44	0.51	0.80	45.48

6.2.2 Non-persistent Oil Movement (All Vessels)

The movement of non-persistent oil as fuel and cargo by all vessels through the study area in 2016 is depicted in Figure 38 and the estimated amount of oil carriage is shown in Figure 39 and Table 14. Areas of high density correspond to routes traveled by: tankers assessed to be carrying non-persistent products as cargo; tugs associated with oil barges; and cargo and cruise ships that carry non-persistent oil as a secondary fuel for ECA transit. Note that because the scope of the study is confined to the commercial vessels specified in Section 2.1, this analysis does not include important categories of vessel that carry non-persistent diesel fuel like ferries and fishing boats. The plot in Figure 38 is therefore representative for all vessels *in the study*, not all vessels.

The passage line chart and table show that an estimated 18.7 million m^3 of non-persistent oil crossed the SJDF passage line in 2016, principally carried in tankers (11.8 million m^3) where approximately 55%[15] of volumes were associated with tankers headed to Canadian ports. Also representing significant volumes were tugs with oil barges (5.0 million m^3) where approximately 31%[16] of volumes were associated with tugs headed to Canadian ports.

The East Salish Sea passage line (accessing U.S. ports) saw an estimated total of 15.2 million m^3 of non-persistent oil pass through the area, principally due to 6.7 million m^3 being moved by tugs (with barges filled with non-persistent oil) and 7.4 million m^3 by tanker.

The South Strait of Georgia passage line (accessing Canadian ports) saw the third highest level of oil movement with 12.6 million m^3 of non-persistent oil, primarily carried in tankers (7.7 million m^3) and tugs (3.4 million m^3). Non-persistent oil carried as secondary fuel in cargo ships contributed approximately 1.5 million m^3 to each of these passage lines as well.

Though smaller in absolute volume terms, the movement of non-persistent oil by tugs within the confined waterways east of Vancouver Island and through the Inside Passage is worthy of closer examination. The analysis found that tug movements were responsible for 0.91 million m^3 of oil moved through the North Strait of Georgia passage line and 0.49 million m^3 of non-persistent oil moved via the Alaska Inside Passage. Of the non-persistent oil moved within the Canadian Inside Passage via tug and oil barge only 44%[17] was found to be for domestic consumption in B.C. and more than half (56%) was involved in Alaska-Washington trade.

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[15] Where: CAN/SSG = 7.73m^3; US/ESS = 6.57m^3; Total Tanker NPO Est = 14.3m^3; CAN Tanker NPO Est. = 55%

[16] Where: CAN/SSG = 3.34m^3; US/ESS = 7.36m^3; Total Tankers NPO Est = 10.7m^3; CAN Tug(&Barge) NPO Est. = 31%

[17] Where: NSG = 0.88m^3; AIP = 0.49m^3; Total NPO by US Tug(&Barge) = 56% or CAN = 44%)

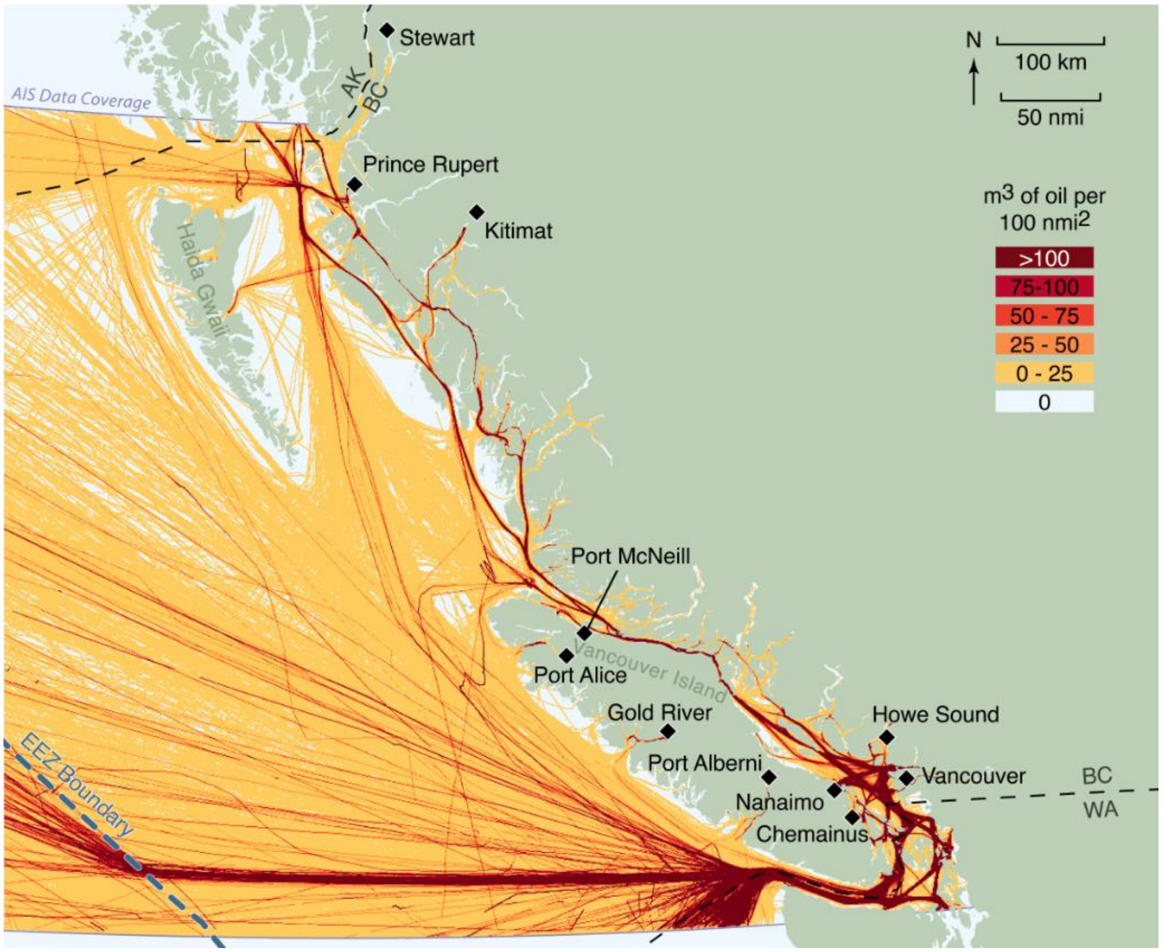

Figure 38. Non-Persistent Oil Density - All Vessels

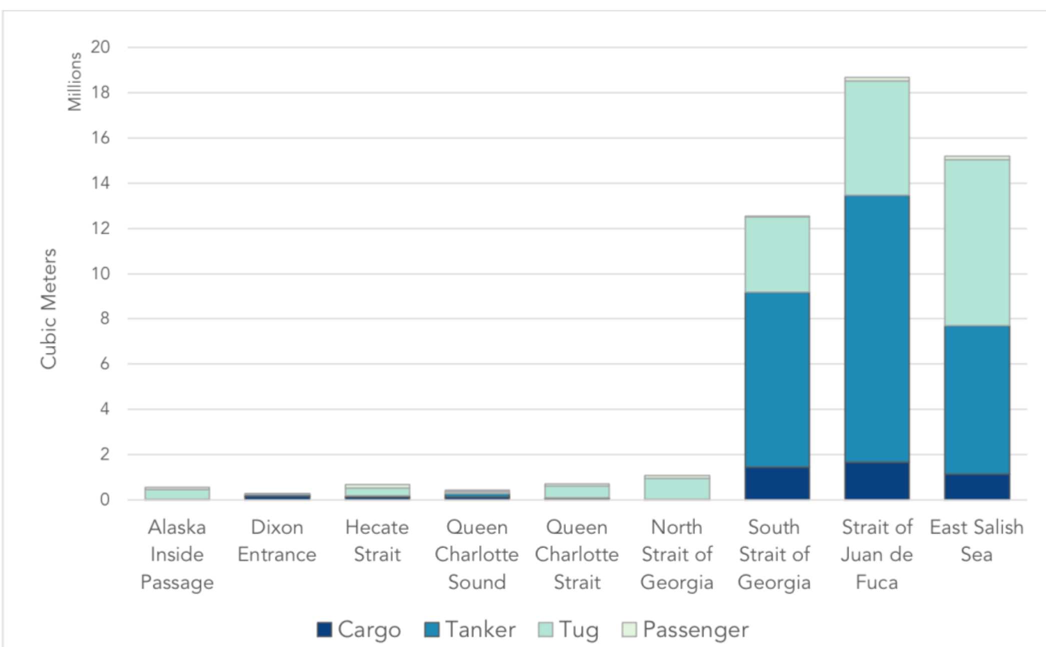

Figure 39. Estimated Non-Persistent Oil Carriage by Vessel Type for Each Passage Line

Table 14. Estimated Non-Persistent Oil Carriage by Vessel Type for Each Passage Line (2016)

Passage Line	Non-Persistent Oil Carriage (million cubic metres)				
	Cargo	Passenger	Tanker	Tug	All
Alaska Inside Passage	0.01	0.11	-	0.44	0.55
Dixon Entrance	0.15	0.03	0.08	0.01	0.27
Hecate Strait	1.14	1.71	0.78	3.15	6.78
Queen Charlotte Sound	0.13	0.08	0.14	0.09	0.43
Queen Charlotte Strait	0.05	0.11	0.02	0.54	0.72
North Strait of Georgia	0.04	0.11	-	0.91	1.06
South Strait of Georgia	1.45	0.03	7.73	3.34	12.55
Strait of Juan de Fuca	1.65	0.17	11.83	5.04	18.69
East Salish Sea	1.12	0.16	6.57	7.36	15.21

6.3 Strait of Juan de Fuca Oil Movement Analysis

Figure 40 depicts the amount of non-persistent oil and persistent oil estimated to have been transported through the Strait of Juan de Fuca in 2016 by vessel type. A detailed analysis of traffic was performed to determine the breakdown of oil movements into Canada and the U.S., and also to determine the amount involved in trade between the two countries. Total oil movement through the Strait of Juan de Fuca, as seen in Table 15, was captured using the 'round trip voyages' technique (requires two passage line crossings, in and out of the region). The total estimated oil movement with this technique was 6% lower than other methods that used a vessel's crossing of only one passage line, in or out of the region.

