PRINCE RUPERT PORT AUTHORITY

MARINE NAVIGATIONAL AND ANCHORAGE AREAS RISK ASSESSMENT

FINAL REPORT

June 2020

Project: 19-1396

Table of Contents

Figures

Tables

Appendices

Executive Summary

Port of Prince Rupert (the Port) is the second biggest port on the West Coast of Canada. In the past decade the Port has experienced significant growth that has resulted in an increase of vessel traffic. This growth, which is expected to continue through the next decade, presents challenges regarding the safety and efficiency of port operations. As such, Prince Rupert Port Authority (PRPA) commissioned Dillon Consulting Limited (Dillon) to carry out a two part study, a Marine Navigational Risk Assessment (MNRA) and an Anchorage Area Risk Assessment (AARA) to ascertain the potential risks of navigational incidents (collisions, and groundings) of vessels calling to the port or transiting the area surrounding and adjacent to the Port. It was requested that this study include a focus on the projected potential increase in the number of vessels within the study area as well as the projected increase in vessel size since larger vessels will require additional space to manoeuver. The second part of this study, the AARA, was requested to also analyse the suitability of the current anchorages and to highlight the risk associated with the projected growth scenario.

After collection and preliminary review of relevant data and documentation, a hazard identification (HAZID) workshop was held in Prince Rupert. The workshop was attended by representatives of the PRPA, Transport Canada, Marine Communications and Traffic Services (MCTS), Pacific Pilotage Authority, BC Pilots, BC Ferries, several Port tenants, representatives of two Indigenous groups and several other stakeholders all of whom have vested interest in safe and efficient operations of the Port. The HAZID workshop sought insight on both parts this study (MNRA and AARA). The information obtained during the HAZID workshop was critical in the process and helped to get the better understanding of the challenges that the Port is experiencing and concerns that exist with the knowledge of the continued projected growth.

The results of the MNRA indicated that in the current scenario the highest risk to the port, posed by marine navigation, is in the inner harbour and the channel transiting to the inner harbour. Using data from 2018, the risk of a ship to ship collision, for all ships, was calculated to be 1 in 21 years for the waters within the Port. This risk increases to 1 in 19 years for the Port area in 2030 (9% increase). The highest risk of ship to ship collisions with current traffic within the Sub Area for larger commercial vessels is with Passenger-Ferry-Roro vessels at 1 in 131 years, followed by GDC-Bulker ships at 1 in 245 years. For 2030, there is no major increase in the expected number of ship to ship collisions for larger commercial vessels of these categories. It was noted that a vessel incident occurring in this area may cause a disruption to the Port's operations and therefore to the transfer of goods within Canada.

The MNRA results outlined a high risk of accidents by grounding within the sub area. In the current scenario results:

- A small vessel (such as a fishing vessel) is expected to ground once annually;
- Small commercial vessel groundings are expected to occur once every 13 years; and
- A large commercial vessel is expected to ground once every 32 years.

The 2030 scenario results were not notably higher.

The AARA's analysis of ship traffic near the anchorage areas found that the anchorages within the inner harbour are most at risk of having a transiting ship come into contact with them. Anchorages 7 and 8 were found to have a higher risk of contact by transitioning ships due to their proximity to vessels manoeuvring and turning in confined waters. The AARA also found that risk to the anchorages is not significantly increased by the increase in traffic.

The results of the AARA showed that presently the anchorage areas are not at capacity; however, in the future, there are likely to be instances where an anchorage area is not immediately available for a ship upon its arrival. This may require the Port to re-examine its guidelines for assignment of anchorages. The results also found that some anchorage areas do not currently have the required swing circle radius (the anticipated area that a ship may move while at anchor), and should therefore be re-defined, to adhere to the most up to date safety standards, where the geographical and operational limits allow. A review of recent anchor dragging incidents was conducted and supported the recommendation that the Port continues to collect detailed data on anchor dragging incidents. The AARA's analysis of anchorage holding capacity found that inner harbour anchorages are at a higher risk of dragging anchor at winds in the 90th percentile.

An international review of other ports found that the Port operates with many of the best practices required to reduce incidents.

Based on the results of the MNRA and AARA the following recommendations are suggested to improve marine safety of the Port:

- Provide detailed knowledge of each anchor area within the Port Information Guide, including depth of water and bottom type.
- The Port should consider issuing wind warnings when sustained winds are expected to exceed 20 knots.
- The Port should consider making it a requirement for all vessels to use 10 shackles when anchoring throughout the year, the current policy is to request vessels to use 10 only in winter.
- Consider repurposing anchorage 7 and 8 as they are in close proximity to vessels manoeuvring and turning in confined waters. As well consider decommissioning anchorages 11-14 as they are not expected to ever be used.
- Examine moving the pilot station further west to give the pilots more time to prepare for the transit into the Port.
- Review anchorage area assignment guidelines to optimize anchorage utilization. This would minimize the number of vessels having to move anchorages and reduce the likelihood of a vessel arriving and there being no anchor area available.
- Consider expanding the swing circle for certain anchorage areas to accommodate the projected increase to vessel size and to increase factors of safety.

- Consider collecting additional data on anchor dragging incidents, including number of shackles vessel used, wind direction, ballast condition, and speed as recorded on the vessel and what speed was rung on the engine to stop the dragging.
- The Port should consider continuing with its program to provide AIS to fishing vessels in the area.
- Consider implementing other best practices identified from the international jurisdiction review including requiring ships to weather major storms at sea instead of at anchor, a review to consider Pilot needs if several ships need to go out to sea due to a weather event, and other recommendations.

1.0 Introduction

The Port of Prince Rupert (the Port) has undergone tremendous growth over the past 10 years resulting in employment levels almost doubling since 2009. In 2017, the Port recorded over $35 billion in trade, which included a 28% increase in total cargo volume and a 26% growth in container volume (Prince Rupert Port Authority, 2018).

The Prince Rupert Port Authority (PRPA) has ambitious growth plans to ensure the needs of its tenants are met, future trade opportunities can be secured, and regional economic development goals are coordinated and balanced. This growth, as outlined in the Port's Gateway 2020 Vision, includes:

1. A liquefied petroleum gas (LPG) terminal opened in May 2019 on Ridley Island by AltaGas.
2. A LPG terminal in Port Edward by Pembina Pipeline coming online in late 2020.
3. A new LPG terminal, refined petroleum product and methanol facility on Ridley Island proposed by Vopak that would come online in 2022.
4. A proposed second jetty at Ridley Island Terminals.
5. A bunkering terminal proposed by Wolverine Terminal that is expected to come online in 2021.
6. Expansion to the Fairview container terminal.
7. Additional developments on the north coast that will increase marine traffic through the Hecate Strait and Dixon entrance.

To better understand the baseline navigational risks in and around Prince Rupert, and to take into consideration the cumulative risk profile of the above-referenced future projects, the PRPA required a Marine Navigation Risk Assessment (MNRA) and an Anchorage Area Risk Assessment (AARA) be undertaken. The goal of these assessments is to provide the necessary analysis to ensure that the port growth is able to be managed safely and properly.

The MNRA (**Section 4.0**) was completed to examine the current level of marine traffic and highlight navigational risks that could result in accidents. In addition, a future scenario was completed using 2030 forecasted vessel traffic to determine the potential changes in the risks to navigational safety of the waters around the port.

In 2012, the PRPA commissioned a study to assess the risk of vessels at anchor within the Port. However, since that time, local concerns have been raised with regards to the 21 vessels that have dragged their anchors over the past several years. Therefore, the AARA (**Section 5.0**) was completed to examine the suitability of the anchorages including their capacity, holding ground, swing circles, anchor dragging incidents and the potential for an incident to occur with ships in transit within their proximity. This was done for both the current level of traffic and the future traffic scenario to provide an overview of potential challenges that future growth may present in the Port.

This report provides an overview of the methodology and results of the MNRA and AARA and a summary of a literature review of other jurisdictions for best practices (**Section 6.0**). Recommendations for the Port are described in **Section 7.0** while detailed results and methodologies can be found in the appendices.

1.1 Objectives

Given the expansion of the Port and the increase in vessel traffic associated with this growth, combined with local concerns, the PRPA requested a re-evaluation of the marine navigational risks for the approaches to the Port and the capacity of the current anchorage areas. Specifically, the following analyses were completed:

1. A MNRA to determine what the risks are with respect to the increase in vessel traffic and changes in vessel types and sizes; and to identify practical ways to mitigate the determined risk.
2. An AARA to determine if the current anchorages meet industry best practices and new regulations for the current and projected needs of the Port.

2.0 Port of Prince Rupert

The Port, managed by the PRPA and located within the traditional territory of the Tsimshian, has undergone tremendous growth over the past 10 years. As an export nation, Canada's Gross Domestic Product is tied to our ability to effectively move goods and services through ports to foreign markets.

The Port is located in Prince Rupert, British Columbia with multiple terminals in the inner harbour and on Ridley Island. The study area for this project included the jurisdiction of the Port, as well as the surrounding waters. The study area is outlined in red in **Figure 2-1** with the Port jurisdiction outlined in blue.

The PRPA has ambitious growth plans that are outlined through the Gateway 2020 Vision. With over 1,000 hectares (ha) of federal crown land dedicated for terminal-related development, the sustainable growth strategy needs to capitalize on the opportunities, while at the same time address the corresponding risks that come with growth and increased terminal activity. As such, this study was conducted using two vessel traffic scenarios: the current scenario modeled 2018 vessel traffic data, while a growth scenario considered potential future vessel traffic and changes to vessel size as projected by PRPA and nearby LNG projects. Environmental data used during this study is also outlined in this section; these inputs were used for both scenarios.

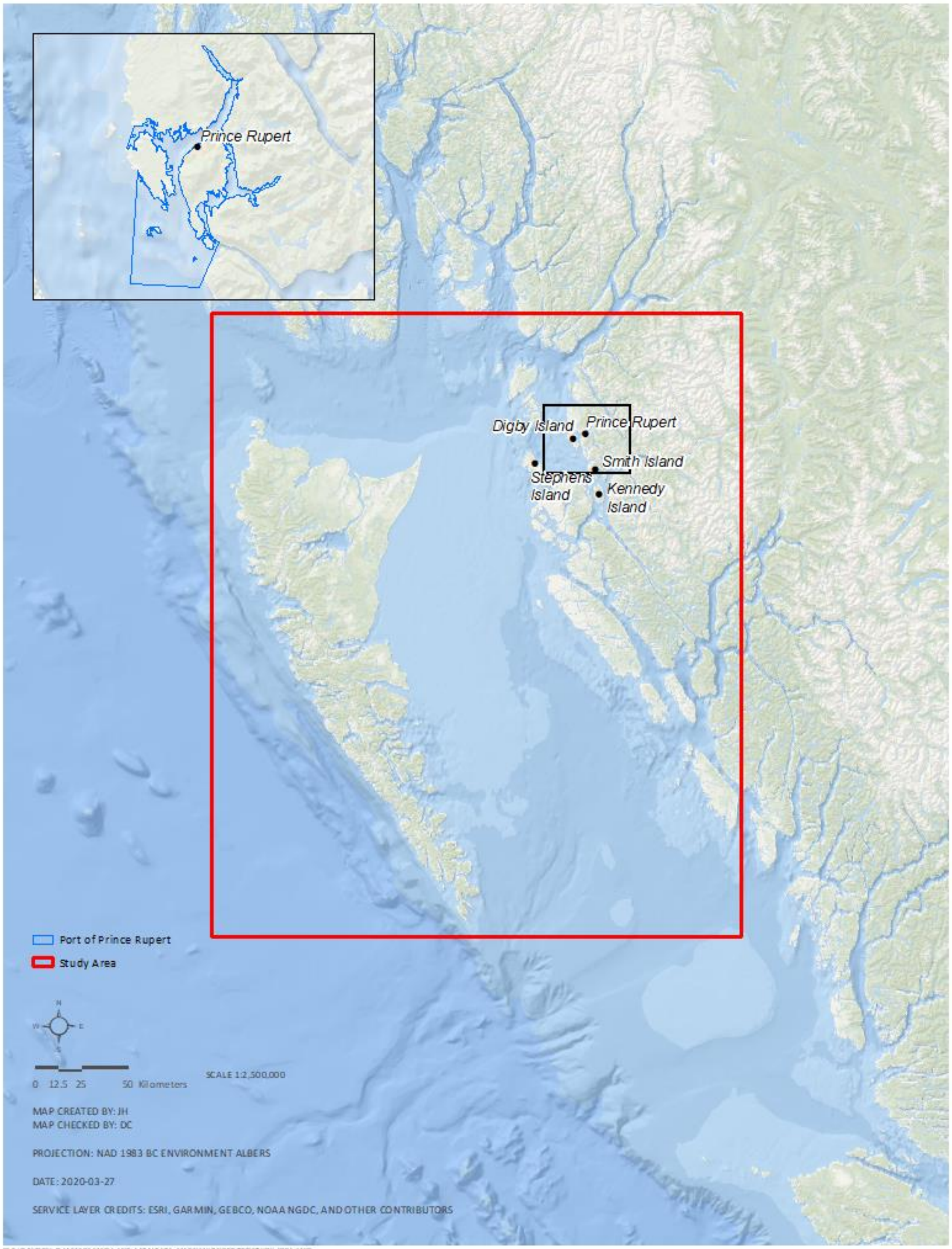


Figure 2-1: Study Area

2.1 Port of Prince Rupert – Current Scenario

Information was obtained directly from the Port and the Port Information Guide (Prince Rupert Port Authority, 2019) and used to determine the current infrastructure and terminals at the Port. The Port Information Guide was also used to determine the anchorage areas and current guidelines for anchoring vessels. AIS data for the 2018 calendar year was provided by Alaska Marine Exchange to the Port. This AIS data was used to determine current vessel traffic calling on the Port and using the anchorage areas. In addition, a HAZID workshop was conducted to bring together stakeholders, terminal owners and mariners to identify hazards from their perspectives. Details on the HAZID workshop are discussed in **Section 3.0**.

2.1.1 Port Infrastructure/Terminals

The Port has a number of terminals, listed below in **Table 2-1**, which were included in the current scenario.

Table 2-1: Terminals within the PRPA Jurisdiction

Name of Facility	Facility Type	Operator
Fairview Container Terminal	Intermodal	DP World
Northland Cruise Terminal	Cruise Dock & Passenger Terminal	Prince Rupert Port Authority
Ridley Coal Terminal	Bulk Export	Ridley Terminals Inc.
Prince Rupert Grain Terminal	Bulk Export	PRG Ltd.
Westview Wood Pellet Terminal	Wood Pellet Export Terminal	Pinnacle Renewable Energy Group
Alaska Marine Highway Ferry Terminal	Passenger Facility	Alaska Department of State Transportation and Public Facilities
Atlin Terminal	Port Administration Complex	Prince Rupert Port Authority
BC Ferries Terminal	Passenger Terminal	BC Ferries
Ridley Project Cargo Facility	Project Cargo	PRPA
Rushbrook Harbour	Public Marina	Port Edward Harbour Authority
Fairview Harbour	Public Marina	Port Edward Harbour Authority
Alta Gas Propane Export Facility	Propane Export	Alta Gas
Cow Bay Harbour	Public Marina	Port Edward Port Authority
Port Edward Harbour Port Authority	Public Marina	Port Edward Harbour Authority

2.1.2 Anchorage Areas

The PRPA has 31 designated anchorage areas that it oversees, as illustrated in **Figure 2-2**. Port operations require that the Port maintain anchorage areas for ships that may need to wait for an available berth, or for health and pest inspections. To manage the needs of the various terminals, inspections, and health and safety risks, the Port has developed anchorage assignment guidelines. These guidelines are also dictated by the size of the vessels, since not all anchorage areas will have an appropriate swing radius (the anticipated area that a ship may move while at anchor) required for larger ships. **Table 2-2** provides details on the 31 anchorage areas including the designed swing radius and the guidelines for assignment which was developed through review of the Port Information Guide and information collected at the HAZID.

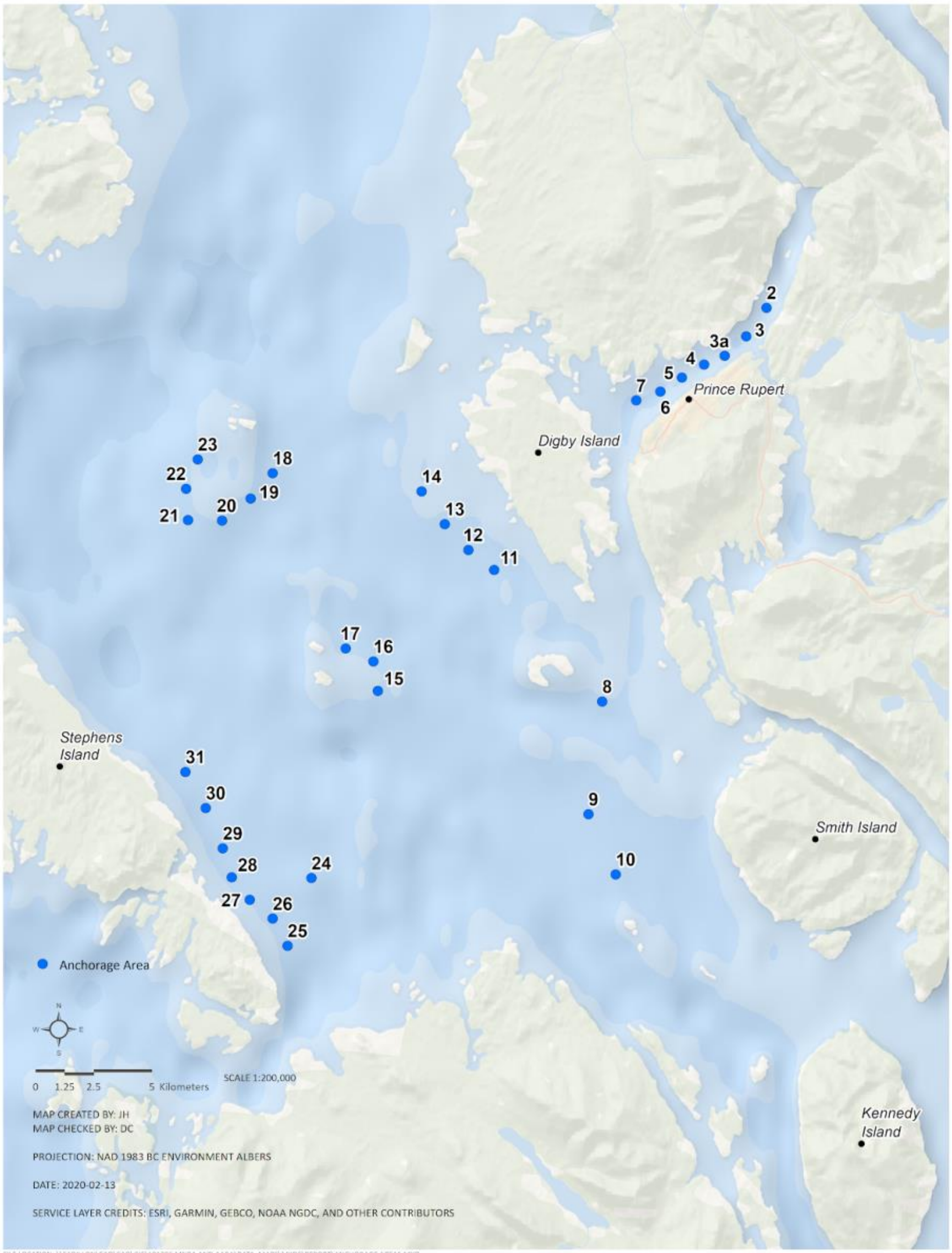


Figure 2-2: Anchorage Areas for the Port of Prince Rupert

Table 2-2: Anchorage Area Assignment Guidelines

Anchorage Number	Swing Radius (m)	How it is Assigned	Other Details
2	550	225 m Mainly log vessels assigned. Small grain vessels mainly and small log vessels	Expect to be serviced by proposed fuel barge
3	550	225 m Small grain vessels mainly, pellets, log vessels Limited Dangerous Goods (DGs)	Expect to be serviced by proposed fuel barge
3a	375	Rarely used	Expect to be serviced by proposed fuel barge
4	550	225 m Small grain vessels mainly, pellets Limited DGs	Expect to be serviced by proposed fuel barge
5	550	225 m Small grain vessels mainly, pellets, CFIA inspections	Expect to be serviced by proposed fuel barge
6	600	250 m Large grain and pellet vessels, CFIA inspections	Expect to be serviced by proposed fuel barge
7	600	250 m Large grain and pellet vessels, CFIA inspections	Prefer to leave it empty if large vessels are coming in Expect to be serviced by proposed fuel barge
8	650	270 m Preferred anchorage for fumigation CFIA inspections - preferred	Expect to be serviced by proposed fuel barge
9	725	350 m Intermodal Bulk, LPG, LNG, DGs, Asian Gypsy Moth Inspections (AGM), Typically used for LPG Also used for inspections - preferred	Expect to be serviced by proposed fuel barge
10	870	400m Bulk, LPG, LNG, DG, AGM Intermodal Also used for inspections - preferred	
11	600	Emergency use - rarely used	Located near aquaculture sites
12	600	Emergency use - rarely used	Located near aquaculture sites
13	600	Emergency use - rarely used	Located near aquaculture sites
14	600	Emergency use - rarely used	Located near aquaculture sites
15	650	270 m Grain carriers that do not need inspection sent there if inner harbour is full Larger grain ships anchor here Long term bulk	

Anchorage Number	Swing Radius (m)	How it is Assigned	Other Details
16	650	270 m Grain carriers that do not need inspection sent there if inner harbour is full Larger grain ships anchor here Long term bulk	
17	650	270 m Grain carriers that do not need inspection sent there if inner harbour is full. Larger grain ships anchor here. Long term bulk	
18	700	325 m Bulk Long term bulk	
19	700	325 m Bulk Long term bulk	
20	700	325 m Bulk, AGM re-inspection	
21	700	325 m Bulk AGM re-inspection	
22	700	325 m Bulk Long term bulk	
23	700	325 m Bulk Long term bulk	
24	725	350 m Long term Bulk, LPG, LNG, DG and AGM inspection Larger anchorages, mostly coal vessels	
25	700	325 m Long Term Bulk, DG, LPG Larger anchorages, mostly coal vessels Can accommodate 325-350 m	
26	600	270 m Mostly coal vessels, Long term bulk	
27	650	325 m Larger anchorages, mostly coal vessels	
28	600	270 m Mostly coal vessels	
29	675	Only assigned if other anchorage areas are full Long term bulk	

Anchorage Number	Swing Radius (m)	How it is Assigned	Other Details
30	675	350 m Bulk, LPG, LNG, DG Only assigned if other anchorage areas are full	
31	675	350 m Bulk, LPG, LNG, DG	

2.1.3 Port Access/Traffic

The study area for this risk assessment included areas outside of the Port's jurisdiction in order to capture traffic on the approaches to the Port. In addition to the traffic for the Port, the study area has a significant amount of other vessel traffic not destined to the Port (i.e., recreational traffic from sport fishing, private users and whale watching). Furthermore, commercial shipping traffic uses Hecate Strait to transit from Alaska to other US ports. **Figure 2-3** illustrates AIS signals captured in the study area for 2018 at 10 minutes intervals. A figure illustrating vessel traffic, obtained from the AIS data for 2018, in the approaches to the Port is presented in **Figure 2-4**. The thicker the lines, the more traffic uses the route. The black lines indicate vessels transiting in an eastward or northern direction and the orange indicates vessels transiting in a westward or southern direction.

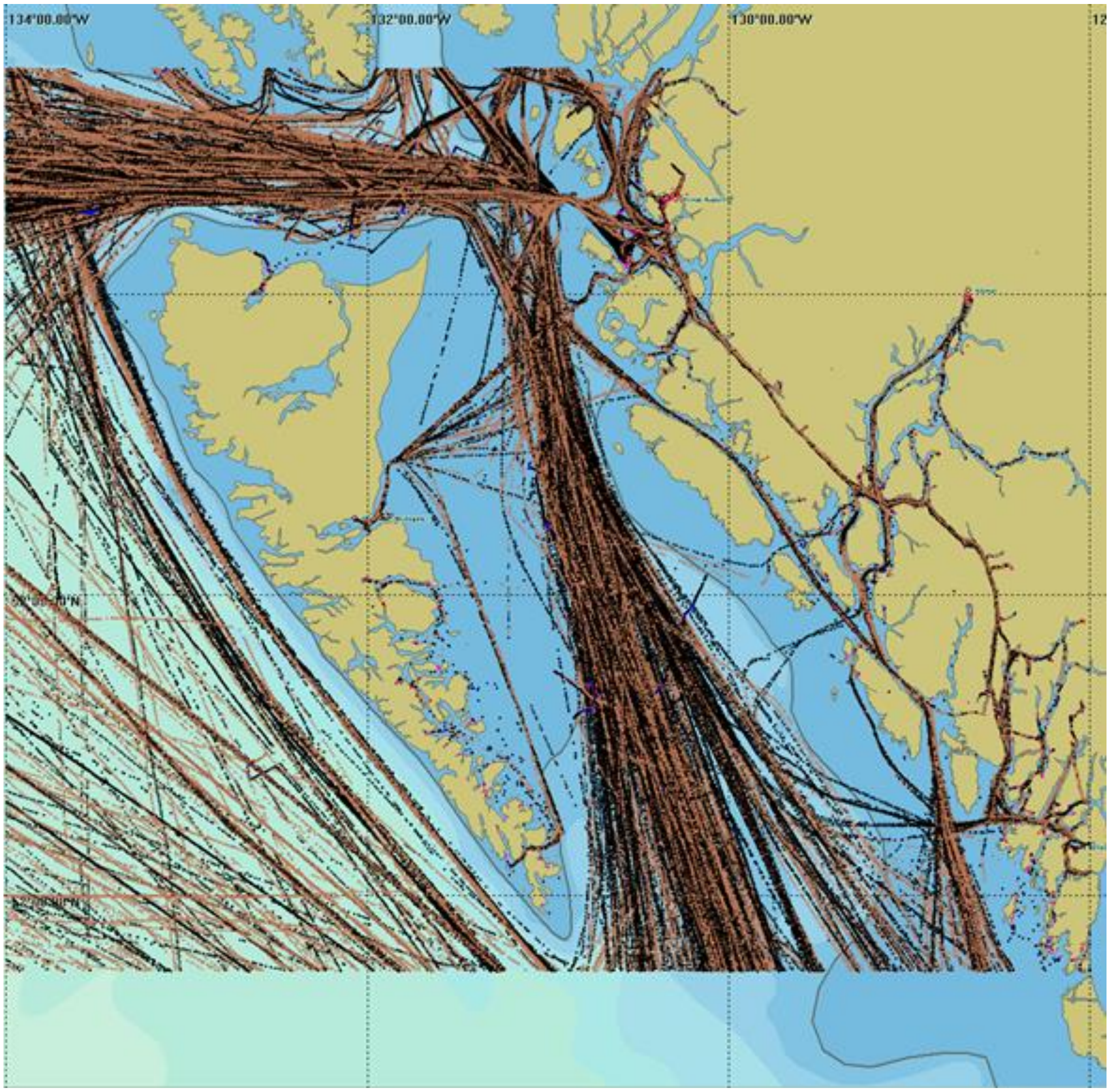


Figure 2-3: AIS Signals Captured in the Study Area for 2018 Plotted at 10 Minute Intervals

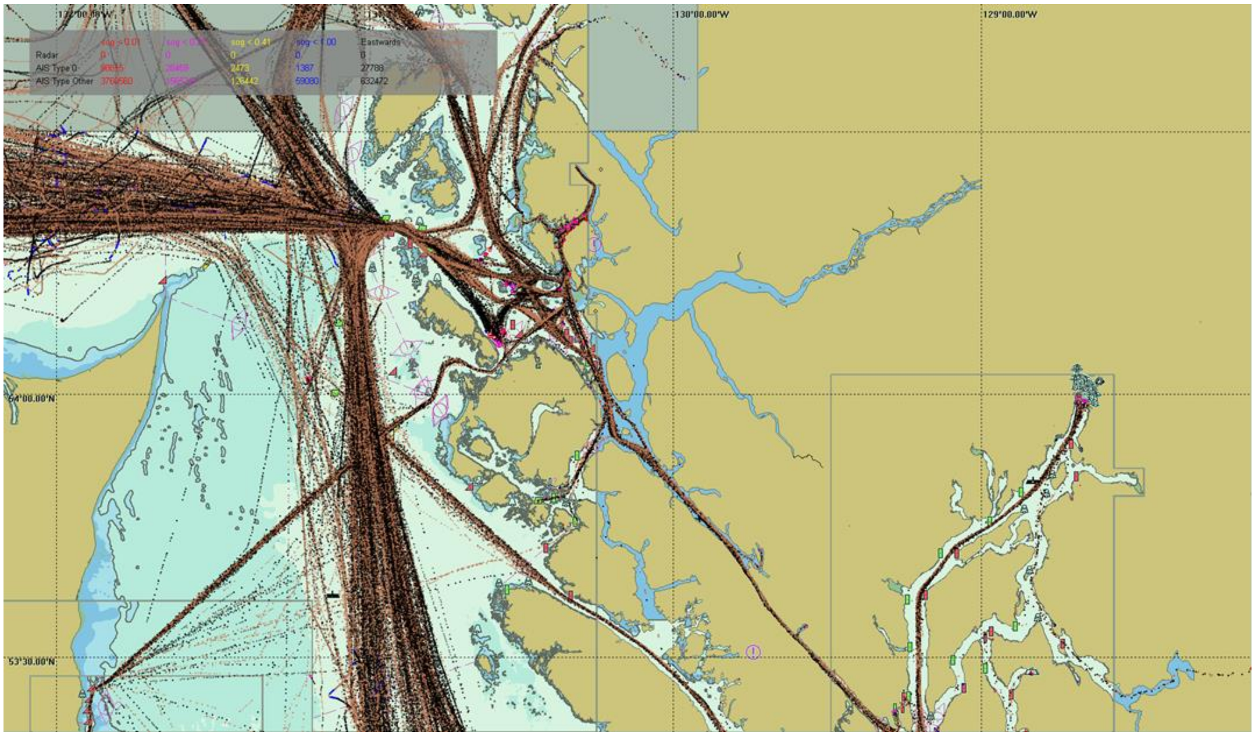


Figure 2-4: AIS Signals for the Approaches to the Port – 2018

2.1.3.1 Port Entrance

There are two ways a ship can enter the port. The majority of the ships are traveling through the large southern entrance. Only a few ships are coming from the smaller northwest entrance (**Figure 2-5**). For the ships passing Crossing Line 2 (crossing lines are identified below in **Figure 2-5**), a statistical overview of the length, breadth, and gross tonnage of the passing ships is provided below in **Table 2-3**, and **Figure 2-6**. It's important to note that **Figure 2-6** includes only the ships crossing line 2 which had length data included in the AIS data. Therefore there is a discrepancy between the numbers in **Table 2-3** and **Figure 2-6**.

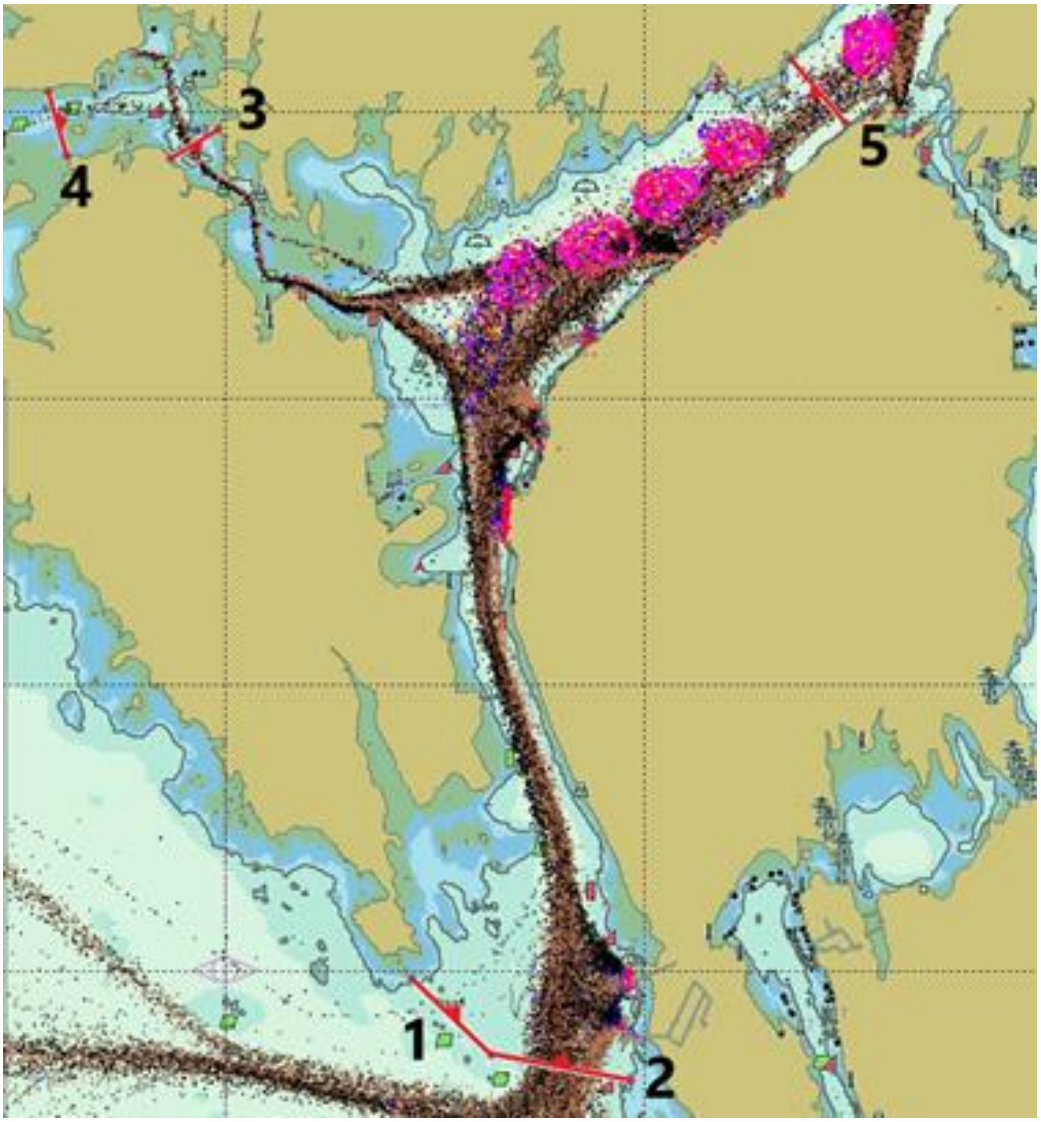


Figure 2-5: Location of the Crossing Lines

Table 2-3: Total Number of Route Bound Vessels Crossing the Different Lines (in the direction of the port as indicated by arrow on line) based on 2018 AIS Data

Ship Type	Crossing Line					Total
	1	2	3	4	5	
BULK_GDC	2	322	1	0	55	380
Tanker	0	3	0	0	0	3
Container	0	187	0	0	0	187
Pass/Roro	8	566	326	17	100	1017
Total	10	1078	327	17	155	1587

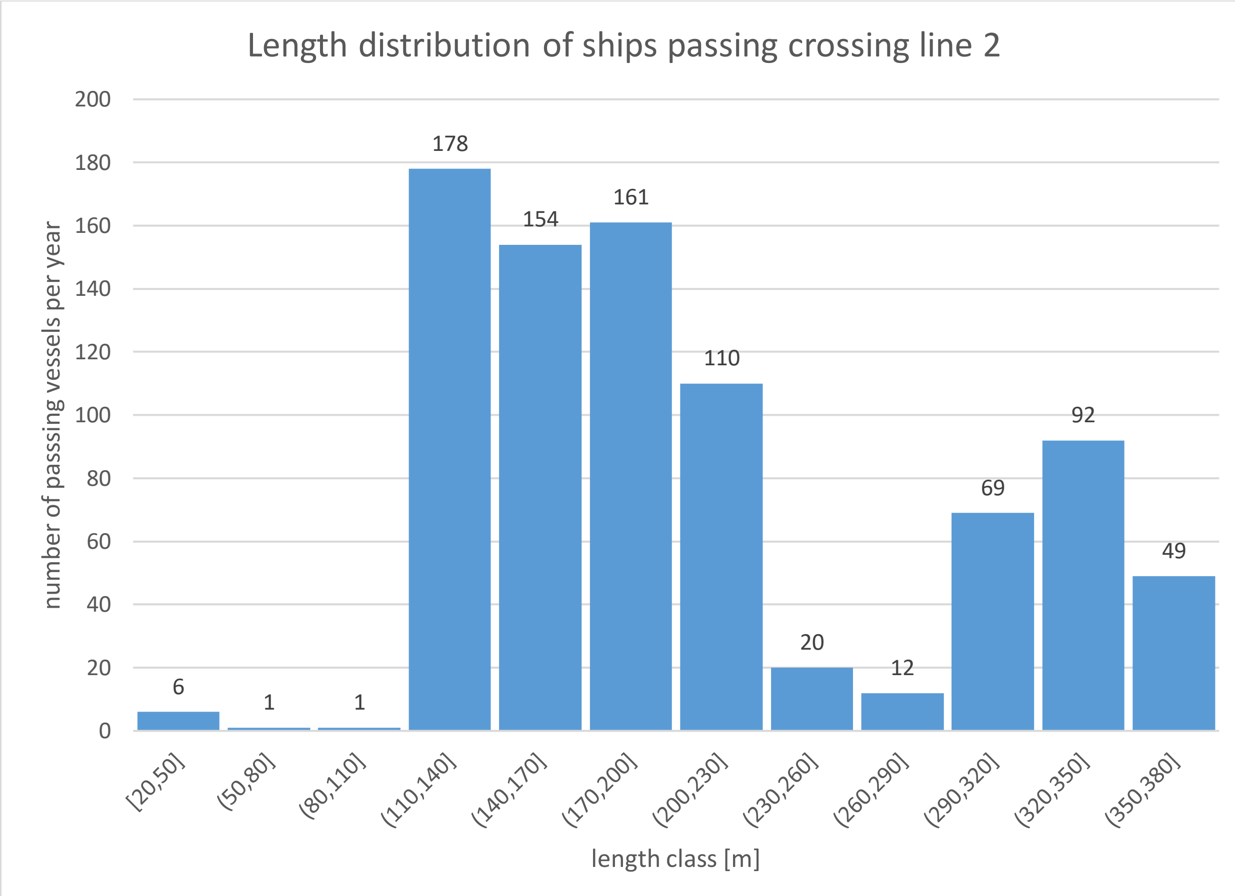


Figure 2-6: Length Distribution of Ships Passing Crossing Line 2

From a navigation safety perspective, the Port is under Vessel Traffic Management Services (VTMS) and Pilotage requirements. Specifically, most of the north coast is under VTMS. In addition to mandatory Pilotage for vessels entering the port and anchorage areas, the larger 'Pilotage requirement areas', provide additional safety to vessels transiting in the area.