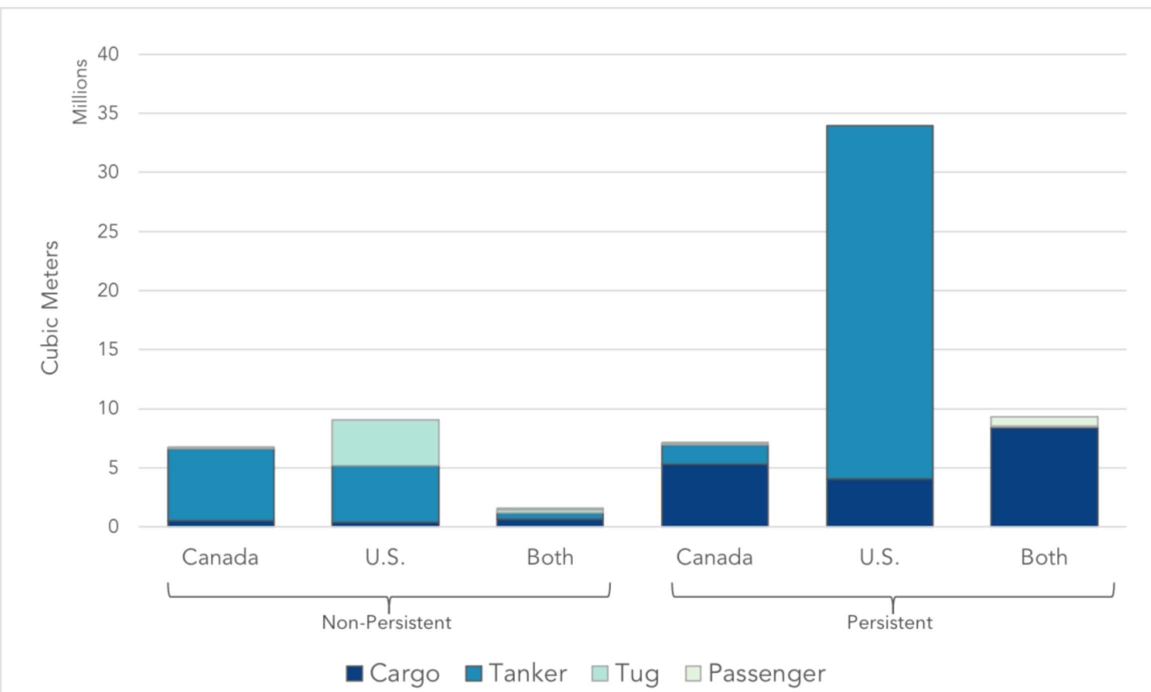

Figure 40. Estimated Volume of Total Oil - Strait of Juan de Fuca (2016)

Using the round-trip voyage technique, the total oil estimated to have been transported through the Strait of Juan de Fuca was 67.6 million m^3. A detailed breakdown by destination, vessel type and oil type is provided in Table 15.

Table 15. Total Oil Volume - Strait of Juan de Fuca – Round Trip Voyages (2016)

Type	Non-persistent Oil (million cubic metres)				Persistent Oil (million cubic metres)			
Sub-type	Canada	U.S.	Both	Total	Canada	U.S.	Both	Total
Cargo	0.52	0.42	0.64	1.59	5.33	4.05	8.37	17.75
Bulk Carrier	0.37	0.06	0.01	0.44	4.05	0.67	0.15	4.87
Container Ship	0.02	0.17	0.45	0.65	0.43	2.40	7.55	10.38
Vehicle Carrier	0.09	0.14	0.17	0.40	0.37	0.42	0.52	1.31
Cargo Other	0.04	0.04	0.02	0.10	0.47	0.56	0.16	1.19
Tanker	6.10	4.78	0.57	11.45	1.65	29.89	0.11	31.65
Tanker <50k DWT	5.56	3.76	0.57	9.89	0.29	2.90	0.03	3.21
Tanker >50k DWT	0.54	1.01	0.00	1.55	1.36	26.92	0.08	28.37
LNG/LPG Carrier	-	0.01	-	0.01	-	0.07	-	0.07
Tug	0.06	3.85	0.21	4.12	0.08	0.00	0.05	0.14
Articulated Tug	-	3.77	0.21	3.99	0.08	0.00	0.05	0.14
Tug	0.05	0.07	-	0.13	-	-	-	-
Passenger	0.01	-	0.15	0.15	0.04	-	0.76	0.80
Cruise Ship	0.01	-	0.15	0.15	0.04	-	0.76	0.80
Total	6.69	9.05	1.57	17.31	7.11	33.94	9.29	50.34

7.0 References

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Appendix A – Vessel Types

Table A-1. Vessel Types and Sub-Types

Vessel Type	Vessel Sub-type	Example Vessels Based on Vessel Registration Sub-types
Cargo	Bulk Carrier	Bulk Carrier
		Bulk Carrier, Self-discharging
		Wood Chips Carrier
	Container	Container Ship
	Vehicle Carrier	Vehicle Carrier
	Cargo Other	General Cargo Ship
		Heavy Load Carrier
		Refrigerated Cargo Ship
		Open Hatch Cargo Ship
		Platform Supply Ship
		Ro-Ro Cargo Ship
Tanker	Tanker >50,000 DWT or Tanker <50,000 DWT	Asphalt/Bitumen Tanker
		Chemical Tanker
		Oil Products Tanker
		Chemical/Products Tanker
		Crude Oil Tanker
		Crude/Oil Products Tanker
	LNG/LPG Tanker	Liquefied Gas Carrier
Tug	Tug	Offshore Tug/Supply Ship
		Tug
	Articulated Tug	Articulated Pusher Tug
Passenger	Cruise Ship	Passenger/Cruise

Appendix B – Port Calls by Year at Each Port (Based on AIS Data)

Table B-1. Vessel Port Calls by Year – Chemainus[18]

Vessel Type Vessel Sub-type	Year 2014	2015	2016	Total	Average
Cargo	115	91	97	303	101
Bulk Carrier	34	26	26	86	29
Container Ship	4	2		6	3
Vehicle Carrier	-	-	-	-	-
Other Cargo	77	63	71	211	70
Tanker	-	-	1	1	1
Tanker <50k DWT	-	-	1	1	1
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-		
Tug	1,156	1,108	1,006	3,270	1,090
Articulated Tug	-	-	-	-	-
Tug	1,156	1,108	1,006	3,270	1,090
Passenger	-	-	-	-	-
Cruise Ship	-	-	-	-	-
Grand Total	1,271	1,199	1,104	3,574	1,191

[18]Not all of these tugs are making port calls here, many are just passing by.

Table B-2. Vessel Port Calls by Year – Gold River

Vessel Type Vessel Sub-type	Year			Total	Average
	2014	2015	2016		
Cargo	9	8	14	31	10
Bulk Carrier	9	8	14	31	10
Container Ship	-	-	-	-	-
Vehicle Carrier	-	-	-	-	-
Other Cargo	-	-	-	-	-
Tanker					
Tanker <50k DWT	-	-	-	-	-
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-	-	-
Tug	29	69	149	247	82
Articulated Tug	-	-	-	-	-
Tug	29	69	149	247	82
Passenger	-	-	-	-	-
Cruise Ship	-	-	-	-	-
Grand Total	38	77	163	278	93

Table B-3. Vessel Port Calls by Year – Howe Sound

Vessel Type Vessel Sub-type	Year			Total	Average
	2014	2015	2016		
Cargo	100	101	84	285	95
Bulk Carrier	4	4	3	11	4
Container Ship	-	-	-	-	-
Vehicle Carrier	-	-	-	-	-
Other Cargo	96	97	81	274	91
Tanker	-	-	-	-	-
Tanker <50k DWT	-	-	-	-	-
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-	-	-
Tug	1,076	981	1,122	3,179	1,060
Articulated Tug					
Tug	1,076	981	1,122	3,179	1,060
Passenger	1	1	4	6	2
Cruise Ship	1	1	4	6	2
Grand Total	1,177	1,083	1,210	3,470	1,157

Table B-4. Vessel Port Calls by Year – Kitimat

Vessel Type / Vessel Sub-type	Year 2014	2015	2016	Total	Average
Cargo	30	29	50	109	36
Bulk Carrier	8	9	25	42	14
Container Ship	-	-	-	-	-
Vehicle Carrier	-	-	-	-	-
Other Cargo	22	20	25	67	22
Tanker	6	5	4	15	5
Tanker <50k DWT	6	5	4	15	5
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-	-	-
Tug	76	46	45	167	56
Articulated Tug					
Tug	76	46	45	167	56
Passenger	-	-	-	-	-
Cruise Ship	-	-	-	-	-
Grand Total	112	80	99	291	97

Table B-5. Vessel Port Calls by Year – Nanaimo[19]

Vessel Type / Vessel Sub-type	Year 2014	2015	2016	Total	Average
Cargo	242	225	223	690	230
Bulk Carrier	153	131	142	426	142
Container Ship	7	13	4	24	8
Vehicle Carrier	-	-	-	-	-
Other Cargo	82	81	77	240	80
Tanker	3	4	-	7	2
Tanker <50k DWT	3	4	-	7	4
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-	-	-
Tug	2,051	2,163	2,281	6,495	2,165
Articulated Tug	608	453	376	1,437	479
Tug	1,443	1,710	1,905	5,058	1,686
Passenger	4	6	9	19	6
Cruise Ship	4	6	9	19	6
Grand Total	2,300	2,398	2,513	7,211	2,403

[19] Some cruise ships and tugs are passing by the port, not actually making a port call.

Table B-6. Vessel Port Calls by Year – Port Alberni

Vessel Type	Year			Total	Average
Vessel Sub-type	2014	2015	2016		
Cargo	68	64	56	188	63
Bulk Carrier	47	37	33	117	39
Container Ship	-	-	-	-	-
Vehicle Carrier	-	-	-	-	-
Other Cargo	21	27	23	71	24
Tanker	-	-	-	-	-
Tanker <50k DWT	-	-	-	-	-
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-	-	-
Tug	90	92	109	291	97
Articulated Tug					
Tug	90	92	109	291	97
Passenger	-	-	-	-	-
Cruise Ship	-	-	-	-	-
Grand Total	158	156	165	479	160

Table B-7. Vessel Port Calls by Year – Port Alice

Vessel Type	Year			Total	Average
Vessel Sub-type	2014	2015	2016		
Cargo	15	14	15	44	15
Bulk Carrier	10	14	14	38	13
Container Ship	-	-	-	-	-
Vehicle Carrier	-	-	-	-	-
Other Cargo	5		1	6	3
Tanker	-	-	-	-	-
Tanker <50k DWT	-	-	-	-	-
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-	-	-
Tug	145	169	104	418	139
Articulated Tug	-	-	-	-	-
Tug	145	169	104	418	139
Passenger	-	-	-	-	-
Cruise Ship	-	-	-	-	-
Grand Total	160	183	119	462	154

Table B-8. Vessel Port Calls by Year – Port McNeill

Vessel Type	Year			Total	Average
Vessel Sub-type	2014	2015	2016		
Cargo: Bulk Carrier	50	37	41	128	43

Table B-9. Vessel Port Calls by Year – Prince Rupert

Vessel Type / Vessel Sub-type	Year			Total	Average
	2014	2015	2016		
Cargo	475	434	441	1,350	450
Bulk Carrier	315	255	246	816	272
Container Ship	154	170	189	513	171
Vehicle Carrier	-	-	-	-	-
Other Cargo	6	9	6	21	7
Tanker	11	3	5	19	6
Tanker <50k DWT	4	3	5	12	4
Tanker >50k DWT	7	-	-	7	7
LNG/LPG Carrier	-	-	-	-	-
Tug	665	536	583	1,784	595
Articulated Tug	-	-	-	-	-
Tug	665	536	583	1,784	595
Passenger	10	10	12	32	11
Cruise Ship	10	10	12	32	11
Grand Total	1,161	983	1,041	3,185	1,062

Table B-10. Vessel Port Calls by Year – Stewart

Vessel Type / Vessel Sub-type	Year			Total	Average
	2014	2015	2016		
Cargo	26	26	41	93	31
Bulk Carrier	21	24	28	73	24
Container Ship	-	-	-	-	-
Vehicle Carrier	-	-	-	-	-
Other Cargo	5	2	13	20	7
Tanker	-	-	-	-	-
Tanker <50k DWT	-	-	-	-	-
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-	-	-
Tug	34	37	74	145	48
Articulated Tug					
Tug	34	37	74	145	48
Passenger	-	-	-	-	-
Cruise Ship	-	-	-	-	-
Grand Total	60	63	115	238	79

Table B-11. Vessel Port Calls by Year – Burrard Inlet (Vancouver)

Vessel Type Vessel Sub-type	Year			Total	Average
	2014	2015	2016		
Cargo	1,751	1,700	1,690	5,141	1,714
Bulk Carrier	1,192	1,108	1,152	3,452	1,151
Container Ship	343	397	389	1,129	376
Vehicle Carrier	4	20	13	37	12
Other Cargo	212	175	136	523	174
Tanker	219	221	244	684	228
Tanker <50k DWT	166	184	219	569	190
Tanker >50k DWT	53	37	25	115	38
LNG/LPG Carrier	-	-	-	-	-
Tug	2,712	2,519	2,515	7,746	2,582
Articulated Tug	87	76	45	208	69
Tug	2,625	2,443	2,470	7,538	2,513
Passenger	241	227	218	686	229
Cruise Ship	241	227	218	686	229
Grand Total	4,923	4,667	4,667	14,257	4,752

Table B-12. Vessel Port Calls by Year – Roberts Bank (Vancouver)

Vessel Type Vessel Sub-type	Year			Total	Average
	2014	2015	2016		
Cargo	465	482	486	1,433	478
Bulk Carrier	237	237	216	690	230
Container Ship	227	243	267	737	246
Vehicle Carrier	-	-	-	-	-
Other Cargo	1	2	3	6	2
Tanker	-	-	-	-	-
Tanker <50k DWT	-	-	-	-	-
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-	-	-
Tug	627	518	561	1,706	569
Articulated Tug					
Tug	627	518	561	1,706	569
Passenger	-	-	-	-	-
Cruise Ship	-	-	-	-	-
Grand Total	1,092	1,000	1,047	3,139	1,046

Table B-13. Vessel Port Calls by Year – Fraser River (Vancouver)

Vessel Type / Vessel Sub-type	Year			Total	Average
	2014	2015	2016		
Cargo	515	509	490	1,514	505
Bulk Carrier	125	128	113	366	122
Container Ship	75	74	78	227	76
Vehicle Carrier	191	200	225	616	205
Other Cargo	124	107	74	305	102
Tanker	-	-	-	-	-
Tanker <50k DWT	-	-	-	-	-
Tanker >50k DWT	-	-	-	-	-
LNG/LPG Carrier	-	-	-	-	-
Tug	5,861	5,403	5,950	17,214	5,738
Articulated Tug	546	549	608	1,703	568
Tug	5,315	4,854	5,342	15,511	5,170
Passenger	-	-	-	-	-
Cruise Ship	-	-	-	-	-
Grand Total	6,376	5,912	6,440	18,728	6,243