The Port has 31 anchorage areas. AIS signals from the anchorage areas were identified and highlighted in pink illustrated **Figure 2-7** below. Several of the designated anchorage areas, including the anchorage areas south of Digby Island (anchorage areas 11-14) were not used in 2018, according to the AIS data.

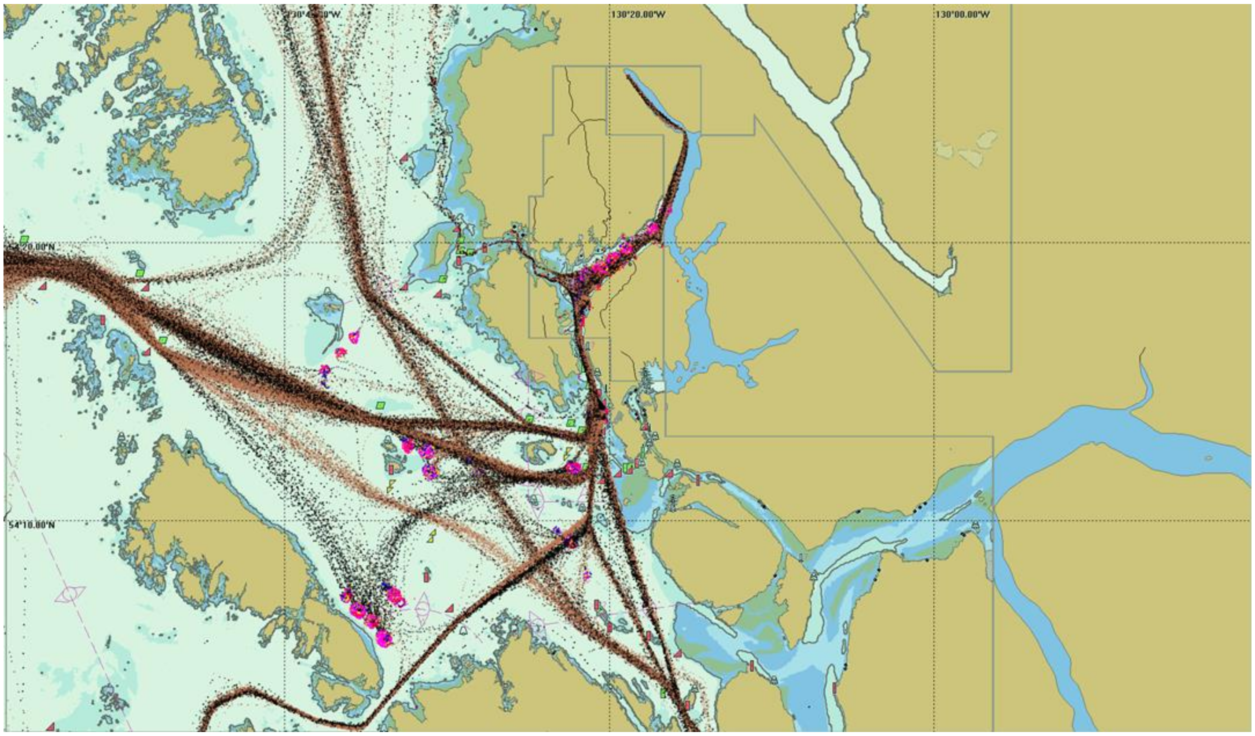


Figure 2-7: AIS Signals for 2018 with Anchorage Area Signals in Pink

As can be seen in **Figure 2-7** above, there are several anchorage areas near Rachel Island (anchorages 15-17), which are located near the traffic that transits in and out of the Port. In addition, transiting vessels pass closely to the anchorage area 8 next to Kinahan Island. **Figure 2-8** provides a more detailed illustration of vessel traffic in relation to anchorages 8, 17, 16 and 15.

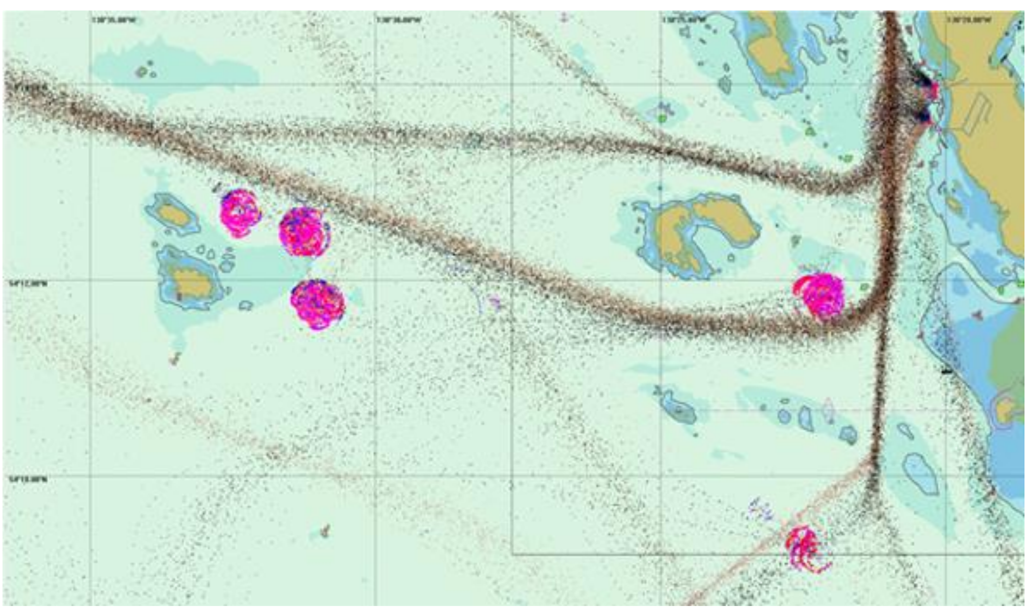


Figure 2-8: AIS Signals for 2018 with Anchorage Area Signals in Pink

2.2 Projected Growth Scenario – 2030

The Port is projecting commercial vessel traffic increases from current volumes of a 576 vessels per year to 1,282 vessels per year by 2030. Even if the total vessel calls do not reach the projected 1,282, it is anticipated that commercial vessel traffic calling on the Port will increase above the 2018 numbers due to the development of the new terminals and a planned increase in intermodal traffic. The following sections outline the growth scenario infrastructure, vessel traffic, and anchorage areas used in this study.

2.2.1 Port Infrastructure/Terminals

The PRPA and its tenants have several new terminal developments and expansions that are planned to take place between 2019 and 2030. The new proposed terminals and the changes to existing terminals are outlined below in **Table 2-4** and illustrated in **Figure 2-9**.

Table 2-4: New Proposed Terminals for the Port

Terminal	Commodity	Proposed Opening	Traffic Calling to the Terminal
Wolverine Terminals	Mobile Bunkering	TBD	Bunkering will be done by a barge maneuvered alongside vessels at anchorage.
Ridley Island Terminals - 2nd Jetty	LPG	TBD	Additional 18 vessels a year
Pembina Pipelines	LPG	2020	10/year progressing to 48/year
VOPAK	LPG, Methanol, Clean Petroleum Products	Estimated 2022	27 vessels a year LPG 55 vessels a year Clean petroleum products 146 vessels a year for methanol
DP World	Intermodal	To be determined	Additional 312 container ships by 2030.

Figure 2-9: Recent and Future Planned Terminal Expansion Locations

2.2.2 Anchorage Areas

The anchorage areas at the Port will be subject to an increase in use as traffic to the Port increases. The Port has experienced a number of anchor dragging incidents within the past few years which represents an increase in risk to the Port. This is especially true in the inner harbour where there is limited space to manoeuver or time to respond if a vessel is dragging its anchor. More details on incidents involving vessels dragging their anchors within the Port is found in **Section 5.3**.

Figure 2-10 shows the number of assignments for the anchorage areas in 2030, incorporating the projected growth in vessel traffic in the Port. Using the projected vessel traffic growth in 2030 it is expected that the 31 anchorages within the Port will not be at full capacity. However, there is a large increase in the utilization of anchorages which are designated for dangerous goods cargo (anchorages 2-10 and 24 -31), which is expected given the increase in LPG traffic from many projects around Ridley Island. More details on the anchorage utilization and modelling for the future scenario are found in **Section 5.2** for the Anchorage Assessment.

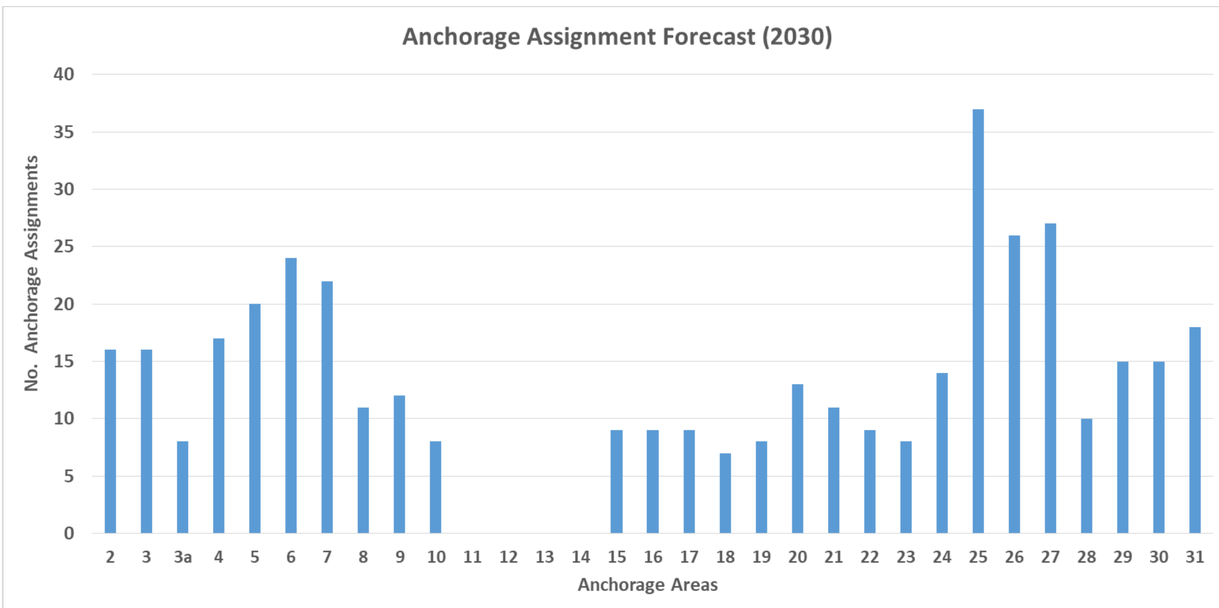


Figure 2-10: Projected Anchorage Assignments for the Future 2030

2.2.3 Traffic Projections

The Port provided a forecast for vessel traffic growth to 2030. As illustrated in **Figure 2-11**, the largest increase in the number of vessels calling on the Port over the next ten years is expected to come from tankers carrying liquid cargoes including LPG, Methanol and Clean Petroleum Products as well as an increase in container ships.

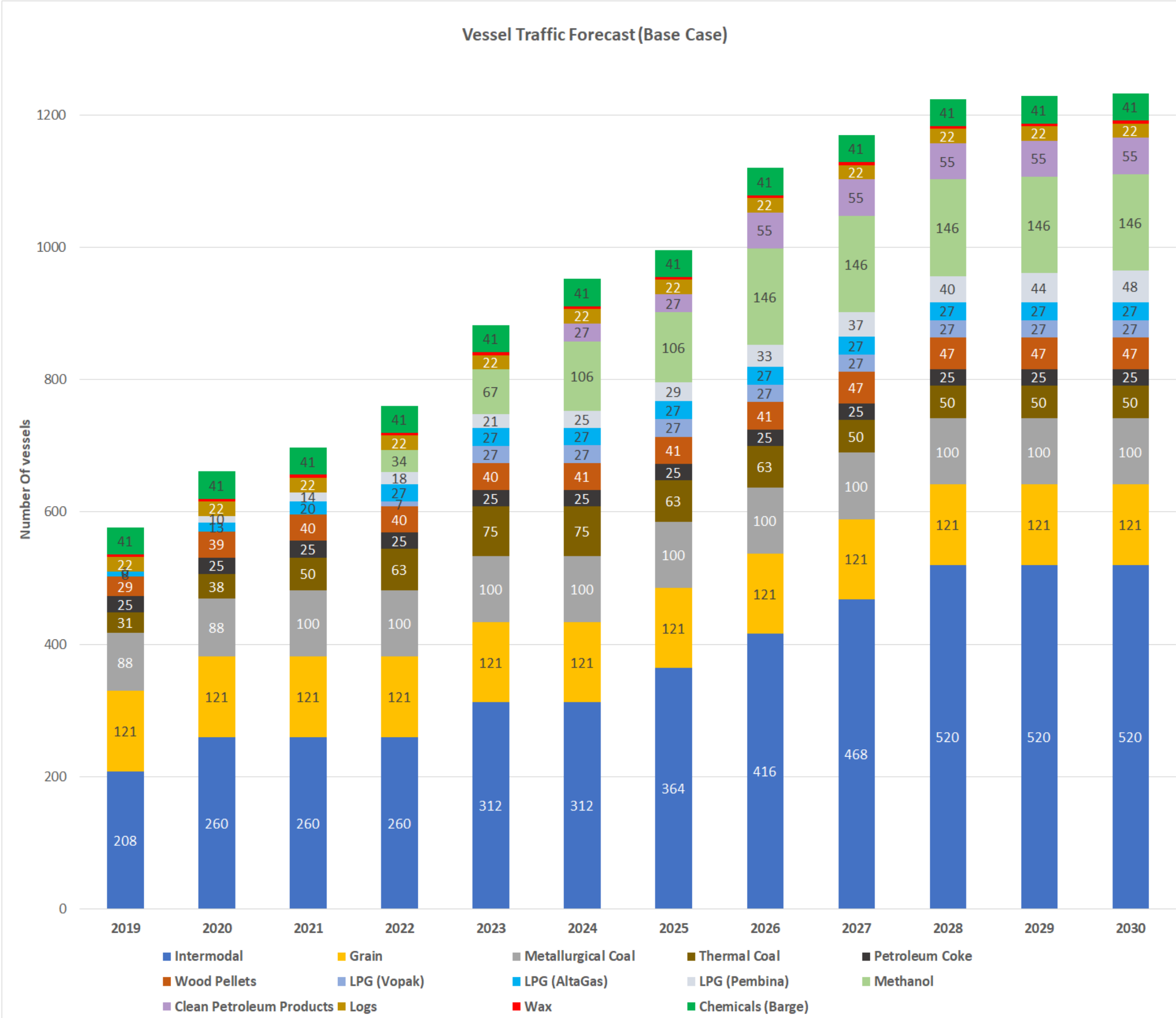


Figure 2-11: Vessel traffic Forecast provided by the Port

2.3 Environmental Data

In order to complete the MNRA and AARA environmental data is required in the form of the following:

- Wind;
- Current; and
- Bathymetry.

Wind and current data were provided by Tetra Tech from their 3D hydrodynamic model of the study area (Tetra Tech, 2020). Bathymetry data was obtained from the BC Marine Conservation Analysis (BCMCA, 2012).

2.3.1 Hydrodynamic Model

Tetra Tech's in-house three-dimensional hydrodynamic model, H3D, was used to hindcast 3D ocean currents throughout the Study Area for a representative year. The H3D model is a semi-implicit model using the numerical scheme described in Backhaus (1983), and uses a staggered Arakawa C-grid (Arakawa and Lamb, 1977). H3D was implemented on a variable grid with resolution varying between 820 m to 970 m, rotated to align with the major axis of the study area. Vertical resolution to represent the water column varies: layers are relatively thin near the surface to adequately represent river plumes, wind drag and heat exchanges processes, and gradually increase in thickness with depth. Environmental processes that impact the calculation of surface currents such as wind, river inflows and estuarine circulation were included in the model.

A representative year was selected to provide wind and current data over the area of interest.

Three major meteorological and hydrodynamic processes are taken into account when selecting an appropriate simulation year in the study area: tidal dynamics, winds and river flow. The impact of tidal variability can be safely neglected because tidal dynamics are characterized by relatively minor inter-annual variability in terms of tidal range and tidal currents. The impact of river flows is minor as well due to the size of domain that includes large open-water areas. Therefore, the selection of simulation year was primarily driven by wind conditions alone.

Five wind stations containing decades of hourly wind data and operated by Environment Canada were selected over the entire domain of study. Average wind speed and direction was computed for each station. Then, year 2015 was selected based on best fit between the representative year and average wind speed and direction. Hence, the simulation period covers the entire year 2015: surface currents and winds were extracted for this entire year.

Figure 2-12 shows the bathymetry and extent of the hydrodynamic model. Wind forcing over the entire domain of study is derived from interpolation of observed data at 29 buoys and coastal meteorological stations. These stations are operated by Environment Canada. Each model grid point calculates a value for the wind (speed and direction) based on an inverse distance weighting interpolation from the surrounding wind stations. In other words, the closer the wind station is from the grid point, the more influence this wind station has on the model grid point.

The discharge of freshwater from major creeks and rivers was incorporated in the hydrodynamic model, and the locations of the freshwater sources.

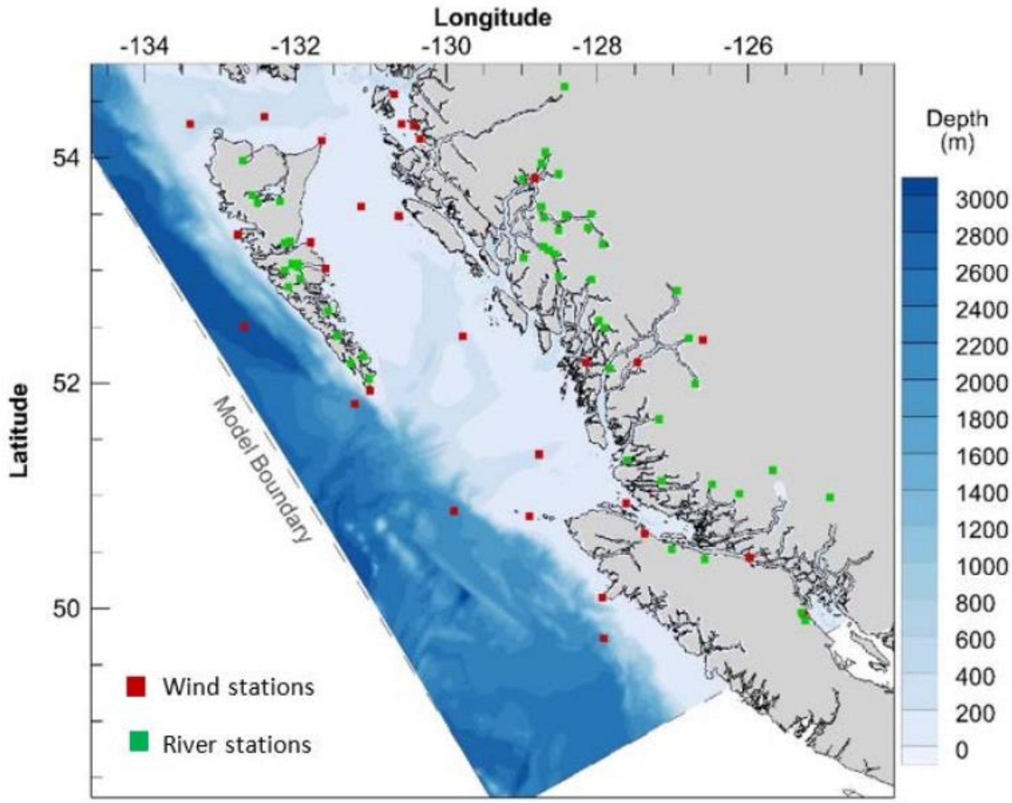


Figure 2-12: Extent of Hydrodynamic Model and Wind Stations and River Stations used in the Model

2.3.1.1 Wind Data

Locations of interest for wind data collection were provided by MARIN and were then extracted by Tetra Tech from the hydrodynamic model. Wind data was extracted from 21 locations within the study area and are shown in **Figure 2-13**.

An analysis of the mean wind speed per location and the 90th percentile wind speed is included in **Table 2-5** for each location. Wind speed was used in the MNRA to determine drifting rates and directions for disabled vessels. As well mean wind speed and 90th percentile wind speed were used in the AARA to determine holding capacity of the anchorage areas. For each location a wind rose was constructed, an example of the wind rose for station P3 and P5 is illustrated in **Figure 2-14** and in **Figure 2-15**. These two wind stations are the two stations closest to the Inner Harbour of the Port and were used during the AARA to model the conditions that would lead to a vessel dragging its anchor. Complete wind roses for each station and a deeper analysis of Environmental Data can be found in **Appendix A**.

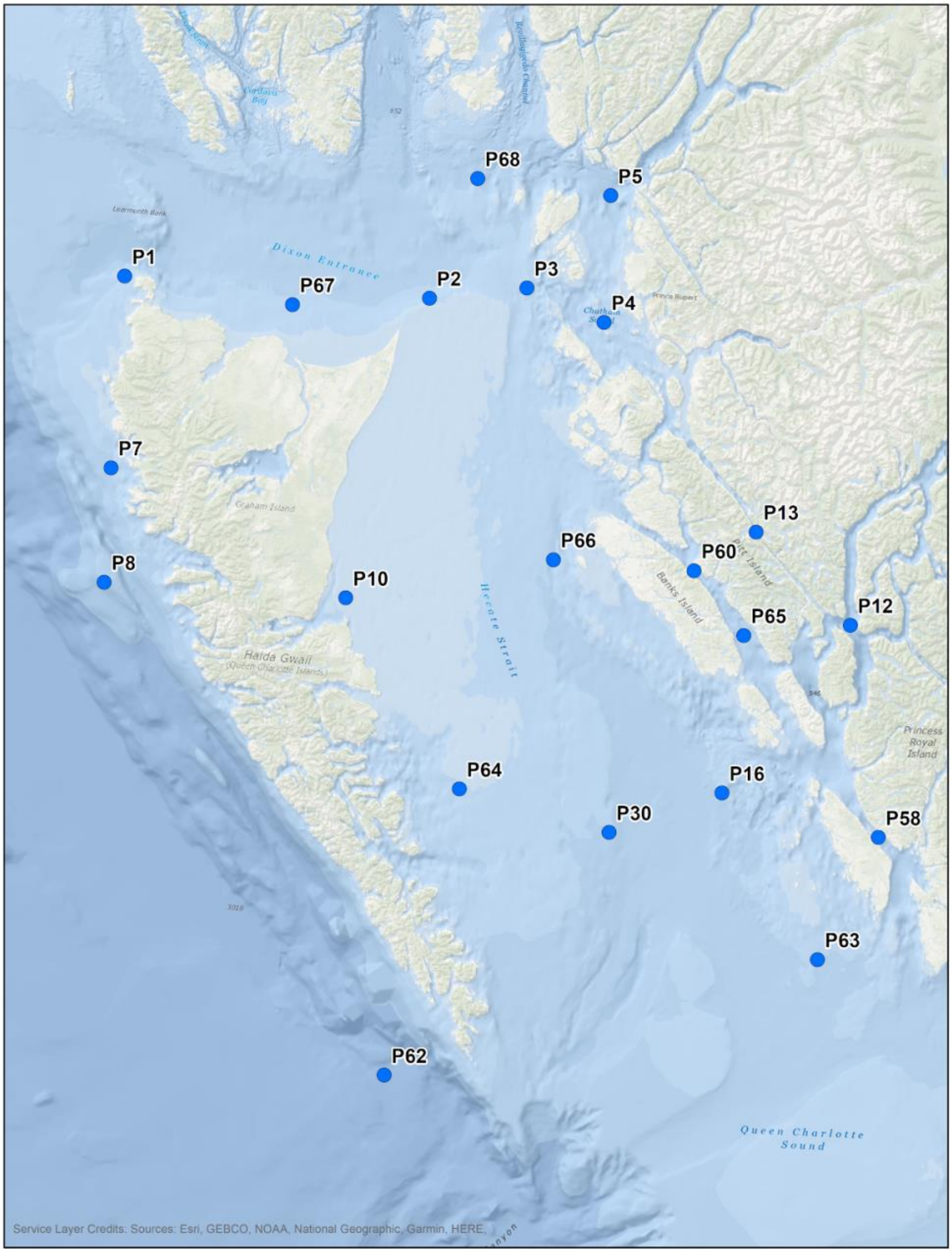


Figure 2-13: Location of Environmental Data Collection Points

Table 2-5: Wind Location Data Points and Wind Data

Station Number	Mean Wind Speed (m/s)	Mean Wind Speed (Knots)	90th Percentile Wind Speed (m/s)	90th Percentile Wind Speed (Knots)
P1	6.94	13.49	11.06	21.50
P2	6.68	12.98	11.92	23.17
P3	6.73	13.08	13.12	25.50
P4	4.86	9.45	9.64	18.74
P5	7.41	14.40	14.24	27.68
P7	5.50	10.69	9.69	18.84
P8	6.18	12.01	11.47	22.30
P10	3.14	6.10	7.29	14.17
P12	4.06	7.89	6.94	13.49
P13	4.27	8.30	7.29	14.17
P16	5.46	10.61	9.47	18.41
P30	5.64	10.96	9.69	18.84
P58	4.82	9.37	8.18	15.90
P60	5.20	10.11	9.02	17.53
P62	6.83	13.28	11.16	21.69
P63	6.10	11.86	10.37	20.16
P64	5.20	10.11	9.86	19.17
P65	4.58	8.90	7.98	15.51
P66	6.39	12.42	11.03	21.44
P67	6.37	12.38	10.44	20.29
P68	6.27	12.19	11.19	21.75

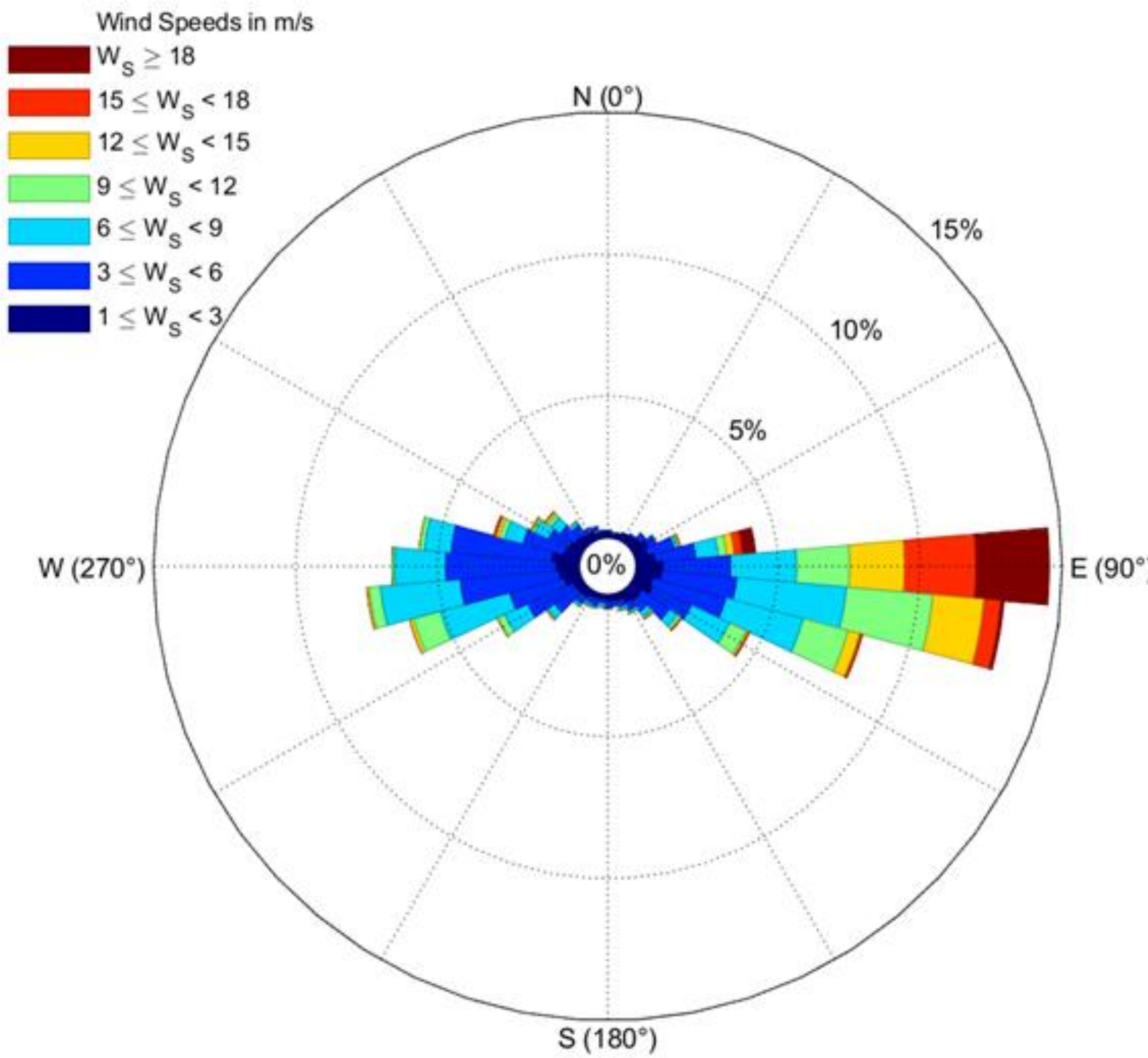


Figure 2-14: Wind Rose from Station P3

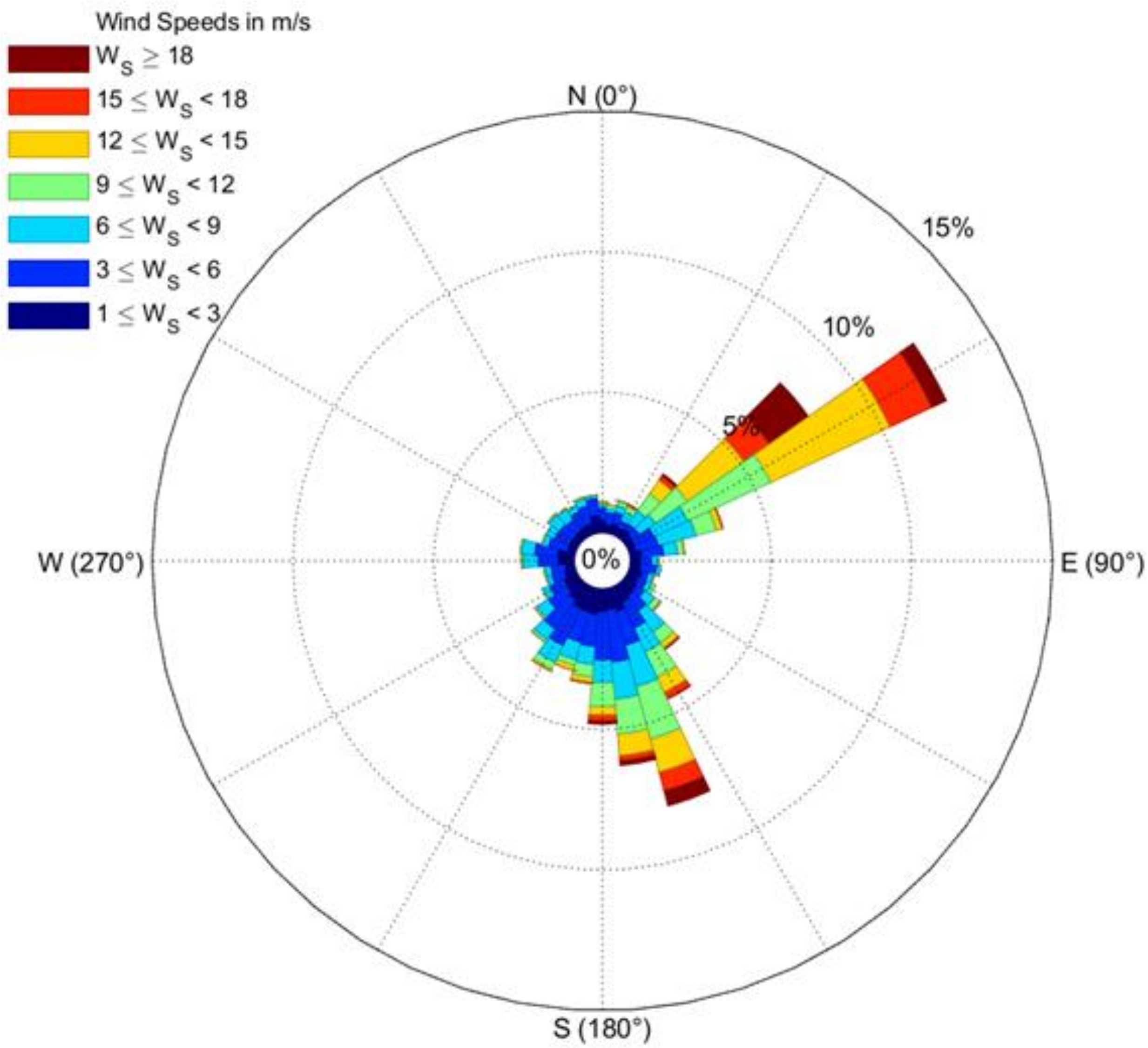
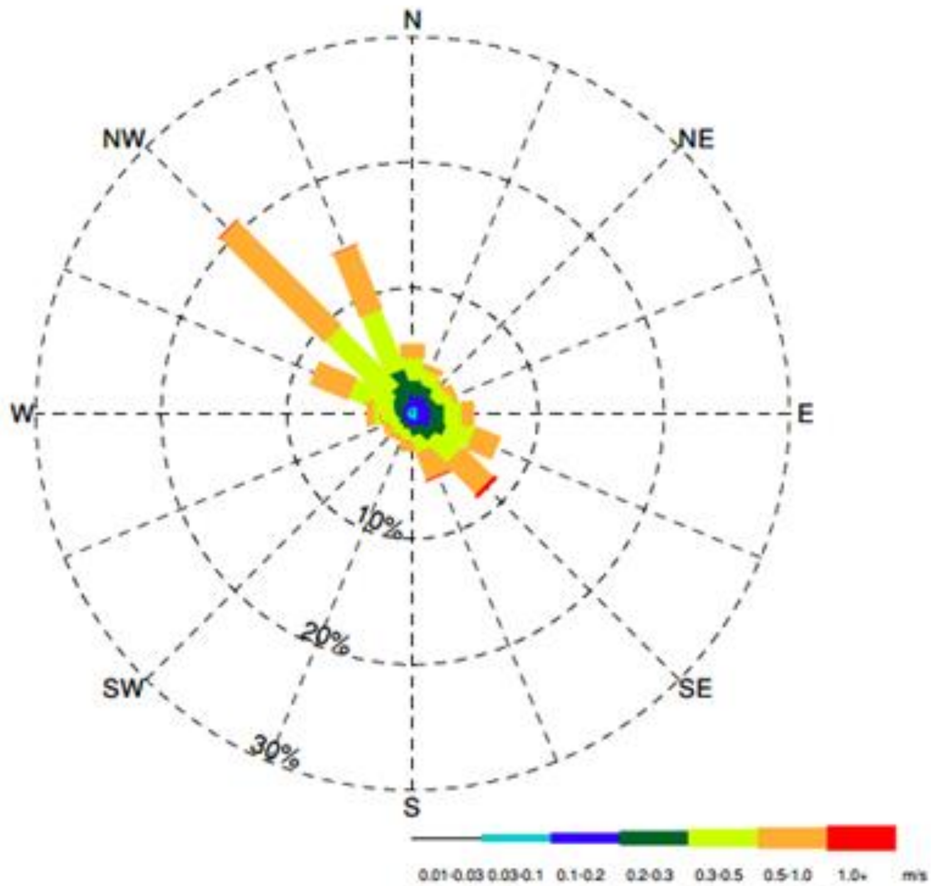


Figure 2-15: Wind Rose for Station P5

2.3.1.1 Current Data

A total of 21 locations were counted over the study area and are shown in **Figure 2-13**. Coordinates of these locations are shown in **Table 2-5**. Surface current time series at these locations were extracted by finding the closest model grid point, given the coordinate of each location of interest. A current rose for station P3 is included in **Figure 2-16** below. P3 is located on the west approaches into the harbour, as seen in **Figure 2-13**.



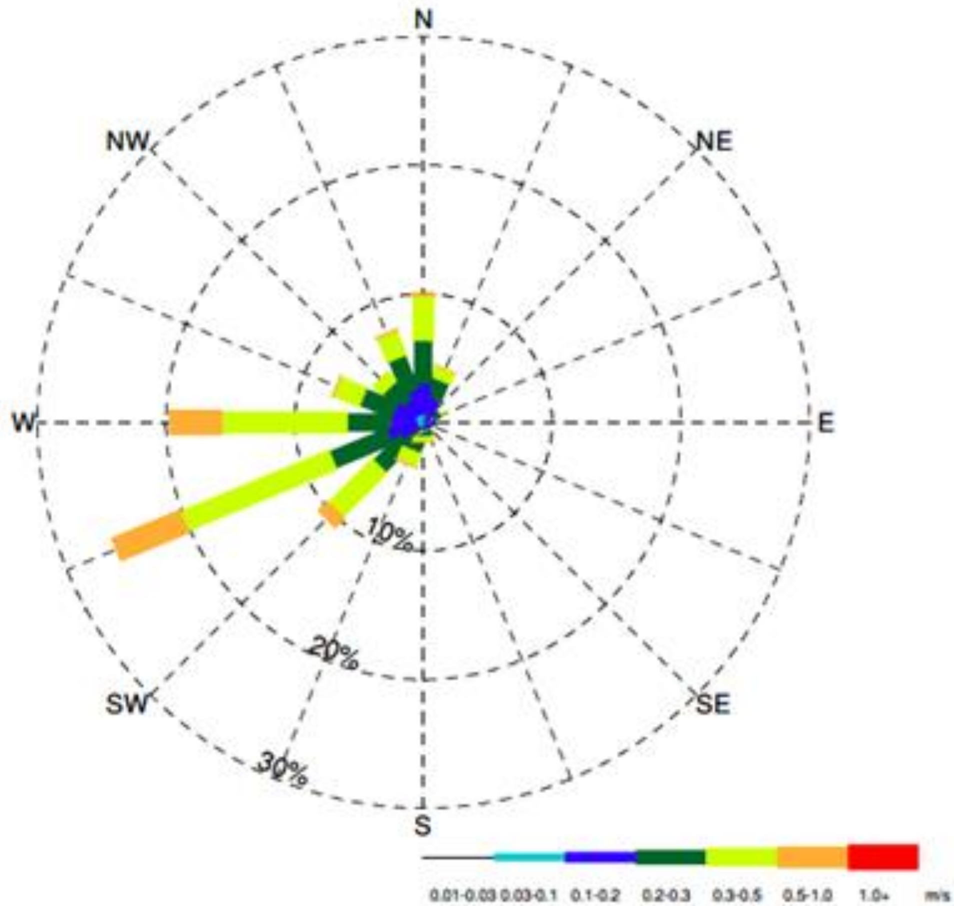
P3 Station
Location:
N54° 19' 21.4" W130° 59' 54.2"
Depth: Surface Layer
Sea level: msl
Length of Record: 1 years
Start Date: January 1, 2015
End Date: December 31, 2015
Comment:

Speed & Direction Frequency Distribution Table

Direction	Percent Occurrence (%) 0.0-0.01 m/s	0.01-0.03 m/s	0.03-0.1 m/s	0.1-0.2 m/s	0.2-0.3 m/s	0.3-0.5 m/s	0.5-1.0 m/s	1.0+ m/s	Total (%)
ENE	-	0.01	0.37	1.00	0.69	1.31	0.36	-	3.74
NE	-	0.03	0.32	0.91	0.66	1.16	0.30	-	3.38
NNE	-	0.02	0.40	1.07	0.91	1.16	0.48	-	4.04
N	-	0.02	0.28	1.03	1.32	1.77	1.14	-	5.56
NNW	-	0.01	0.35	1.13	2.07	5.09	5.50	0.03	14.18
NW	-	0.02	0.17	0.70	1.49	6.60	11.77	0.05	20.80
WNW	-	0.02	0.19	0.49	1.08	3.42	3.25	-	8.45
W	-	0.03	0.13	0.52	0.81	1.56	0.61	-	3.66
WSW	-	-	0.19	0.54	0.56	1.09	0.19	-	2.58
SW	-	0.01	0.15	0.47	0.40	0.90	0.22	-	2.15
SSW	-	0.01	0.22	0.51	0.39	0.81	0.49	-	2.42
S	-	0.02	0.13	0.50	0.54	0.89	0.95	-	3.03
SSE	-	-	0.20	0.64	0.87	1.32	2.30	0.10	5.44
SE	-	0.02	0.17	0.76	1.42	2.36	3.40	0.29	8.42
ESE	-	0.02	0.32	1.13	1.38	2.21	2.16	-	7.23
E	-	0.05	0.32	1.04	1.07	1.42	0.99	-	4.91
Calm	-	-	-	-	-	-	-	-	-
Total (%)	-	0.31	3.89	12.47	15.67	33.06	34.13	0.47	100.00

Figure 2-16: Current Rose for Station P3

A current rose for station P5, is included in **Figure 2-17** below. P5 is located in the nearby northern approach to the Port.