Appendix C – Petroleum Movements

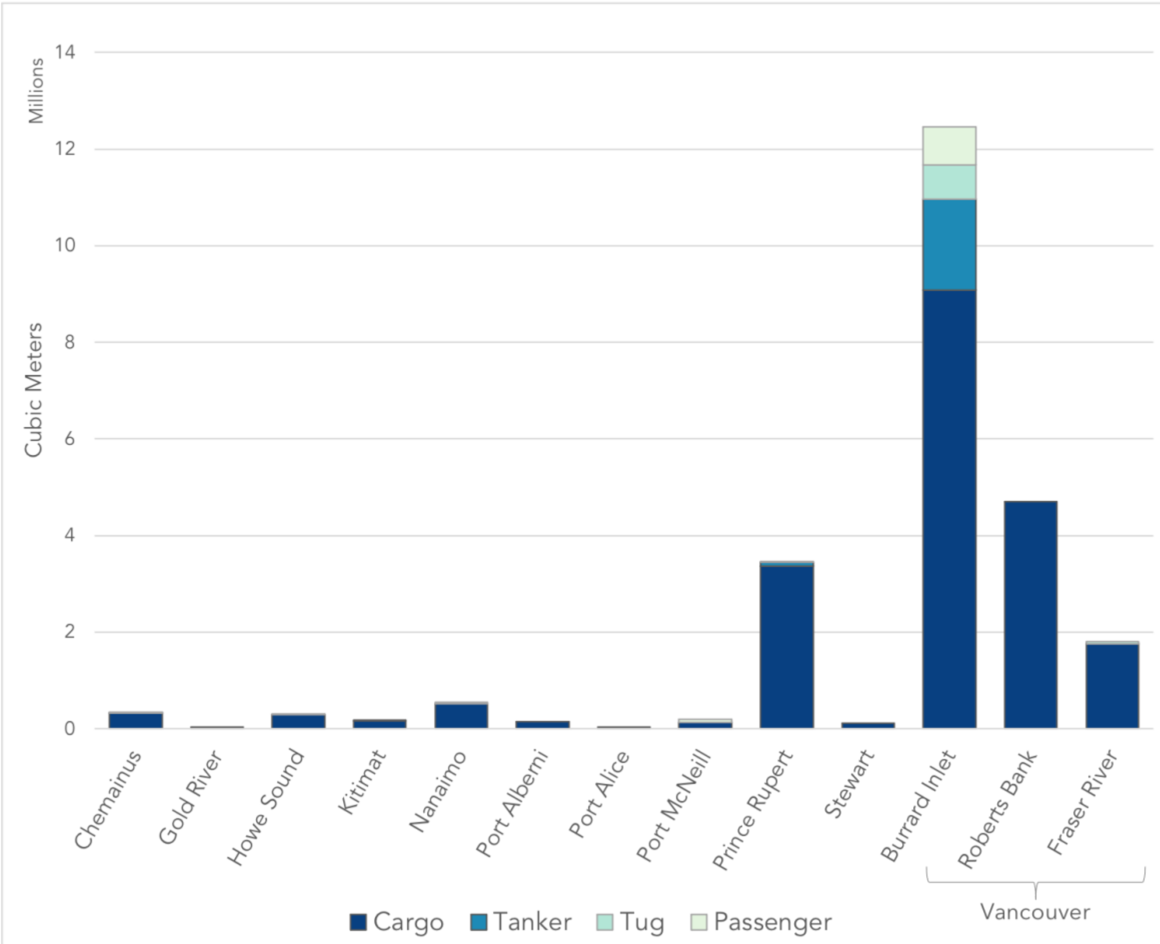

Figure C-1. Persistent Oil Movements – Port

Table C-1. Persistent Oil Movements - Port

Port	Persistent Oil Carriage (million cubic metres)				
	Cargo	Passenger	Tanker	Tug	All
Chemainus	0.33	0.00	0.00	0.02	0.35
Gold River	0.03	0.00	0.00	0.00	0.03
Howe Sound	0.30	0.01	0.00	0.00	0.31
Kitimat	0.15	0.00	0.02	0.00	0.17
Nanaimo	0.51	0.03	0.00	0.01	0.55
Port Alberni	0.14	0.00	0.00	0.00	0.14
Port Alice	0.03	0.00	0.00	0.00	0.03
Port McNeill	0.13	0.07	0.00	0.00	0.20
Prince Rupert	3.36	0.02	0.09	0.00	3.46
Stewart	0.11	0.00	0.00	0.00	0.11
Vancouver - Burrard Inlet	9.08	0.80	1.89	0.70	12.47
Vancouver - Roberts Bank	4.69	0.00	0.00	0.00	4.69
Vancouver - Fraser River	1.75	0.00	0.01	0.04	1.80

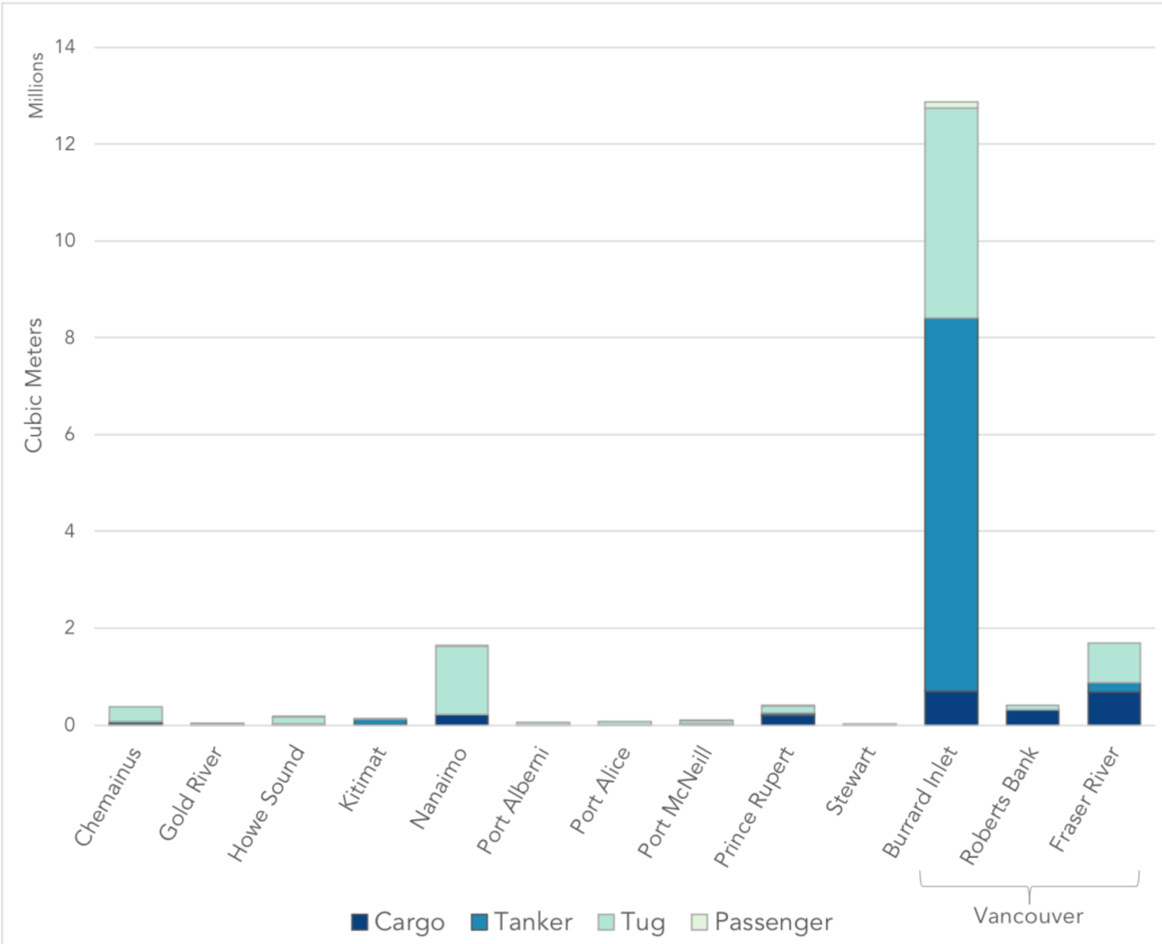

Figure C-2. Non-Persistent Oil Movements – Port

Table C-2. Non-Persistent Oil Movements - Port

Port	Non-Persistent Oil Carriage (million cubic metres)				
	Cargo	Passenger	Tanker	Tug	All
Chemainus	0.03	-	0.04	0.31	0.37
Gold River	0.00	-	-	0.04	0.04
Howe Sound	0.03	0.00	-	0.14	0.17
Kitimat	0.01	-	0.11	0.02	0.14
Nanaimo	0.22	0.00	-	1.42	1.64
Port Alberni	0.01	-	-	0.05	0.06
Port Alice	0.00	-	-	0.08	0.08
Port McNeill	0.02	0.01	-	0.07	0.10
Prince Rupert	0.20	0.00	0.06	0.13	0.39
Stewart	0.01	-	-	0.00	0.01
Vancouver - Burrard Inlet	0.70	0.13	7.71	4.33	12.87
Vancouver - Roberts Bank	0.31	-	-	0.09	0.41
Vancouver - Fraser River	0.68	-	0.20	0.81	1.70

Table C-3. Persistent Fuel Capacity – Vessel Type

Vessel Type	Persistent Fuel Capacity (cubic metres)		
Vessel Sub-type	Maximum	Average	Minimum
Cargo	15,071	3,364	370
Bulk Carrier	6,204	2,378	800
Container Ship	15,071	8,620	570
Vehicle Carrier	6,526	3,218	753
Other Cargo	4,830	1,998	370
Tanker	5,030	2,309	589
Tanker <50k DWT	3,237	1,386	589
Tanker >50k DWT	5,030	2,688	1,179
LNG/LPG Carrier	3,400	2,853	2,285
Tug	-	-	-
Articulated Tug	-	-	-
Tug	-	-	-
Passenger	3,462	2,395	293
Cruise Ship	3,462	2,395	293
All Vessels	15,071	3,213	293

Table C-4. Persistent Cargo Capacity – Vessel Type

Vessel Type / Vessel Sub-type	Persistent Cargo Capacity (cubic metres)		
	Maximum	Average	Minimum
Tanker	210,960	107,116	-
Tanker <50k DWT	53,897	41,109	15,808
Tanker >50k DWT	210,960	121,784	77,514
LNG/LPG Carrier	-	-	-
Tug	30,869	10,352	-
Articulated Tug	30,869	26,374	21,879
Tug	10,248	6,792	-
All Vessels	210,960	93,293	-

Table C-5. Non-Persistent Fuel Capacity – Vessel Type

Vessel Type / Vessel Sub-type	Non-Persistent Fuel Capacity (cubic metres)		
	Maximum	Average	Minimum
Cargo	3,622	325	30
Bulk Carrier	2,710	214	60
Container Ship	1,192	477	92
Vehicle Carrier	3,622	961	92
Other Cargo	2,010	227	30
Tanker	1,257	240	53
Tanker <50k DWT	600	195	53
Tanker >50k DWT	1,257	309	118
LNG/LPG Carrier	380	282	220
Tug	805	191	16
Articulated Tug	768	451	76
Tug	805	169	16
Passenger	2,600	347	54
Cruise Ship	2,600	347	54
All Vessels	3,622	302	16