P5 Station
Location:
N54° 37' 32.9" W130° 35' 3.5"
Depth: Surface Layer
Sea level: msl
Length of Record: 1 years
Start Date: January 1, 2015
End Date: December 31, 2015
Comment:

Speed & Direction Frequency Distribution Table

Direction	Percent Occurrence (%)								
	0.0-0.01 m/s	0.01-0.03 m/s	0.03-0.1 m/s	0.1-0.2 m/s	0.2-0.3 m/s	0.3-0.5 m/s	0.5-1.0 m/s	1.0+ m/s	Total (%)
ENE	-	-	0.31	0.55	0.09	-	-	-	0.96
NE	-	0.02	0.24	0.66	0.47	0.14	-	-	1.53
NNE	-	0.02	0.45	1.52	1.50	0.97	0.06	-	4.52
N	-	0.04	0.43	2.50	3.40	3.42	0.31	-	10.10
NNW	-	0.01	0.55	2.04	2.74	2.01	0.18	-	7.54
NW	-	0.03	0.37	1.56	1.79	1.06	-	-	4.81
WNW	-	0.03	0.48	1.88	2.68	2.17	0.15	-	7.38
W	-	0.05	0.49	1.98	3.42	9.74	4.11	-	19.78
WSW	-	0.03	0.54	2.30	4.74	12.50	5.78	-	25.89
SW	-	0.03	0.28	1.63	2.88	4.76	1.12	-	10.69
SSW	-	-	0.26	0.99	1.07	1.12	0.10	-	3.54
S	-	0.03	0.15	0.48	0.42	0.41	0.06	-	1.55
SSE	-	-	0.21	0.35	0.05	0.08	-	-	0.70
SE	-	0.02	0.11	0.18	-	0.01	-	-	0.33
ESE	-	-	0.09	0.16	-	-	-	-	0.26
E	-	0.01	0.12	0.23	0.04	-	-	-	0.40
Calm	0.02	-	-	-	-	-	-	-	0.02
Total (%)	0.02	0.36	5.09	18.99	25.31	38.36	11.87	-	100.00

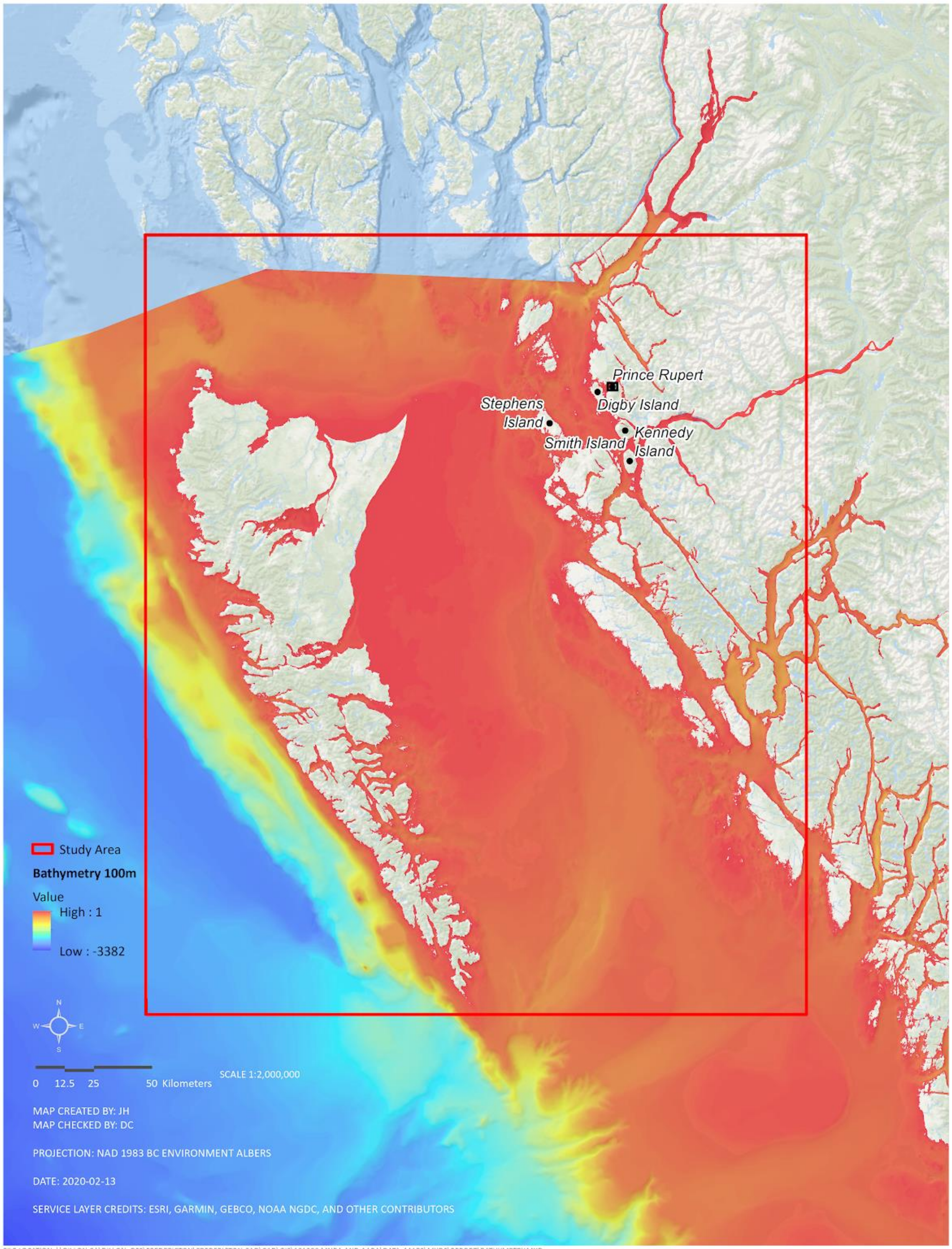
Figure 2-17: Current Rose for Station P5

2.3.2 Bathymetry

Bathymetry data was obtained from the BC Marine Conservation Analysis (2012) for the study area. The bathymetry data provides the depths of water as well as seafloor geology. The data provided is on a 100 m by 100 m grid and depth accuracy is plus or minus 10% (BCMCA, 2012). The bathymetry data was used in the AARA and MNRA.

The water depth plotted for the entire study area is presented on **Figure 2-18**. Depths within the Port ranged from 0 to greater than 225 m. Depths within the Inner Harbour were generally less than 100 m.

The seafloor geology is presented in **Figure 2-19**. As per the figure, the seabed in all anchorages is mud, which has the best holding characteristics for the anchor and chain. Exceptions to this may be the area just west of the Digby Island, which is designated Emergency Anchorage area only and seldom used, mainly because of the vicinity of aquaculture sites and the potentially hard seabed that does not have good holding characteristics in the area.



FILE LOCATION: \\DILLON.CA\DILLON_DFS\FREDERICTON\FREDERICTON CAD\CAD\GIS\191396 MNRA AND AARA\DATA_MAPS\MXDS\REPORT\BATHYMETRY.MXD

Figure 2-18: Map of the Bathymetry in the Study Area

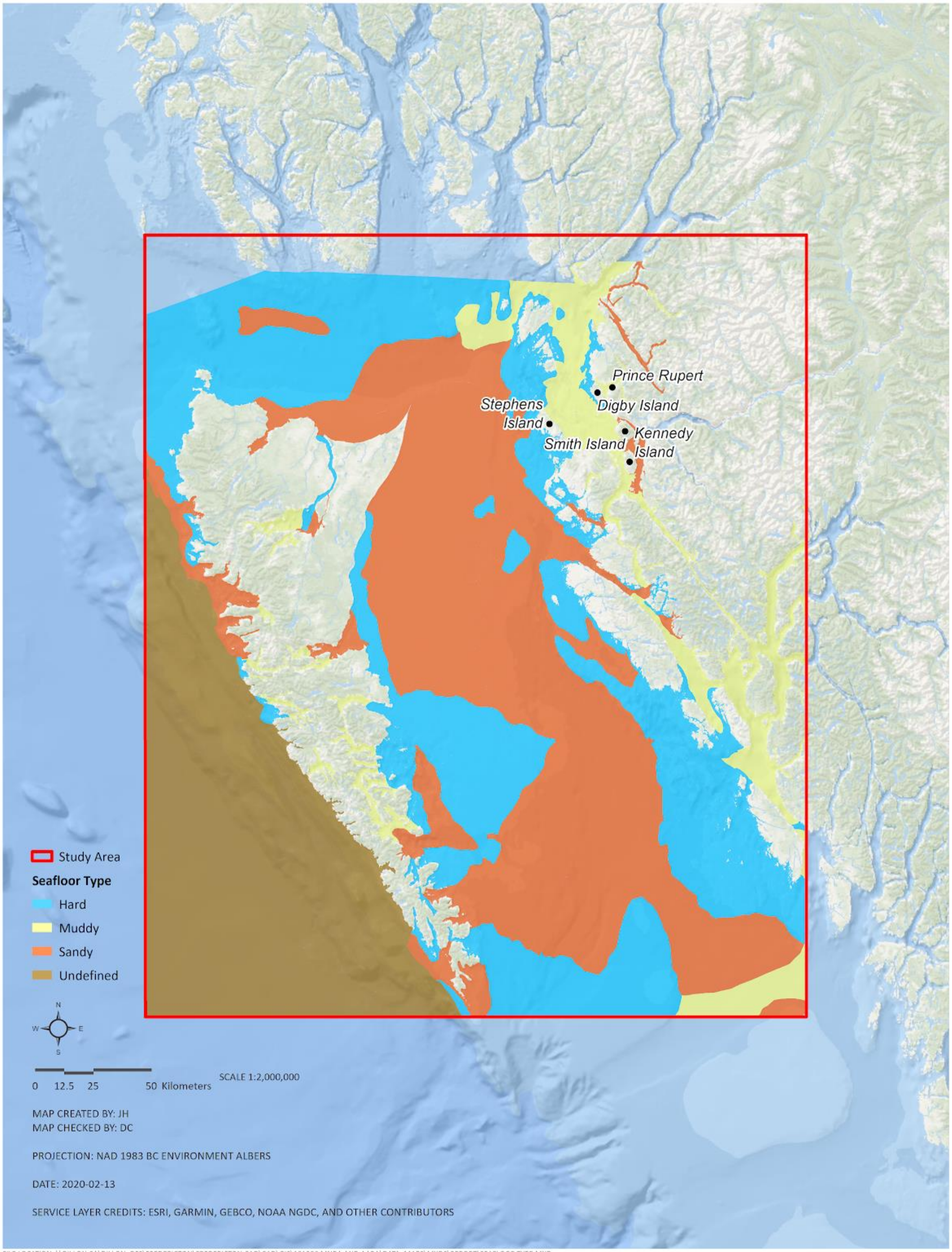


Figure 2-19: Map of the Seafloor Type in the Study Area

3.0 HAZID Workshop

On November 5, 2019, a HAZID workshop was held at the PRPA to identify and discuss navigational hazards in the approaches to the Port and throughout the Port's jurisdiction. Additionally, hazards were identified for designated anchorage areas.

A high level summary of the information gathered through the discussions at the workshop is presented below. In addition to the information below, maps were marked up with pens, markers or stickers to indicate areas where there are concerns for recreational and fishing traffic, weather hazards and areas of high consequence. This information was input into the GIS platform for further analysis. Maps illustrating this data can been seen in **Appendix B**. Feedback was grouped into several common themes as presented below.

3.1 Fishing and Recreational Traffic

Fishing and recreational traffic was identified as a major concern for navigation and maneuvering of larger commercial vessels approaching the harbour. Specifically, participants said:

- Commercial fishing sometimes takes place in the deep sea traffic route and adjacent to ships at anchor. Specific fishing sites and routes were identified on maps and will be included in our analysis. These are included in **Appendix B**.
- Fishing and recreational vessels are not required to have AIS and sometimes do not even show up on the radar which is an issue for large commercial ships navigating in the area.
- PRPA has tried in the past to provide the Port Information Guide to all commercial fishing license holders as an attempt to educate on shipping lanes and traffic flows but did not see an improvement in issues.
- PRPA has undertaken a historical study to assess the numbers and types of vessels transiting Porpoise Channel. This study was provided to Dillon.
- In order to help gain an understanding of fishing activity and to inform commercial vessels of fishing activities several AIS units were distributed by the PRPA to local fishers.
- DFO does not have the capacity to enforce and pull fishing equipment out of the water that are in areas of no fishing.
- Aquaculture sites are located adjacent to the four identified emergency anchorages areas (anchorage areas 11-14).
- Communication issues are prevalent, especially with recreational boaters as they are not monitoring the right VHF radio frequencies. Sometimes there is a language barrier.
- Large commercial ships have had to do dangerous maneuvers to avoid fishing or recreational vessels.
- Smaller vessels will regularly cut off large commercial ships.
- A container ship ran aground while attempting to avoid a fishing vessel.

3.2 Future Traffic

Future traffic projections were provided by the PRPA. The future traffic projections were reviewed with HAZID participants and a summary of the comments is presented below.

- There are a number of projects in the area that will increase the amount of traffic going to and from the Port as well as increase the amount of traffic in the approaches to the Port.
- Alta Gas (progressing to 27 vessels per year), Pembina (10 vessels per year to start, progressing to 48 a year), Vopak (27 vessels per year) will all add to local LPG traffic.
- Vopak will also introduce 146 Methanol vessels and 55 Clean Petroleum Product vessels by 2030.
- DP World is planning a second container terminal closer to Ridley Island (up to 520 vessels per year between both terminals).
- There are regularly vessels arriving at the container terminal that are up to 366 m in length and there could be up to 400 m long vessels in the future, albeit not many. For the navigational risk assessment it will be assumed that up to two, 400 m vessels would call on the Port each year.
- Ridley Island Terminals is planning to build a second jetty to accommodate more traffic for it and Alta Gas.
- A number of projects in Kitimat will increase traffic including LNG Canada and potentially Cedar LNG. LNG Canada is expected to add an LNG tanker a day that will transit through the study area. Currently there are no LNG tankers in the area.
- Future traffic will make it difficult with the BC Ferries terminal and their schedule.

3.3 Specific Areas of Concern

Participants in the HAZID Workshop were asked to identify specific areas of concern and what makes them areas of concern. Below is a summary of several of them.

- Triple Island/Pilot Station
  - There is a significant volume of traffic in the vicinity of Triple Island that does not have AIS. This includes small recreational vessels and fishing vessels.
  - The pilot station is located as such that the pilot boards and is already taking control of the vessel, altering it, before they are able to properly assess the current situation and set up their Portable Pilotage Unit.
  - Pilot station is in the middle of a high traffic intersection.
  - No room for error in pilot boarding the ships.
  - It was suggested that moving the pilot station further west and having alternative boarding strategies for pilots be looked at. This would have to be studied.
- Venn Passage
  - No lights in the area even though it is a higher traffic area.
  - Traffic in the area is typically smaller vessels.
- Spire Ledge Entrance to Harbour

  - Vessels will cut the corner when making their way into the harbour. This poses a risk to large commercial shipping entering and leaving the harbour as the smaller vessels intentions are typically not clear.
  - Large ships need to conduct a significant course change to enter the harbour and do not have a lot of room for the alteration. Any smaller traffic within their turning radius poses a risk.
  - Popular recreational fishing spot, especially in the winter. This results in a lot of smaller vessel traffic congesting in this area.
  - Smaller ships regularly cut off larger ships which have no room to maneuver.
- Transit Into the Inner Harbour
  - Ships are slowing down here which reduces their maneuverability and makes it very difficult to alter course to avoid smaller vessels.
  - If there was a mechanical failure of a ship at this point it would be problematic as there is little room to recover.
  - There were concerns that the tugs available in the area do not have the power necessary to maneuver vessels that have lost power.
  - There is a dead spot for the radar in this area. This means that VTS may not have a full understanding of traffic in the approaches to the inner harbour.
  - No real-time current data for this area. Furthermore, there are no current stations within the harbour. This makes predicting the currents difficult. With deeper draught vessels entering the harbour, having better current data is key to minimizing the risk.
  - Extremely tight location if ships are arriving and departing at the same time.
- North of Kinahans
  - There is a 90 degree turn required for larger ships here with minimal room for error.
  - There has been a ship that ran aground in the past.
  - Traffic is an issue in this area.
- Berthing
  - Currents can make berthing quite difficult.
  - No real time data for currents to help pilots with berthing. Real time current data would be needed for surface currents as well as currents throughout the water column as they can be different and effect the ship differently.
  - Outbound ships need good power to make the turn at Casey Point; this is hard when the ships have cold engines.
  - Currents are an issue, especially when you have ebb currents.
- BC Ferries
  - Ferries are often coming and/or going when there is a container ship coming in. This is managed right now, but with future traffic this will become an issue.
  - A potential mitigation measure is enacting a Clear Channel requirement when containerships are transiting or leaving the container terminal.
- Port Edward – Porpoise Harbour

    - Pembina LPG traffic will be coming through here.
        - Ships will be a max of 170 m in length, flat top.
        - There is a tethered tug requirement.
        - Lead vessel to clear the path.
        - Port will impose a 25 knot wind restriction as well as 2 nm visibility requirement.
        - LPG carriers will only transit in daylight and at slack water.
        - Ongoing simulations right now, there may be other required mitigations.
    - Currently, there is a significant volume of recreational traffic in the area as well as fishing traffic.
    - No live current data.
- Hecate Strait/Dixon Entrance
    - Generally incidents happen in these areas due to weather and/or mechanical issues.
    - No big navigational hazards other than weather.
    - There has been an increase in traffic pushed out of the inside passage and into Hecate Strait, which has much more difficult weather.
    - Articulated barges being pushed out of the inside passage and into Hecate Strait pose a higher hazard as they do not handle the weather in that area well.
    - When LNG Canada is in operation it is projected that up to two LNG tanker/day will pass through Hecate Strait (one entering and one leaving).
- Tug Traffic
    - There is significant tug and barge activity in the study area. The majority of the tug and barge traffic are following the inside passage route from southern BC to Alaska.
    - At the moment the tug and barge traffic does not negatively impact commercial traffic as the tugs and barge captains are well informed and liaise with the larger commercial vessels to resolve potential close situations before they occur. This may change in the future with increased traffic to the Port and if tug and barge traffic increases.
    - All tugs in the area have AIS and communicate well with vessels.
- Whale Ships/Tours
    - The PRPA does not currently have open discussions with whale ships/tour operators.
    - There is a need to look at marine protected areas long term.
    - Slowing down is an issue for commercial traffic.

3.4 Weather Issues

Participants in the HAZID Workshop were asked to identify concerns related to weather within the Port. Below is a summary of several of them.

- Wind Data
    - Overall there are issues getting real-time wind data. The wind data is collected by ECCC and is available on a third party website, not ECCC's website. It was implied this was a budgetary problem with ECCC to fix their website.

  - Wind data is critical for ships and terminals.
  - Winds can sometimes take down radar and communications.
  - The Port works with MCTS to get out weather warnings ahead of time.
- Inner Harbour
  - When the wind hits empty ships broadside this causes issues and could lead them to drag their anchor.
  - Gusts can come down the Portland Canal from Tuck Inlet and the winds can change rapidly this way.
  - Wind warnings are provided for 25 knots or higher by MCTS.
  - Ships who have to reposition because of anchor dragging often have to get going with a cold engine.
  - Not easy to close the harbour and put all vessels to sea if there is a forecasted major weather event. This is due to the vessels requiring a pilot and the availability of pilots.
- Visibility
  - Visibility can be a challenge in summer and fall due to fog, although there is usually no wind when there is fog which improves handling.
  - MCTS let ships know of traffic they pick up on the radar.
  - Sometimes AIS is not accurate due to being poorly installed/managed.
  - Several close calls / near misses have occurred during low visibility weather where small vessels (fishing and/or recreational) vessels without AIS have come close to large commercial vessels.
- Hecate Strait
  - Relatively shallow waterway which makes the waves break easier.
  - Pilot boarding in this area can be quite dangerous.
  - Sometimes the weather in this area will cause berthing delays.
  - Some ships may wait out bad weather in this area even when they are not Canadian bound.
  - In the past ships have gotten pounded in Hecate Strait and have called to the Port for help.

3.5 Anchorage Areas

Information was provided by the Port on how anchorages are assigned.

- Anchorages 11-14 are emergency use only and never used since they are located near aquaculture sites. Discussion was had by the participants if they should continue to be identified as anchorage areas (even emergency) or if they should be decommissioned.
- Inner harbour anchorages are mostly used for wood and grain ships. Participants stated that it is preferred practice to anchor the grain ships in the inner harbour to facilitate their inspection by Canadian Food Inspection Agency (CFIA). It was stated that CFIA prefers to conduct the inspections within the inner harbour, versus the outer anchorage areas.
- Anchorage 9 has been identified as the anchorage for dangerous goods (mainly LPG).

- There are no discussions that have been done on identifying additional dangerous goods anchorages.
- The proximity of anchorages to the traffic lane is a potential hazard. There is not a lot of room to maneuver.

3.6 Anchor Dragging

During the workshop the participants reviewed the procedure on how a vessel that is assumed is dragging its anchor is identified and dealt with. A general summary of the procedure is as follows:

- MCTS or the PRPA will identify through monitoring if a vessel is dragging their anchor.
- Vessel then gets notified through MCTS.
- The vessel can either drop a 2nd anchor, start the engine in order to try and stay in place, or the PRPA can clear them for departure.
- MCTS and PRPA work together to provide weather warnings when there are high forecasted winds.
- PRPA will also work with Smit for tugs since they are usually the only provider who can get a pilot to the vessel in weather or when the vessel is at anchor.
- Since all the anchorage areas are within pilotage waters, a pilot must be embarked on the vessel prior to the vessel repositioning its anchor.
- PRPA and MCTS will sometimes put ships on notice that they should be ready to drop a second anchor or pull their anchor and leave.
- Wind direction can be more of a factor than wind speed in anchor dragging.

3.7 Potential Impacts of Incidents

There are a number of potential impacts that have bene identified within the Study Area should an incident occur.

- There are a number of spots that are very biologically diverse near the Port. Maps of these have been provided by Lax Kw'alaams Fisheries.
- Matlakatla and West of Digby Island are noted to be culturally sensitive.
- Should any incident occur in the Fairview Channel, this would cut off the Port and would be economically significant.

3.8 Potential Mitigations Suggested

The mitigations below were suggested by HAZID participants for potential consideration. They have not been studied for viability and may or may not be included as recommendation in the final report.

- Moving the pilot station so that it is further west.
  - To remove the pilot boarding from a higher traffic area and to allow pilots more time to set up prior to taking control of the vessel.
- More MCTS support for the future traffic scenario.

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  - To accommodate the increase in traffic for the region.
- More AIS to be installed on fishing vessels.
  - To provide more accurate information on traffic for ships navigating in the area.
- More vetting of ships for safety of pilots, including pilot ladders, ahead of time to ensure they can be handled safely.
  - To reduce the risk of incidents or injury/loss of life.
- More escort tugs with a higher capacity.
  - To accommodate future traffic and the larger vessels which are projected to call to the port.
- Live data on currents.
  - To aid in the handling of the ships when transiting and mooring/berthing.
- Improvement on wind data availability.
  - To aid in navigation and manage risks.
- Clean Channel requirements for certain vessels and areas.
  - To reduce risk of collisions or other incidents in specific areas of concern.
- Traffic Separation Scheme.
  - To examine the potential reduction in incidents and near miss incidents.
- Fatigue mitigation measures.
  - To reduce the occurrence of incidents.
- Smart VTS – Future project which would allow anything on radar to transmit to AIS.
  - Currently planned in future years by MCTS to improve accuracy of AIS.
- More emergency towing vessel capacity.
  - To help manage incidents with the increase in traffic for the future scenario.
- Improving the relationship between the Port and the commercial/sport fishing industry.
  - To improve communications between the Port and the commercial/sport fishing industry in order to find solutions to reduce incidents and near misses.

4.0 Marine Navigational Risk Assessment

The MNRA was conducted by the Maritime Research Institute of the Netherlands (MARIN) utilizing their marine traffic modelling software called SAMSON. SAMSON stands for Safety Assessment Models for Shipping and Offshore in the North Sea. The SAMSON Model is a multi-facetted risk analysis tool that was developed over 40 years ago to assess the risk of marine accidents, oil spills and loss of life. As a macro-assessment tool, SAMSON can identify the most probable locations (or hot-spots) of hypothetical accidents. For the PRPA Study Area, the SAMSON Model was used to determine the probable locations of accidents and their likelihood to determine what, if any, are the areas of concern for navigation and marine traffic.

The SAMSON Model utilizes specific inputs in order to calculate the probability of accidents, as illustrated below in **Figure 4-1**.

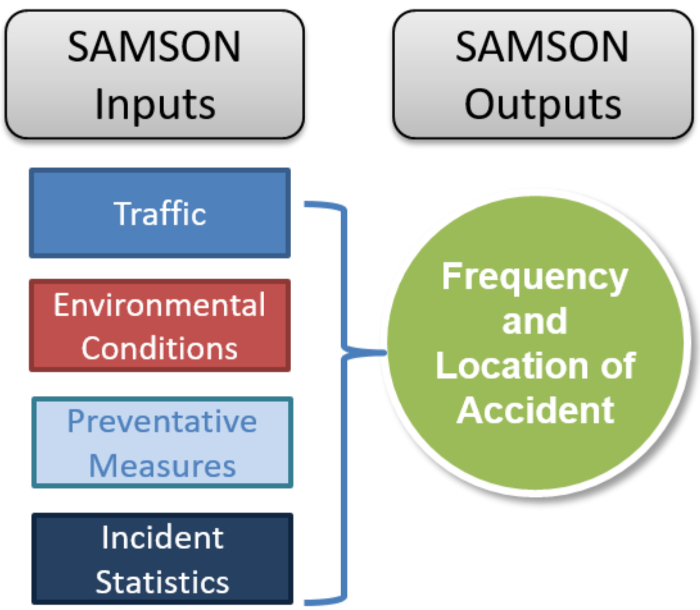


Figure 4-1: SAMSON Model Inputs and Output

4.1 SAMSON Inputs

The SAMSON inputs are critical for proper outputs from the model. This section will describe the SAMSON inputs for this analysis. More detailed information on the model's methodology can be found in **Appendix C** of this report.

4.1.1 Traffic

The SAMSON model utilizes AIS data to model the movement of traffic in a study area. Utilizing this data, it categorizes marine traffic into two categories, Route Bound Traffic and Non-Route Bound Traffic. The Route Bound Traffic is generally shipping traffic that travels from point A to point B. Non-Route Bound traffic is traffic that travels from point A and comes back to point A. Examples of Non-Route Bound traffic are fishing and recreational traffic.

The traffic database consists of a network of nodes and links that describe the Route Bound Traffic and a density that describes the Non-Route Bound traffic. There were 36 ship types distinguished in the Route Bound Traffic and six ship types for Non-Route Bound.

4.1.1.1 Route Bound Traffic – Current Scenario

The route bound traffic database was constructed using 2018 AIS data supplied by Alaska Marine Exchange and combined with information from a ship characteristics database. The Maritime Mobile Service Identify (MMSI) numbers, which are the unique identifiers in the AIS data, are connected to a Lloyd's Marine Intelligence Unit (LMIU) number, the unique identifier in the ship characteristics database. This database only contains seagoing ships >100 GT. The Route Bound Traffic database in SAMSON consists of 36 ship types. In this Study Area, it was decided to not include fishing vessels, work vessels (e.g., tugs, pilot vessels), and supply vessels in the route bound traffic, as these do not act as route bound traffic in the Study Area and were instead included in the Non-route Bound database.

AIS signals for 2018 within the Study Area are shown in **Figure 4-2** below. Based on the traffic flows that can be seen in **Figure 4-3**, a network was defined. The AIS data for the route bound traffic within the Study Area is automatically assigned to the network illustrated in **Figure 4-4**.

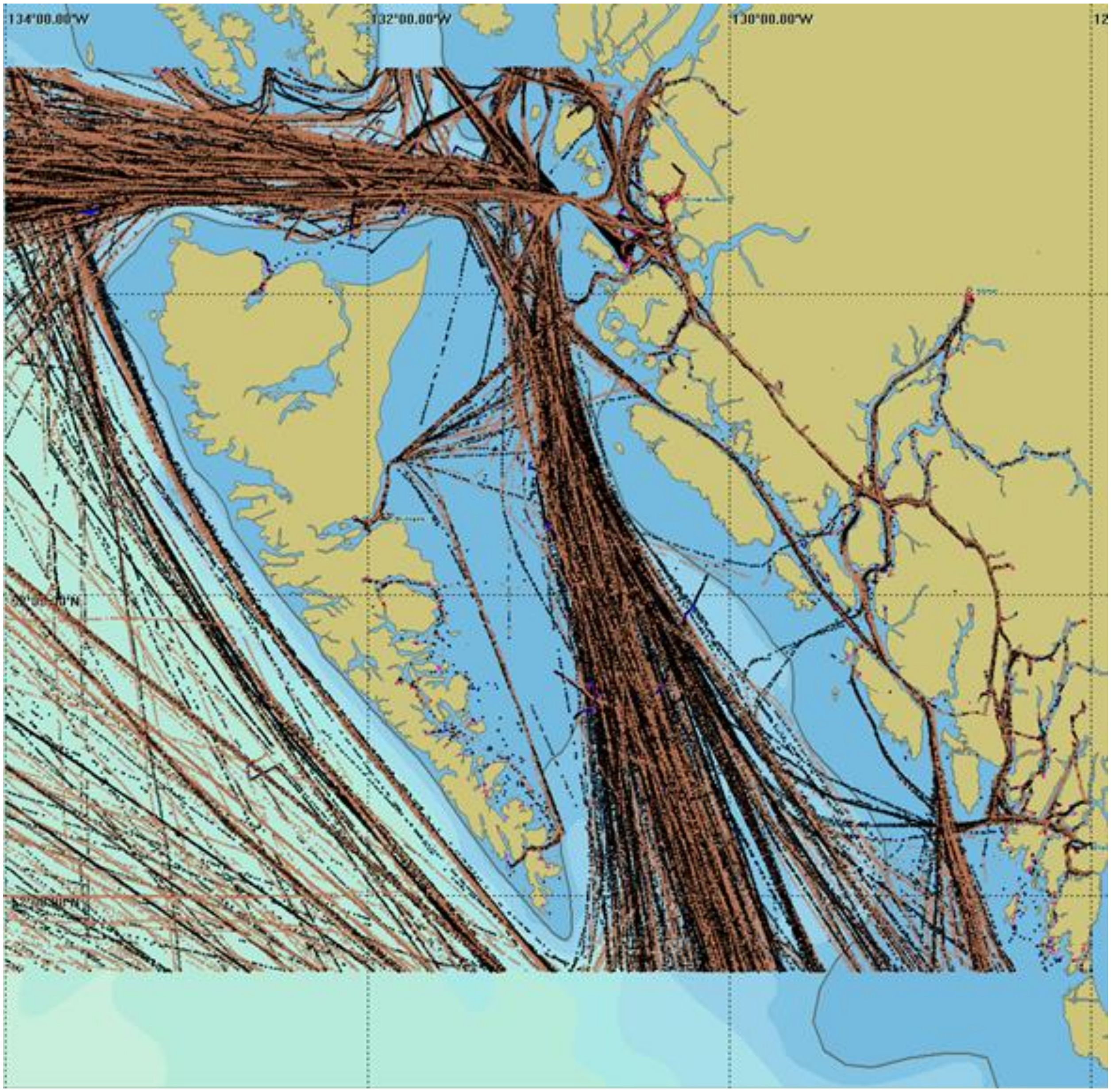


Figure 4-2: AIS Signals for 2018, Plotted at 10 Minute Intervals within the Study Area

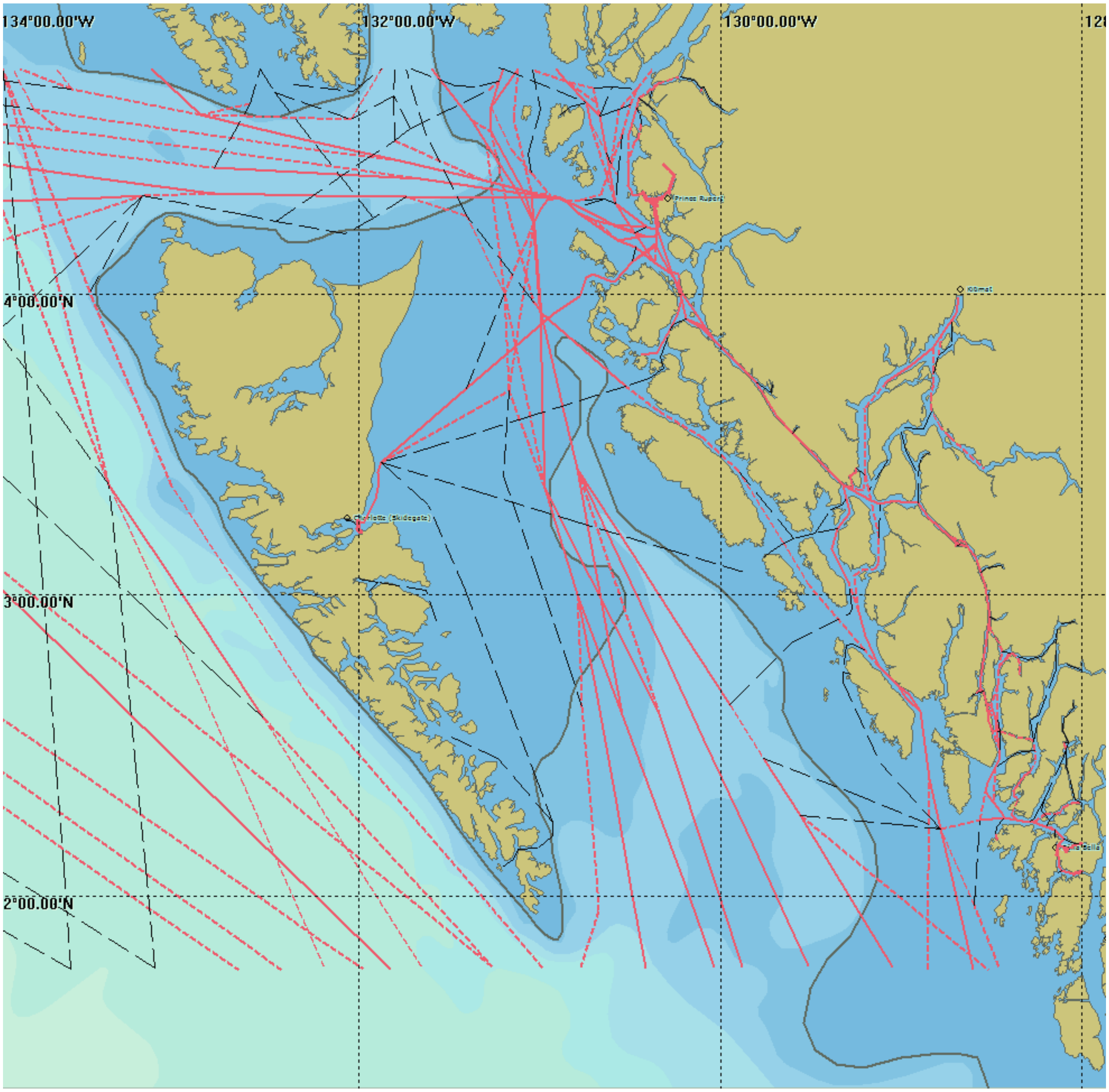


Figure 4-3: Traffic Network based off AIS Signals for 2018

Figure 4-4: Route Bound Traffic Database created based on 2018 AIS Data with Traffic Intensity (numbers represent number of vessels on route in one direction)

Figure 4-5 provides a closer view of the traffic network near the Port area. Black numbers represent the number of ships per year one direction.