Table C-6. Non-Persistent Cargo Capacity – Vessel Type

Vessel Type Vessel Sub-type	Persistent Cargo Capacity (cubic metres)		
	Maximum	Average	Minimum
Tanker	82,058	42,375	14,129
Tanker <50k DWT	57,298	39,760	14,129
Tanker >50k DWT	82,058	56,821	51,952
LNG/LPG Carrier			
Tug	30,869	13,351	1,400
Articulated Tug	30,869	20,881	4,289
Tug	11,368	4,084	1,400
All Vessels	82,058	37,305	1,400

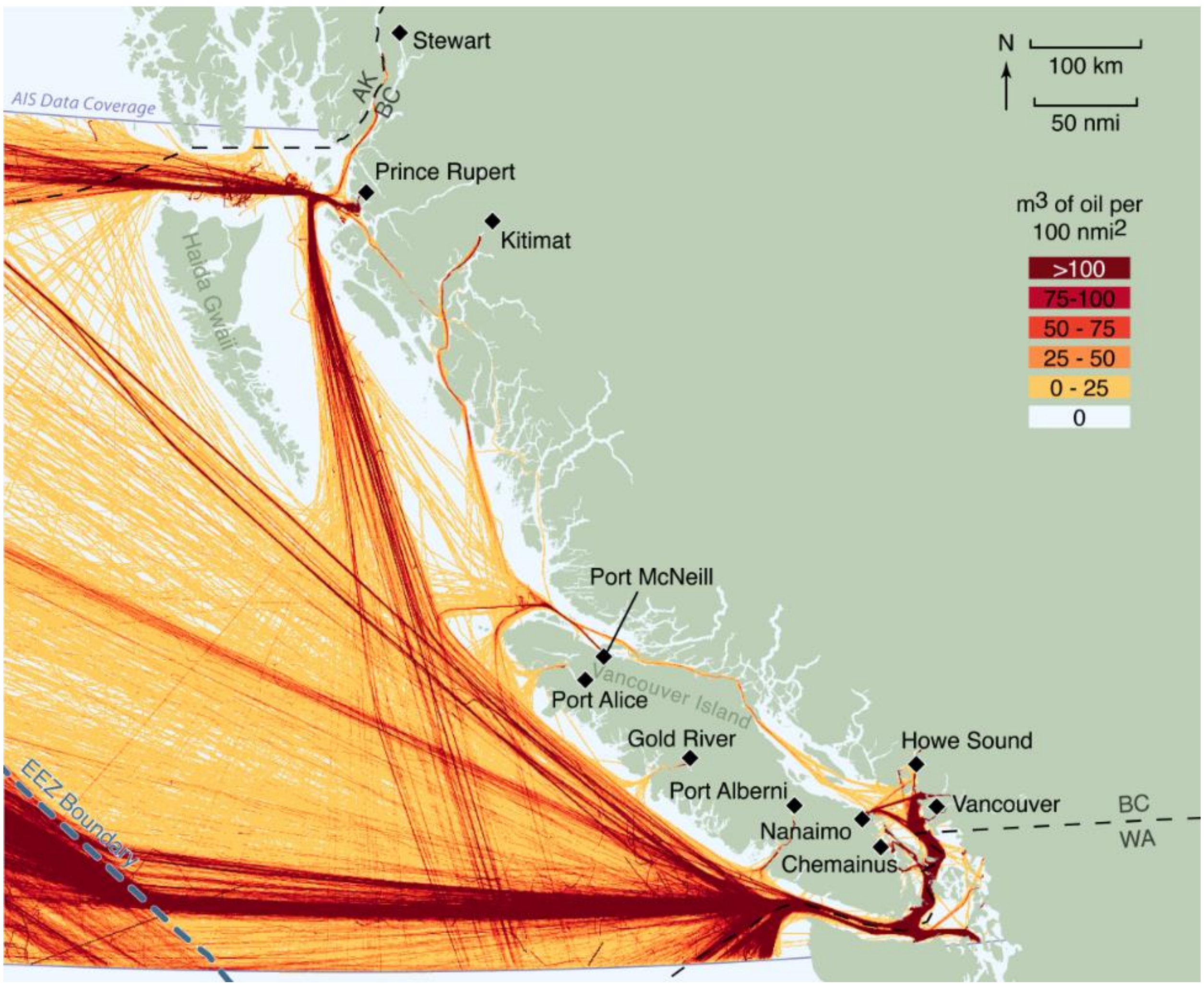

Figure C-3. Persistent Oil Movement Density – Cargo

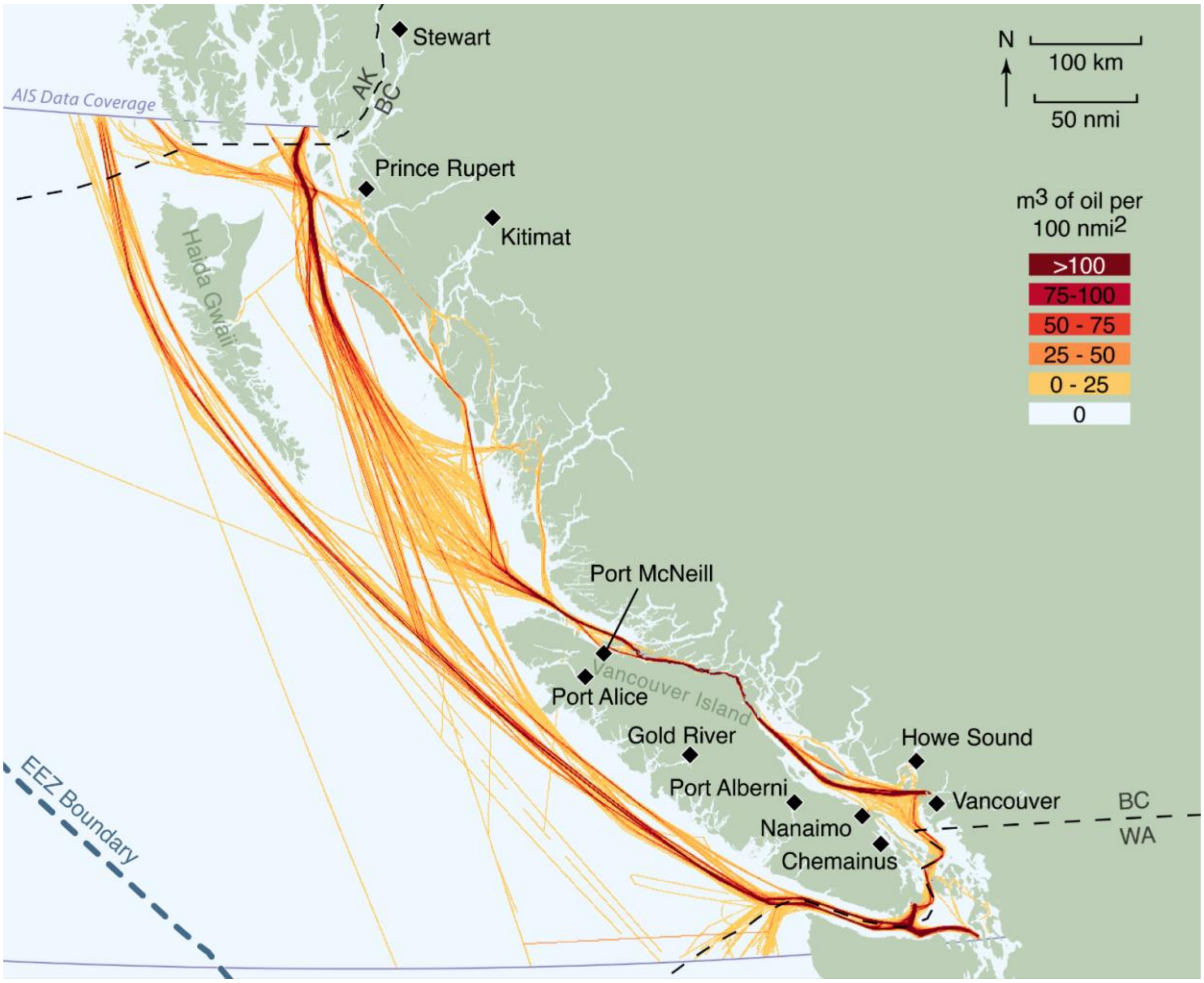