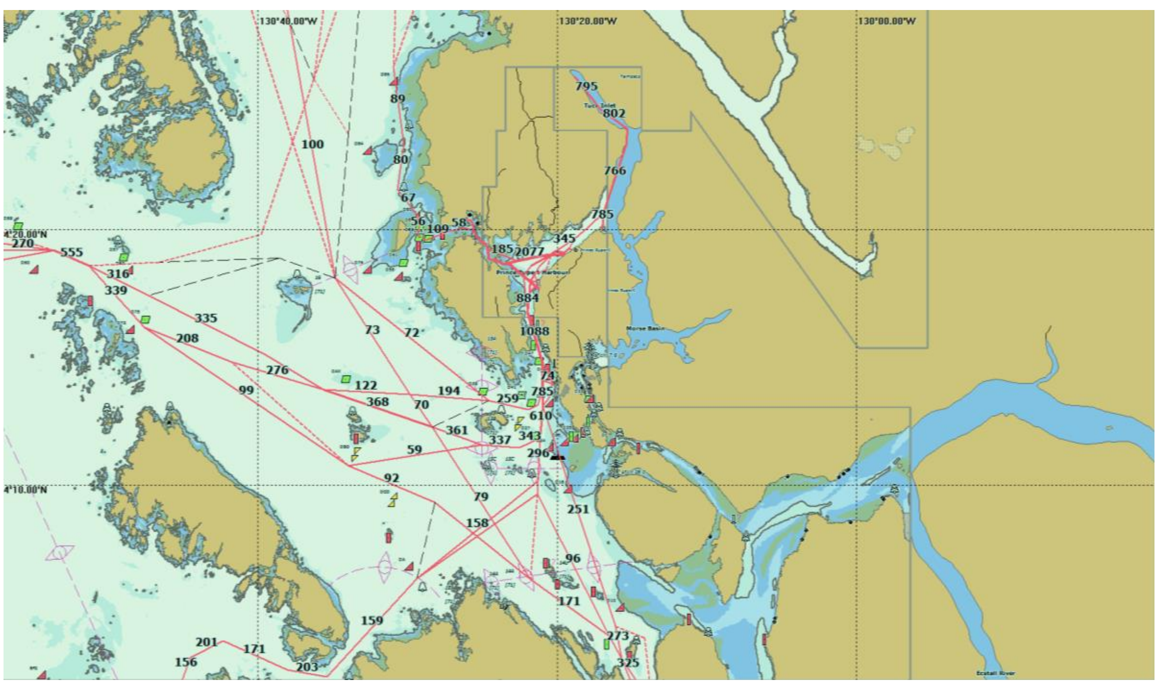


Figure 4-5: Overview of the Traffic Network near the Port

4.1.1.2 Route Bound Traffic – 2030 Scenario

Based on data received from the port authorities additional traffic was added, for select existing and potential new terminals, to the existing traffic database, as outlined below.

Pembina Traffic:

- Anticipated 10 vessels a year commencing 2020[1].
- Assumed to progress to 48 vessels per year.
- Predicted vessel type is 170m LPG flat top carriers.

Alta Gas Traffic:

- Anticipated 27 vessels a year.
- Vessel type is Aframax (250m / 120,000 DWT).

VOPAK Traffic:

- 27 vessels a year LPG. Panamax size tankers (230m / 80,000 DWT).
- 55 vessels a year Clean petroleum products (up to 230m).
- 146 vessels a year for methanol (up to 230m).

Future Container Terminal:

- Assumption: Same size of berth as the current DP World terminal.
- Assumption: Up to 321 new ships per year including 2 container ships with a length of 400m per year towards the end of the forecasting.

Kitimat Traffic:

- LNG traffic from LNG Canada. 170[2] vessels a year in Phase 1 (2023 start), but up to 350 vessels per year by 2030. (+290 m LOA 140,000m3 - 170,000m^3 capacity). **Figure 4-6** illustrates the proposed route for the LNG Canada project traffic.

Figure 4-7 shows the final traffic database for 2030 near the Port.

[1] The model input the traffic commencing in 2021 since the traffic in 2020 was only expected to start later in the year.

[2] The future results presented in this report have been modelled with a 350 LNG vessels from Kitimat annually. However, a run was also done with 170 vessels in 2030. These results can be found in **Appendix D**.

Figure 4-6: Proposed Traffic Route for LNG Canada Traffic

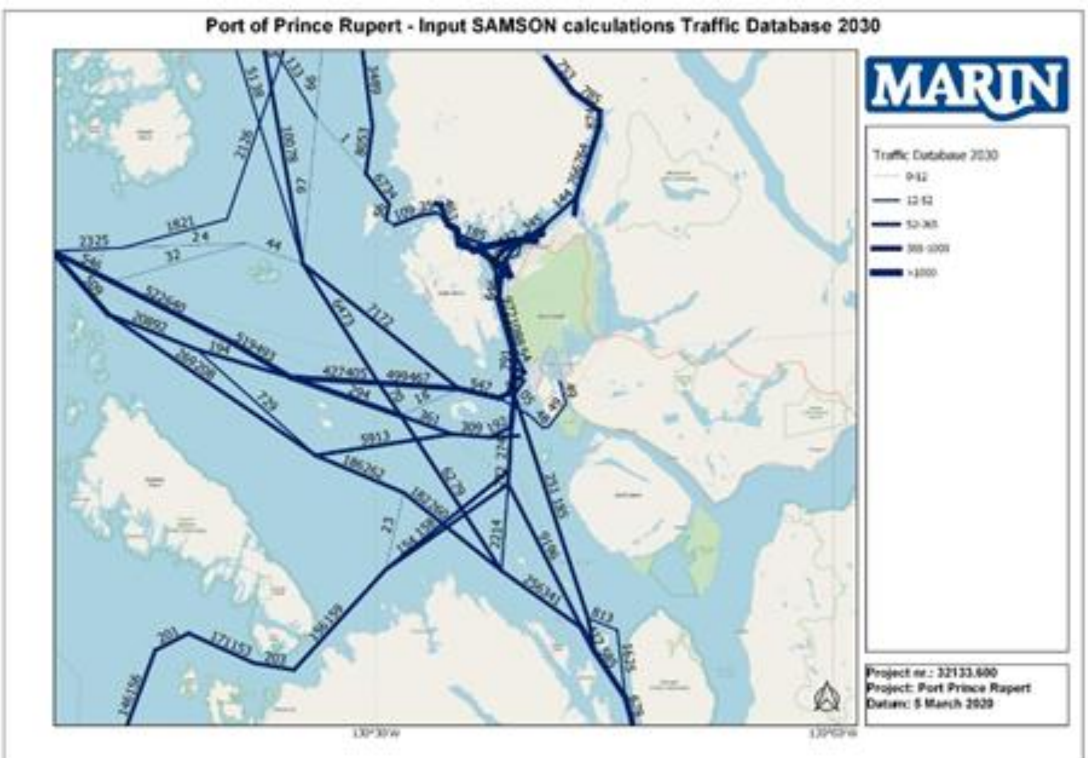


Figure 4-7: Traffic Network for 2030 with the Number of Vessels for Each Direction

4.1.1.3 Non-Route Bound Traffic

The non-route bound traffic database is constructed from three datasets:

1. The first dataset was created by assigning any route bound traffic that could not be assigned to a network, to a density instead. This includes ships that are, for example, waiting and sailing around.
2. The second dataset was created by assigning the typical vessels found in the non-route bound database, such as vessels that have a mission at sea like fishing vessels, supply vessels, escort tugs and other vessels that do not follow a defined network.
3. The third dataset was created by assigning the unknown AIS signals to the non-route bound database. Unknown AIS signals are AIS signals from vessels where there is no information on the type, size or mission of the vessel. It is assumed that unknown ships are all small vessels.

Using the AIS signals of these three datasets, the non-route bound database is created and assigns a vessel density to each grid of the Study Area that is then subsequently used to calculate the probability of an accident.

The non-route bound traffic database for fishing vessels is shown on **Figure 4-8** and the non-route bound traffic database for work vessels is presented in **Figure 4-9**.

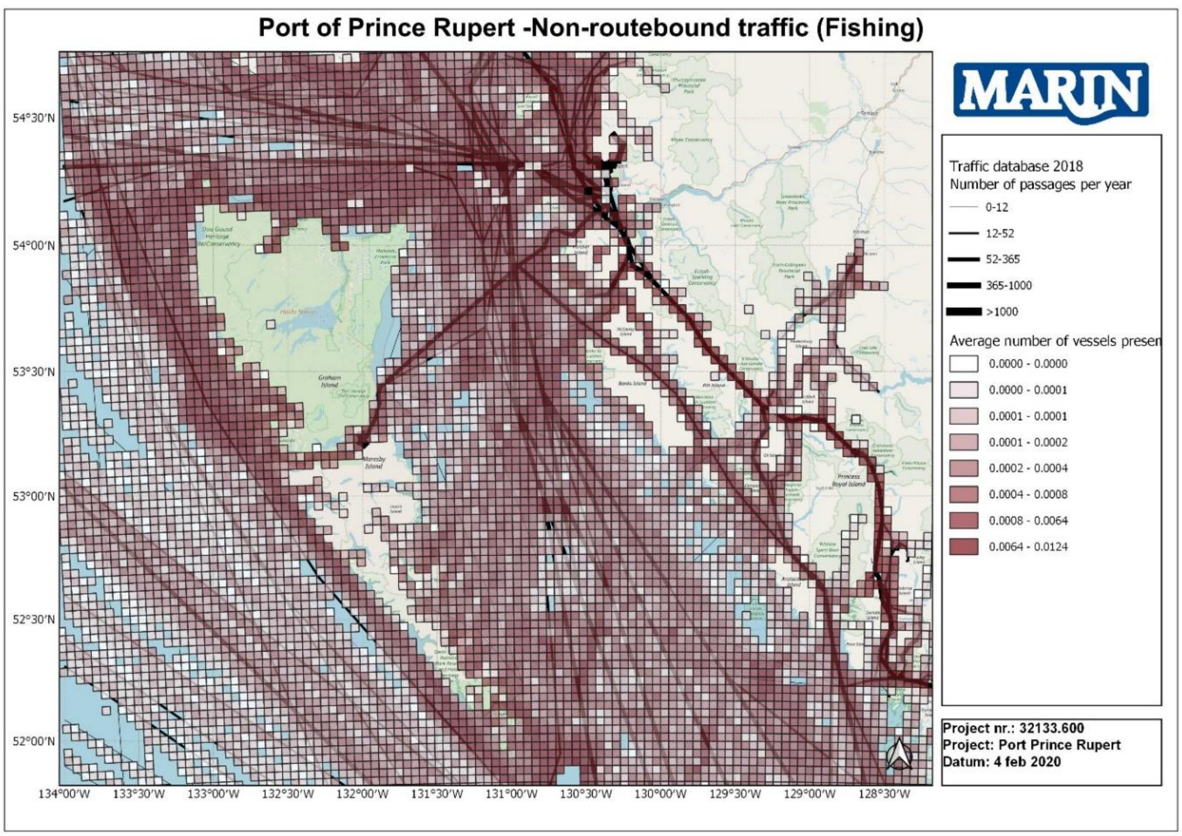


Figure 4-8: Non-Route Bound Fishing Traffic Database

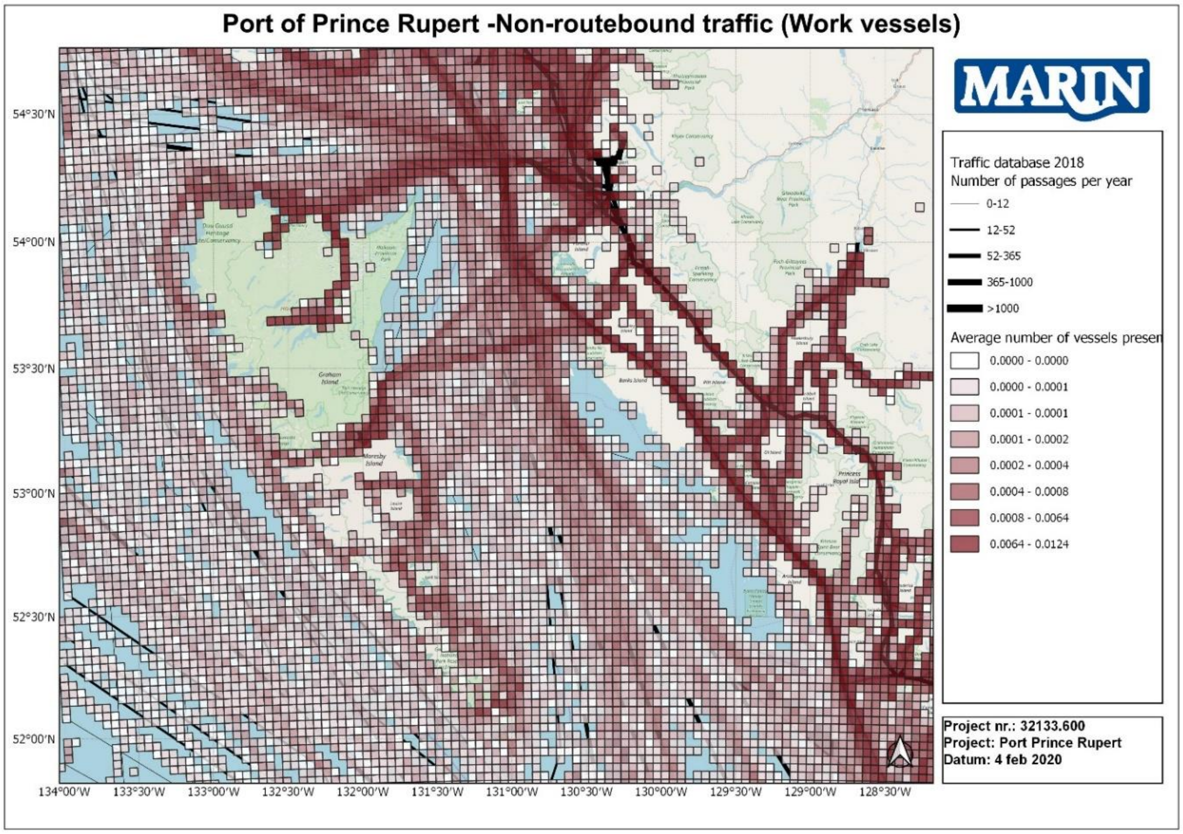


Figure 4-9: Non-Route Bound Work Vessel Traffic Database

The non-route bound traffic database was not changed for the 2030 modelling since the projected increases in traffic are for route bound traffic.

4.1.2 Stranding Lines

The SAMSON Model calculates the expected frequency of a wreck or stranding accident. To do this, the model will assign what is called “stranding lines” in the model. These lines represent the location in the Study Area where a ship has the potential of a wreck or stranding due to the physical characteristics of the area. It is possible to define different stranding lines for ships with a draught of 5 m, 10 m and 20 m. For this study, the stranding line was drawn for vessels with a draught of 5m, 10m and 20m.

For the Study Area, these lines are close to each other; therefore, only one stranding line is used in the calculations. The stranding lines are presented in **Figure 4-10** below. The number of wrecked/stranded accidents is calculated for each stranding line. In the output, the accidents are assigned to the grid cell in which the centre of the stranding line is located. Therefore, each stranding line is divided into pieces of 1 Nm, such that the predicted accidents of each piece are assigned to different grid cells.

Figure 4-10: Stranding Lines Figure Location of the Stranding Lines (including traffic database)

4.1.3 Environmental Conditions

The environmental conditions can be considered by SAMSON. For example, in the case of an engine failure the ship starts drifting. The drifting speed and the trajectory depend on the prevailing current and wind. The wind force also has an impact on the probability that a ship founders or has an engine failure. These probabilities are larger in storm conditions.

Tetra Tech provided detailed wind and current data from which the suitable data could be generated as input for SAMSON. Details of this data is presented in **Section 2.3**.

4.1.3.1 Currents

Data from 21 geographical positions was requested to feed into the SAMSON model. Tetra Tech provided the current data for each point containing an hourly registration of the current size and direction from January to December 2015 (2015 was selected as the best representative year, see **Section 2.3** for more information). The required tidal current is modelled as a sinusoidal current with a spring and a neap top derived from these datasets. Tetra Tech's 3-D hydrodynamic model was used to hindcast 3D ocean currents throughout the study area for the selected year.

In addition, current roses were developed for each data point and provided detailed information for the modelling of the traffic.

4.1.3.2 Winds

Tetra Tech provided the wind data for each point containing an hourly registration of the wind force and direction from January to December 2015 (2015 was selected as the best representative year, see **Appendix A** for more information). The average wind compass in the points, being the input for the SAMSON Model, has been derived from these datasets. A wind rose was developed for each datapoint to provide detailed information for the model.

4.1.4 Preventative Measures

Preventive Measures include the navigational aids and measures that assist in reducing the frequency of an accident. The calculations of the SAMSON model take into account the following preventive measures:

- Traffic Separation schemes (TSS);
- VTMS;
- Pilotage;
- Escort and Tethered Tug;
- AIS;
- Electronic Chart Display and Information System (ECDIS); and
- Port State Control.

Several preventative barriers are also included indirectly in the SAMSON Model and not as separate parameters or factors; those include barriers such as: approach and mooring procedures, and electronic navigation (ENAV). The information on these measures is provided by Electronic Nautical Charts (ENC), which are obtained from the Canadian Hydrographic Service.

Areas where VTMS is implemented and Pilotage is required have been included in the SAMSON modelling. Within the Study Area escort tugs and tethered tugs were modelled for container ships entering the Port (through the Fairview Channel and inner harbour) and tethered tugs were modelled for LNG tankers and tankers transiting to and from Port Edward. The effect of AIS, ECDIS and Port State Control is implicitly included in the probability of being involved in an accident. Mandatory pilotage is applied in the black dashed area

Table 4-1 below shows the reduction in percentage that each preventive measure has on a potential accident. Pilotage reduces the probability of a vessel colliding with another vessel and reduces the likelihood of a navigation error leading to a stranding by 62% ((de Jong, 1998), (SSPA, 2012)). In areas where there is VTMS, vessel movements are being monitored and navigational safety is provided. VTMS is used in the SAMSON model calculations and the percentage effect it has on reducing the risk of collision is 30% ((de Jong, 1998), (SSPA, 2012)).

Table 4-1: Reduction Percentages of the Probability of an Accident Occurring by Preventive Measures

Preventive Measures	Accident Type					
	Allision with Ship at Anchor		Collision	Wrecked/Stranded		Fire/Explosion, Foundered, Hull Failure
	Mechanical Failure – Drifting	Human Error - Ramming		Mechanical Failure – Drifting	Human Error - Ramming	
Pilotage	-	62%	62%	-	62%	-
Vessel Traffic Services	-	-	30%	-	-	-
Tugs Tethered	99%	50%	-	99%	50%	-
Tugs Escort	90%	-	-	90%	-	-
Traffic Separation schemes	TSS reduces the potential for an encounter; therefore, decreasing the number of collisions					-

4.1.5 Incident Statistics

The SAMSON Model uses incident statistics available from the international IHS Fairplay collision database from 1990 to 2012 The international statistics obtained from the IHS Fairplay Database are filtered to include maritime countries in the North Sea with similar regimes to Canada. The countries selected were Germany, France, Netherlands, Norway, and United Kingdom.

4.1.6 Limitations

The following limitations apply to the MNRA:

- The scope of this study was limited to utilizing shipping traffic for the calendar year 2018 and forecasted traffic for 2030. The forecasted traffic numbers may not reflect the reality of traffic in 2030 as many factors can influence the global movement of goods.
- Shipping accident reduction factors for pilotage, Vessel Traffic Management Services, tethered tugs and escort tugs were incorporated within the analysis based on studies completed in the North Sea. At the time the study was completed, no Canadian-equivalent studies are known to exist.
- As per the Navigation Safety Regulations (SOR/2005-134) fishing vessels are not required to carry AIS. A reasonable attempt was made to model fishing vessels without AIS based on historical fish catch data (BCMCA, 2008) and on a traffic study completed by the PRPA for Porpoise Harbour (PRPA, 2014).
- The marine navigational risk assessment only determined the probability of a marine accident involving two ships colliding or vessels grounding or stranding. It did not determine the consequences of the incidents such as a cargo spill.
- The marine navigational risk assessment only considers vessels greater than 100 gross tonnes. This means that smaller fishing vessels and recreational vessels that are less than 100 gross

tonnes are modelled as vessels of 100 gross tonnes. This may lead to an overestimate the likelihood of collision and groundings.