Figure C-4. Persistent Oil Movement Density – Passenger

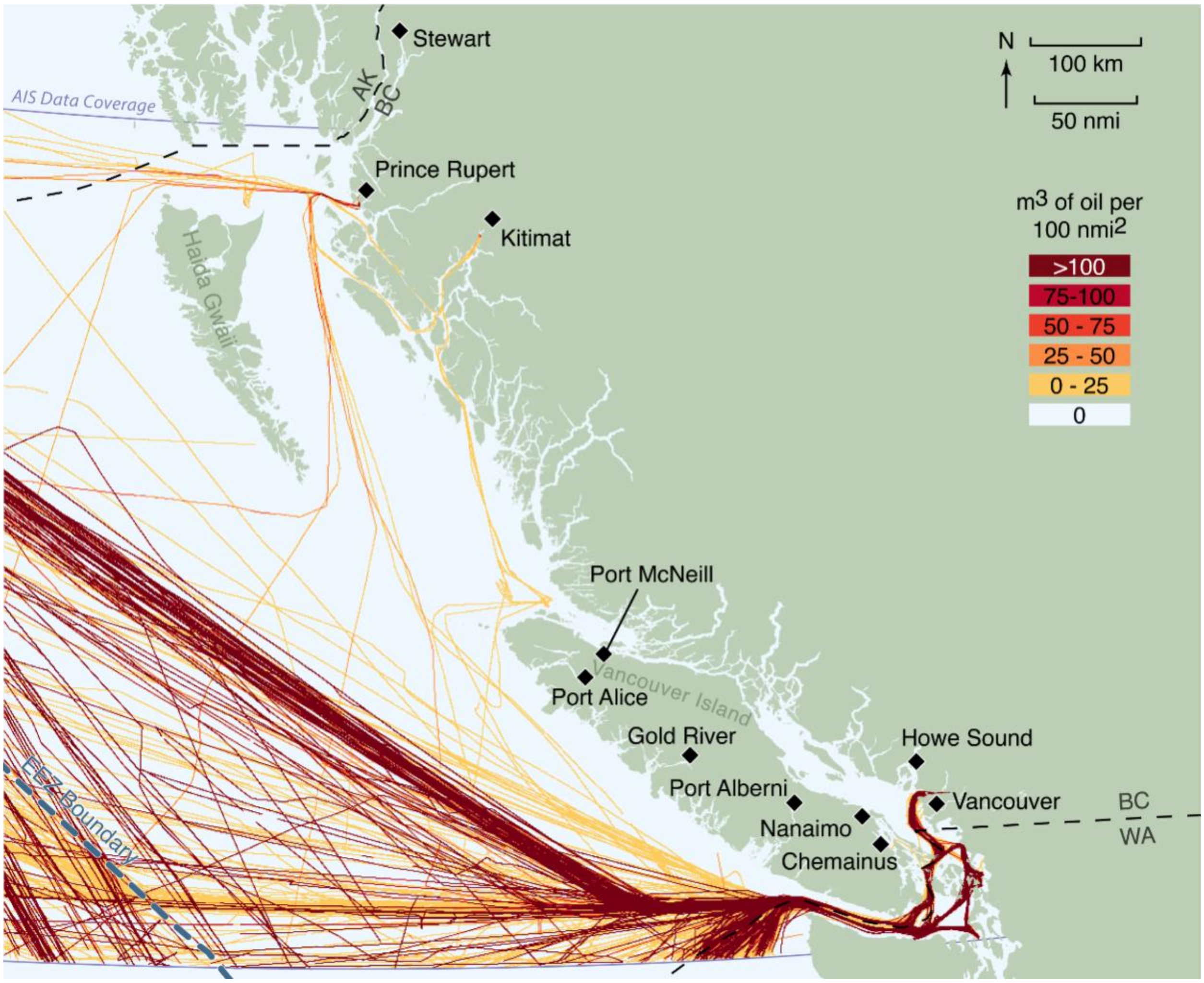

Figure C-5. Persistent Oil Movement Density – Tanker

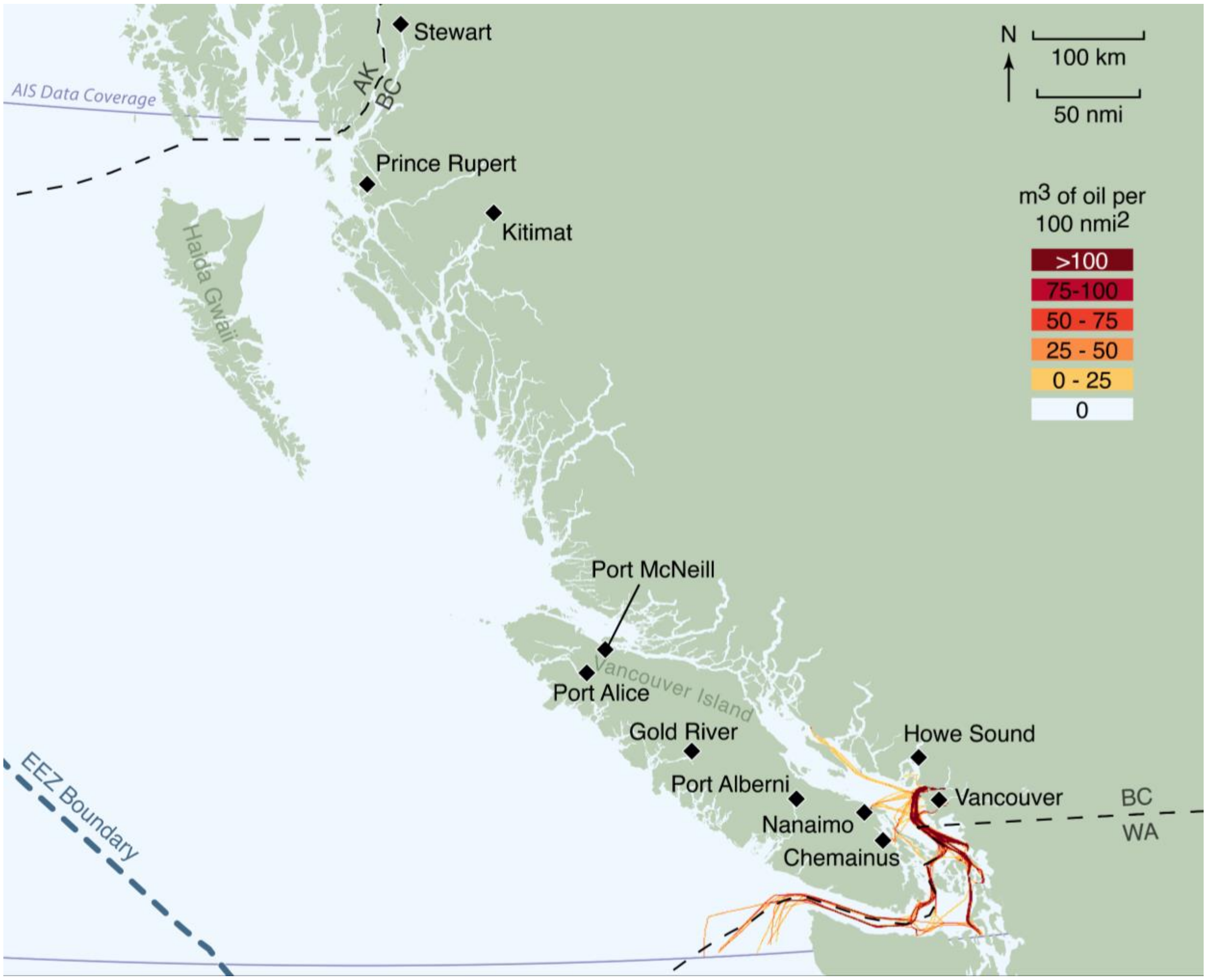

Figure C-6. Persistent Oil Movement Density – Tug

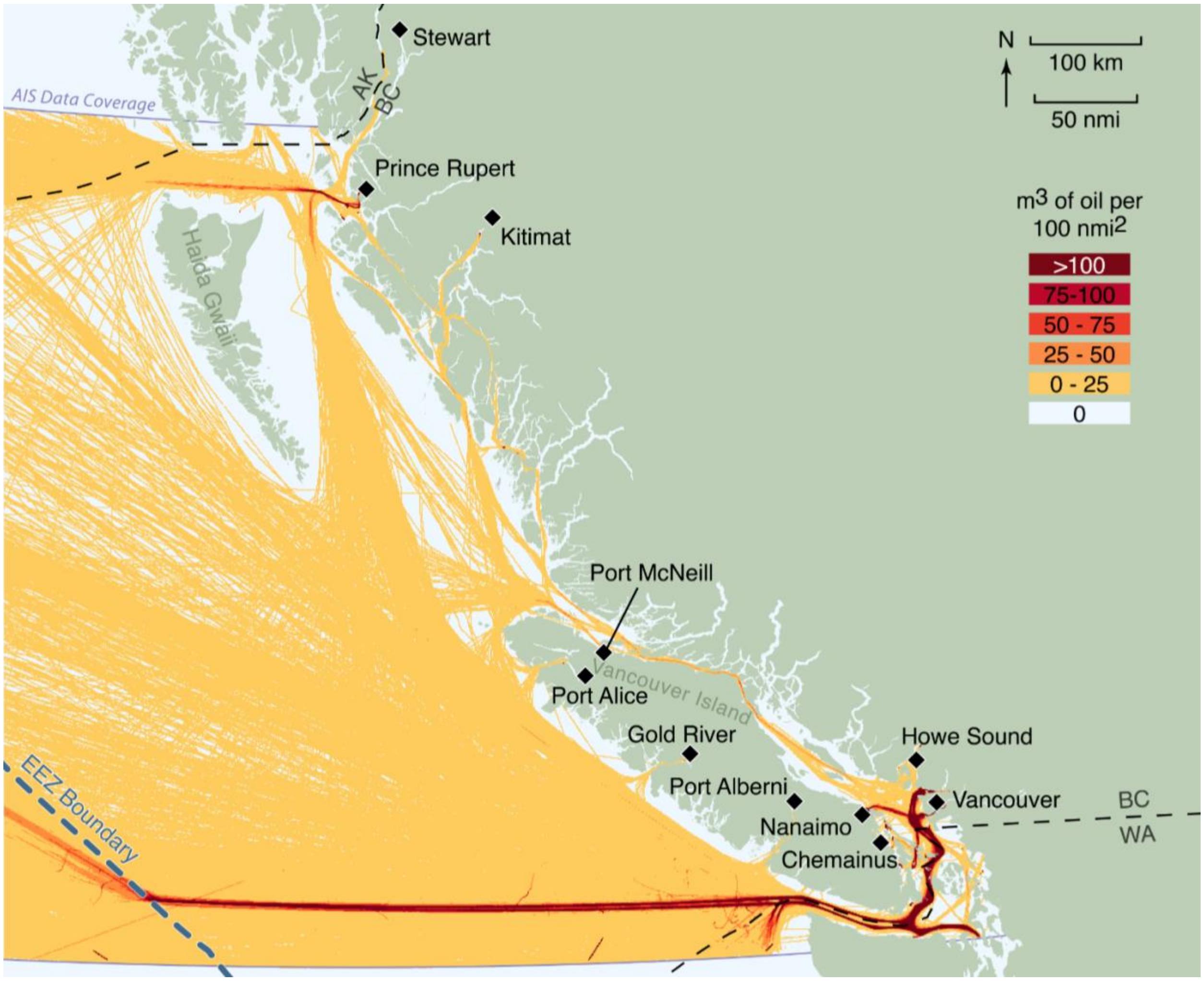

Figure C-7. Non-Persistent Oil Movement Density – Cargo

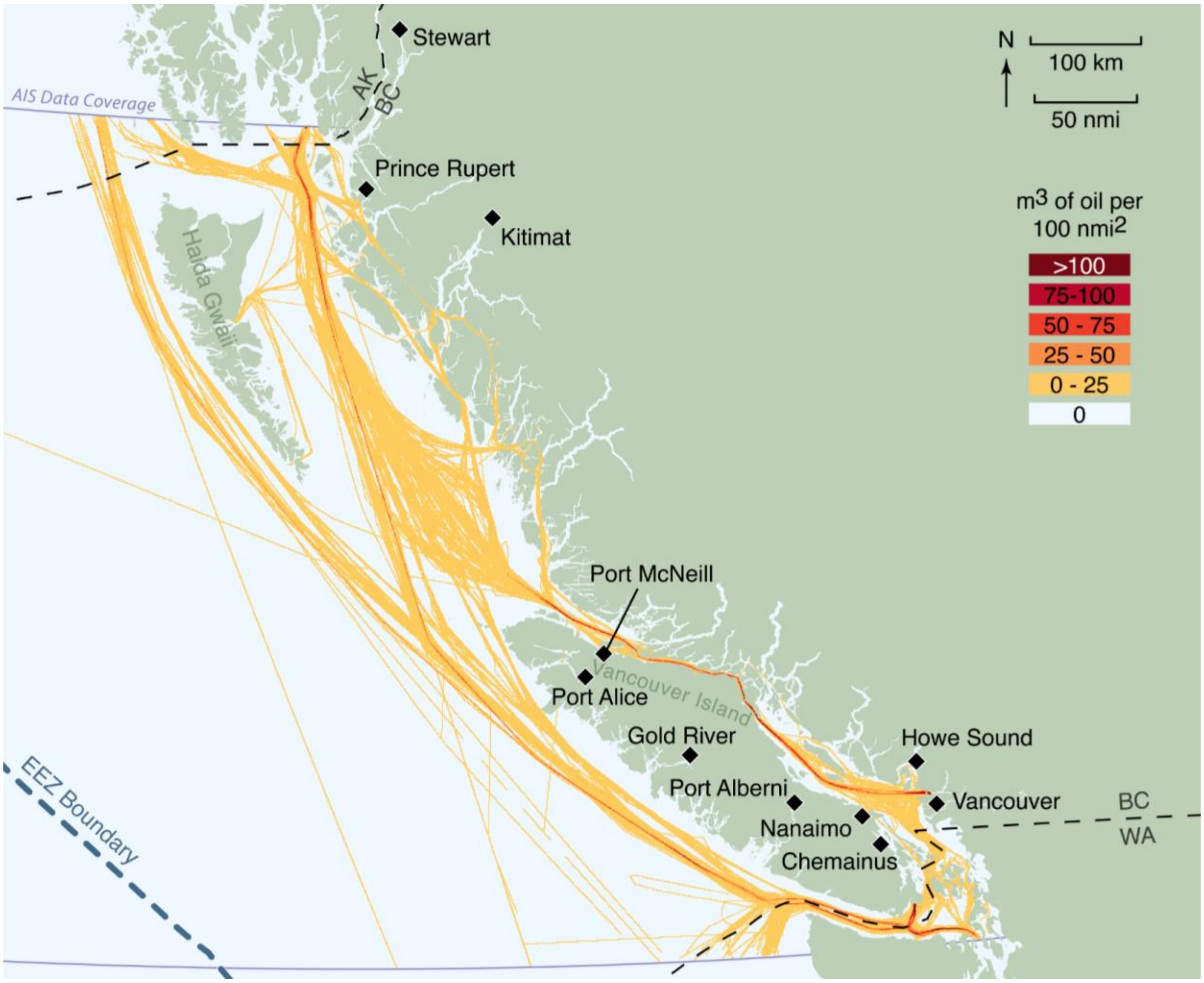

Figure C-8. Non-Persistent Oil Movement Density – Passenger

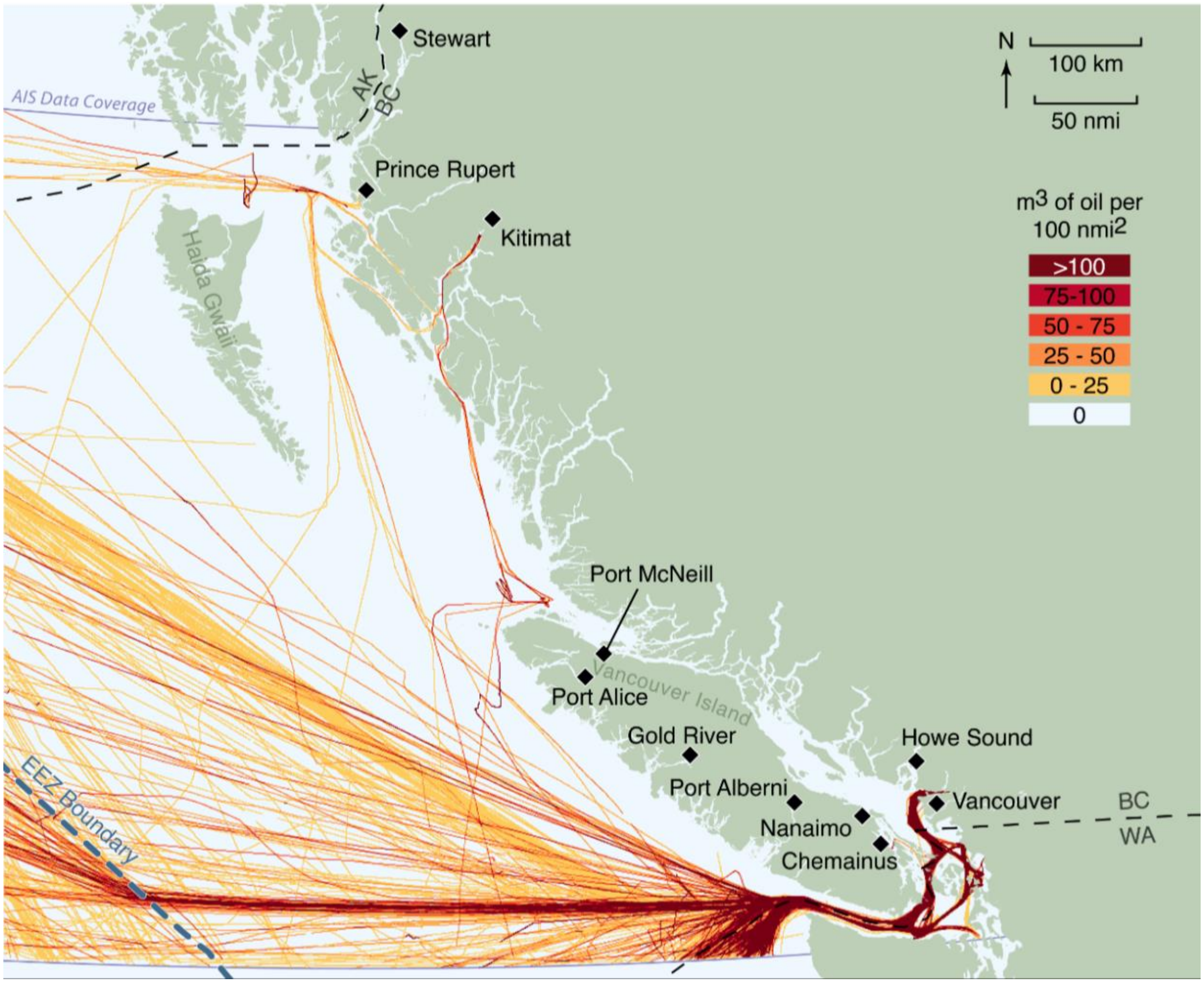

Figure C-9. Non-Persistent Oil Movement Density – Tanker

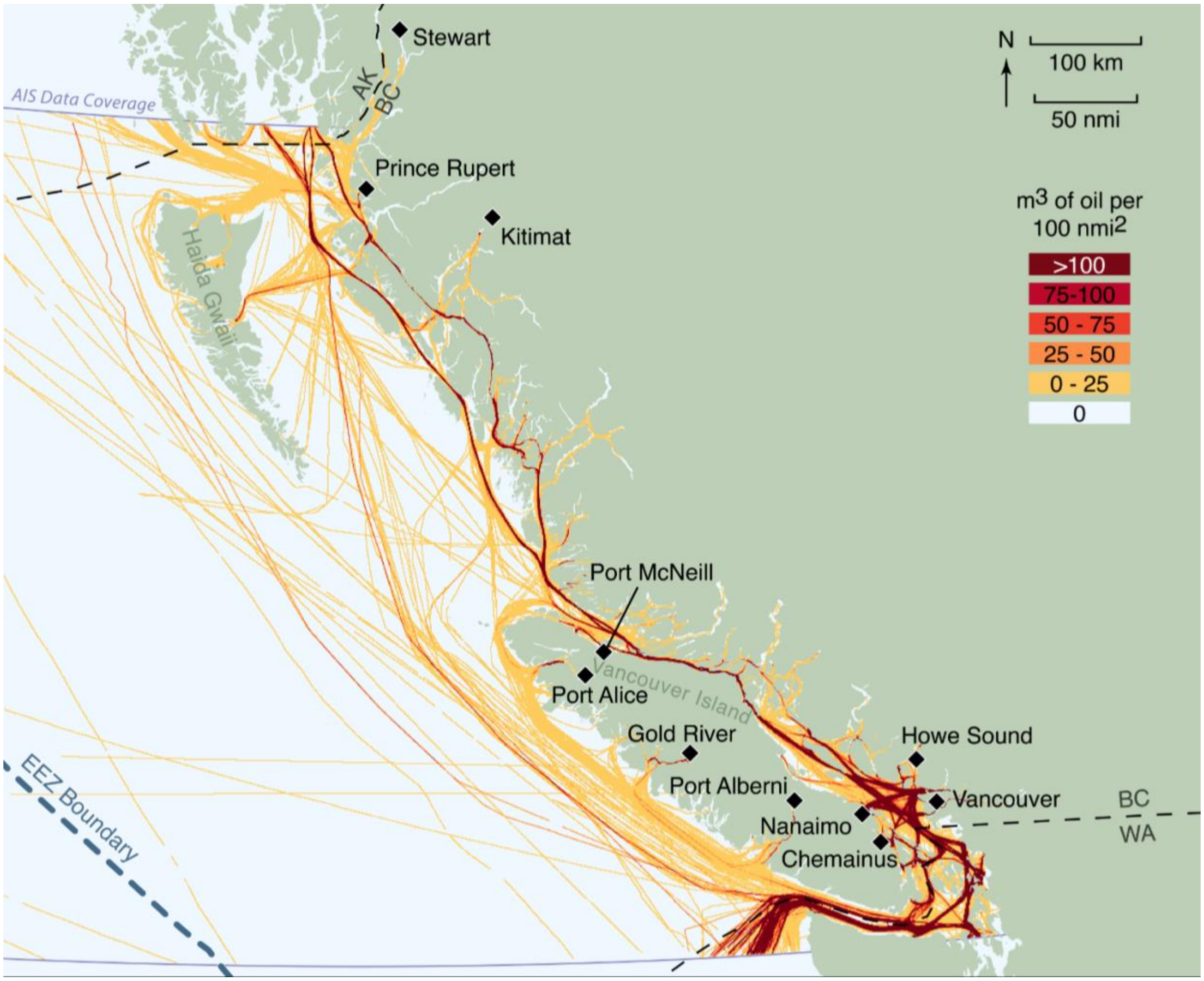

Figure C-10. Non-Persistent Oil Movement Density – Tug

Appendix D – Strait of Juan de Fuca Analysis

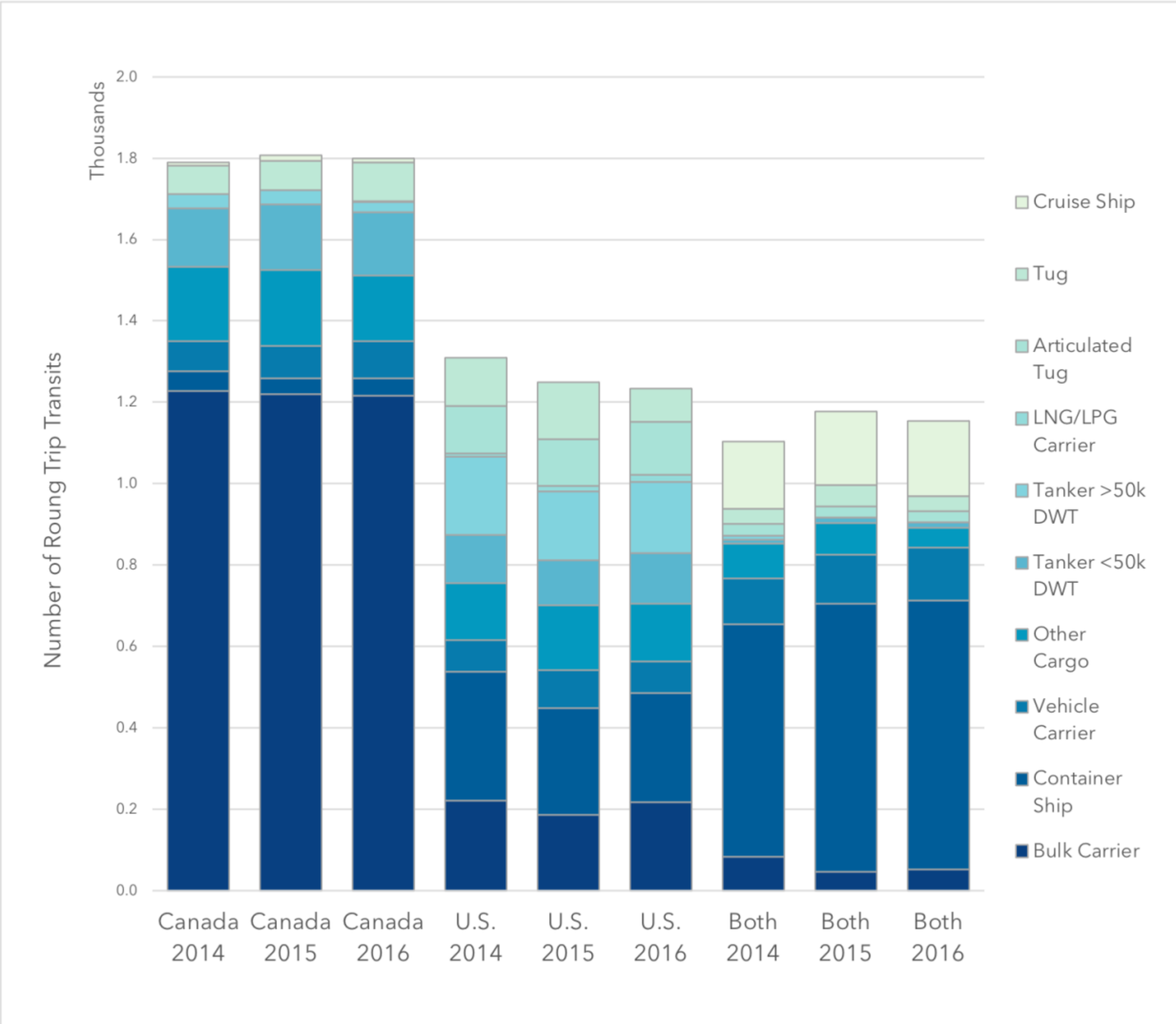

Figure D-1. Comparison of Countries Visited by Vessels Transiting Through the Strait of Juan de Fuca by Vessel Sub-Type and Year

Table D-1. Comparison of Countries Visited by Vessels Transiting Through the Strait of Juan de Fuca by Vessel Sub-Type and Year

Vessel Type	Canada			U.S.			Both		
Vessel Sub-type	2014	2015	2016	2014	2015	2016	2014	2015	2016
Bulk Carrier	1,228	1,220	1,216	221	187	218	84	46	53
Container Ship	49	39	44	318	262	268	570	659	660
Vehicle Carrier	74	79	91	76	93	78	114	121	131
Other Cargo	182	188	160	140	159	141	84	77	47
Tanker <50k DWT	144	160	157	120	112	124	10	14	14
Tanker >50k DWT	35	36	24	191	169	175	10	1	1
LNG/LPG Carrier	-	-	-	8	13	18	-	-	-
Articulated Tug	-	-	3	117	114	131	30	26	26
Tug	70	72	94	119	140	81	36	53	38
Cruise Ship	7	13	10	0	0	0	165	181	184