- The likelihood of a marine accident occurring during the final berthing and docking of vessels was not modeled as part of this assessment.

4.2 Results

The results of the MNRA are presented in a series of maps and tables in the following sections. Some of the results are presented for the entire study area and for a sub area near the Port, as presented in **Figure 4-11**.

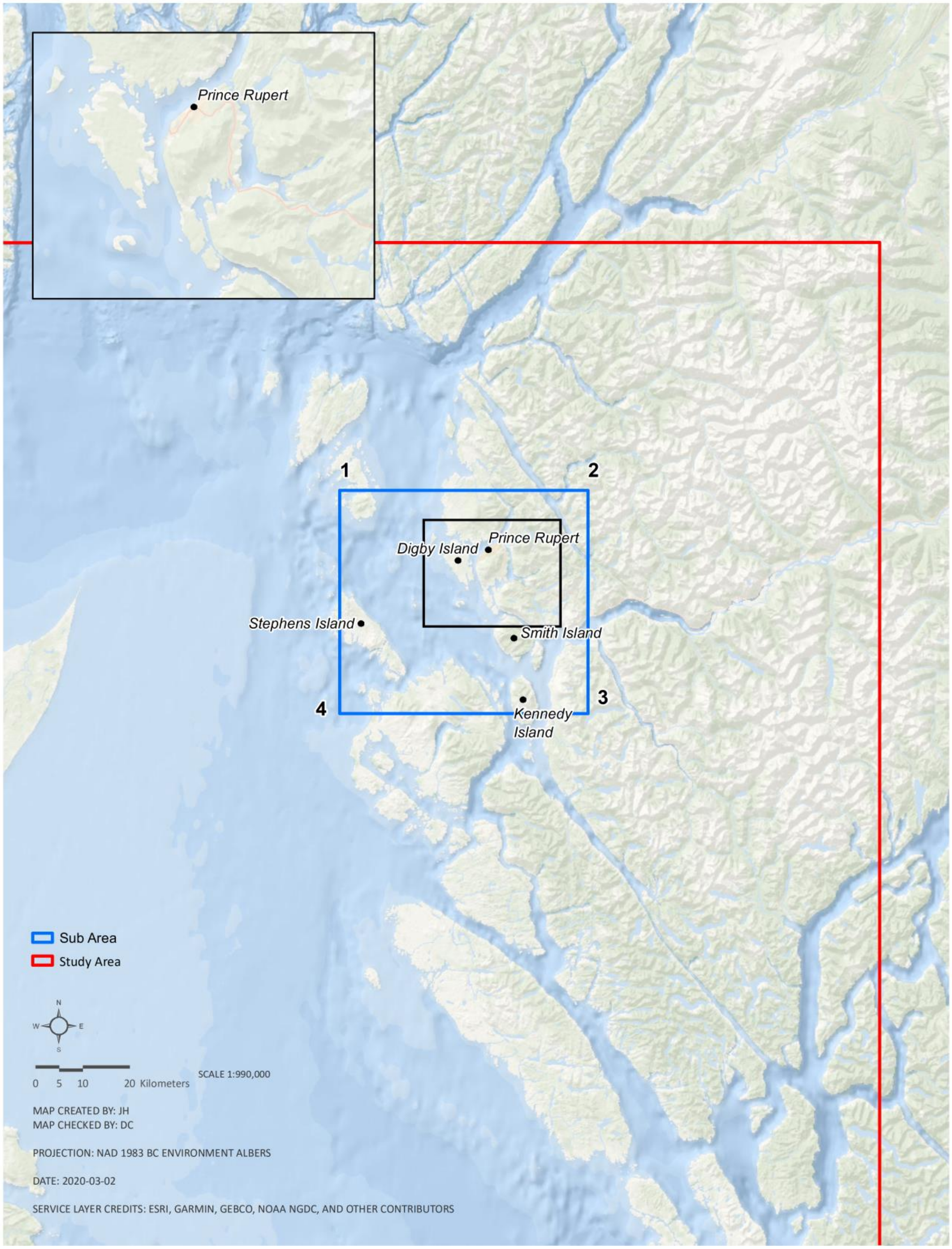


Figure 4-11: Plot illustrating Sub Area where Certain Results are Presented

4.2.1 Nautical Miles Travelled by Vessels

Based on the traffic database the total number of vessels present in both areas and the total number of sailed miles is calculated. Based on the calculated data, there are at any moment on average 20 vessels present in the study area in 2018, 4 of those vessels are route bound vessels. This number is projected to grow to 5 in the 2030 scenario. Examining the Port area of interest, on average there is 0.6 route bound vessels underway at any moment in 2018. This is projected to grow to 0.78 vessels in 2030 (increase of 22%). No change in non route bound vessels was noted since the future traffic was based on projections in commercial traffic in the area and did not include any non route bound vessels. These results are summarized in **Table 4-2** along with the number of nm sailed by vessels within the study area.

Table 4-2: Number of Vessels within the Study Area at any Given Time and Number of nm Sailed by Vessels within Study Area

	Whole Calculated Area			Sub Area		
	2018	2030	% grow	2018	2030	% grow
Average number of route bound vessels present	4.01	5.18	28.98%	0.64	0.78	22.16%
Average number of non-route bound vessels present	15.71	15.71	0.00%	2.74	2.74	0.00%
Total average number of vessels present	**19.72**	**20.89**	**5.90%**	**3.38**	**3.52**	**4.20%**
Total number of sailed nm in the area by route bound vessels	567,651	729,285	28.47%	83,357	102,801	23.33%
Total number of sailed nm in the area by non-route bound vessels	1,349,236	1,349,236	0.00%	234,261	234,261	0.00%
Total number of sailed nm in the area	**1,916,887**	**2,078,521**	**8.43%**	**317,618**	**337,062**	**6.12%**

4.2.2 Likelihood of Ship to Ship Collisions

The SAMSON Model predicts the likelihood of collisions between vessels underway, it provides results for both the route bound and non-route bound traffic within the study area and the sub area. The results for the sub area are presented in **Figure 4-12** for the 2018 scenario and in **Figure 4-13** for the 2030 scenario. Results for the entire study area are presented in **Appendix D**.

The results are presented as a series of return periods. A return period is commonly used to present the likelihood of an event such as a flood, earthquake or oil spill and it provides an estimated time interval, in years, between similar events. A return period of 100 years does not mean that if the event occurs today the next event will occur in 100 years. Instead, it means that in any given year, there is a 1% chance of the event occurring. A return period of less than 1 means that an event is expected to occur every year.

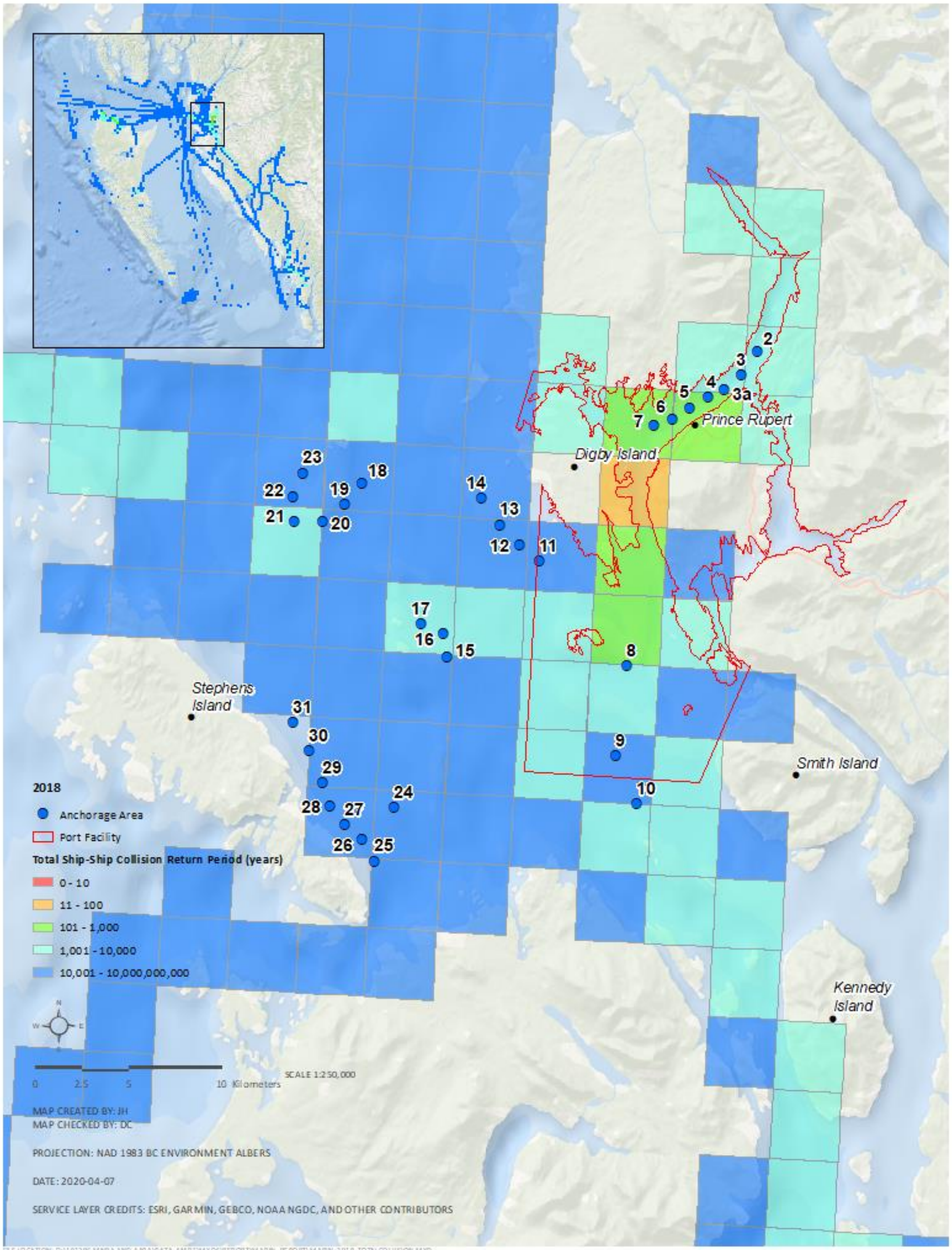


Figure 4-12: Return Period (in years) for Ship to Ship Collisions within the Sub Area for 2018 Scenario

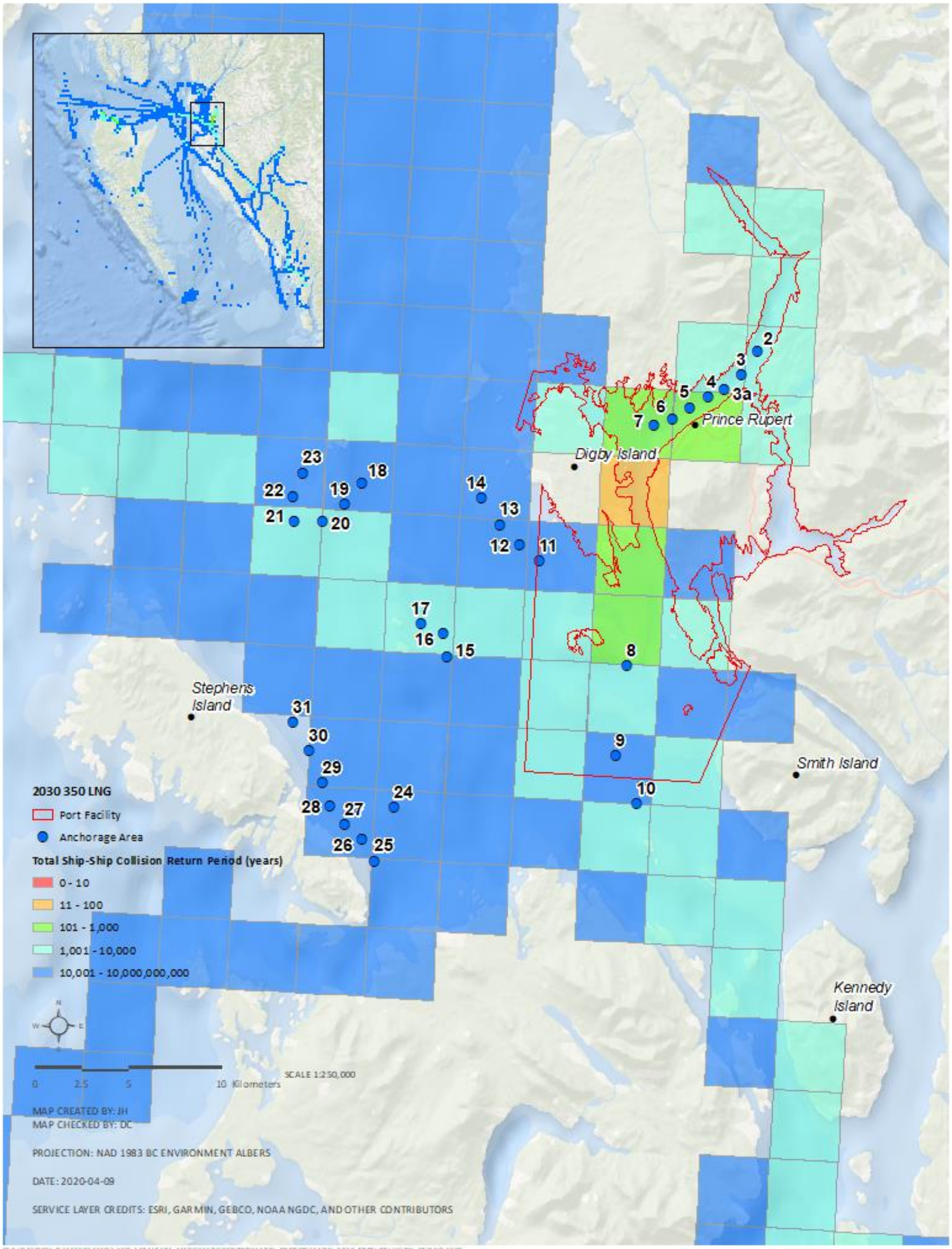


Figure 4-13: Return Period (in years) for Ship to Ship Collisions within the Sub Area for 2030 Scenario

The SAMSON model can calculate the return period for collisions throughout the study area and in the sub area which is presented in **Table 4-3**.

Table 4-3: Expected return Period for Vessel to Vessel Collisions within the Sub Area and Study Area for 2018 and 2030

	Sub Area			Study Area		
	2018	2030	% Increase	2018	2030	% Increase
Collision Return Period All vessels	21	19	9%	11	10	16%
Collision Return Period Route bound vessels (commercial)	158	140	13%	117	71	64%

Reviewing the results of the SAMSON Model it is expected that the collision return period for the Sub Area will change from once every 21 years to once every 19 years in 2030. This represents a 9% increase in the likelihood of a collision within the Port. The most likely location for a collision within the Port is the waters between Digby Island and Container Terminal, near Parizeau Point. This area is one of the narrowest channels within the Port and is where large container vessels berth. Other areas of concern in include the waters around anchorage area 7 and the waters around anchorage area 8. Anchorage area 7 is located at the entrance to the inner harbour. All vessels transiting through the inner harbour or to and from other anchorages in the inner harbour, must pass by anchorage area 7 while executing a turn. Anchorage area 8, is in close proximity to the main navigational channel and vessels have to execute a 90 degree turn as the line up to transit into the Port.

Table 4-3 also breaks down the expected return period for vessel to vessel collisions within the Sub Area and Study Area for route bound vessels only. Route bound vessels are typically commercial vessels as they transit from point a to point b. It is expected that within the Sub Area, there is a collision between route bound vessels once every 158 years with the current traffic and once every 140 years with the 2030 traffic, a 13% increase. However, within the full Study Area, we can see the likelihood of a route bound vessel collision increase from one in 117 years with current traffic to one in 71 years, or a 65% increase. This can be explained by the additional traffic from projects being developed in the Kitimat area. The traffic from these projects will transit within the Study Area and therefore increase the likelihood of a potential collision.

The likelihood of collision results were also broken down into commercial ship categories to analyze the likelihoods of specific commercial categories. **Table 4-4** below outlines the return periods for the expected likelihood of collisions by ship type for the Study Area in 2018, and 2030. The highest likelihood for the Study Area is for uncategorized vessels, which are smaller vessels and/or government vessels. The next likeliest commercial vessel category to have a collision is the Passenger – Ferry – Roro vessels.

Table 4-4: Expected Return Period for Vessel to Vessel Collision within the Study Area by Ship Category

Ship Category	2018	2030
GDC – Bulker	186	163
Container	582	530
Tanker – Chemical	19,780	592
Tanker – Oil	87,951	1,544
LNG-LPG	-	230
Passenger – Ferry – Roro	98	91
Fishing	159	150
Uncategorized	15	15

Table 4-5 below outlines the return periods for the expected likelihood of collisions by ship type for the Sub Area. The highest likelihood is also the Uncategorized category. Passenger – Ferry – Roro are also the second likeliest in the Sub Area.

Table 4-5: Expected Return Period for Vessel to Vessel Collision within the Sub Area by Ship Category

Ship Category	2018	2030
GDC – Bulker	245	232
Container	759	722
Tanker – Chemical	43,098	1,129
Tanker – Oil	110,977	2,899
LNG-LPG	-	2,200
Passenger – Ferry – Roro	131	135
Fishing	311	303
Uncategorized	34	33

4.2.3 Likelihood of Vessels Grounding

The SAMSON Model also determines the likelihood of a vessel grounding. The model determines two different types of groundings. The first one is the vessel loses power and drifts aground, called a drift grounding. The second one involves a navigational error and the vessel goes aground at speed, called a ramming. The return period for a vessel grounding throughout the study area is presented in **Table 4-6** below.

Furthermore, to account for the various different drafts of vessels, from large tankers with deep drafts to smaller vessels with shallow drafts the likelihood of groundings were determined for 3 different drafts. The three drafts are < 5 m, between 5-10 m and greater than 10 m. It is expected that the majority of commercial vessels calling on the Port would have a draft greater than 10 m. The return period's groundings are presented in **Table 4-6** for the 2018 scenario and in **Table 4-7** for the sub area.

Table 4-6: Return Period (in years) of a Vessel Grounding within the Study Area for 2018 Scenario

Draft of Vessel	Ramming			Drifting			Total		
	Route Bound Vessels	Non-Route Bound Vessels	Total	Route Bound Vessels	Non-Route Bound Vessels	Total	Route Bound Vessels	Non-Route Bound Vessels	Total
Draft <5m	8.1	0.4	0.4	23.7	3.4	3.0	6.1	0.4	0.3
5-10 m	5.8	-	5.8	33.8	-	33.8	5.0	-	5.0
>10 m	30.7	-	30.7	489.8	-	489.8	28.9	-	28.9
Total	3.1	0.4	0.4	13.6	3.4	2.7	2.5	0.4	0.3

Table 4-7: Return Period (in years) of a Vessel Grounding within the Sub Area for 2018 Scenario

Draft of Vessel	Ramming			Drifting			Total		
	Route Bound Vessels	Non-Route Bound Vessels	Total	Route Bound Vessels	Non-Route Bound Vessels	Total	Route Bound Vessels	Non-Route Bound Vessels	Total
Draft <5m	9.6	1.5	1.3	49.1	12.3	9.8	8.0	1.3	1.1
5-10 m	13.9	-	13.9	148.3	-	148.3	12.7	-	12.7
>10 m	32.8	-	32.8	1,128.2	-	1,128.2	31.9	-	31.9
Total	4.8	1.5	1.1	35.7	12.3	9.1	4.3	1.3	1.0

From **Table 4-6** a grounding is expected to occur anywhere within the study area yearly. The likeliest vessel to go aground is a non-route bound vessel with a draft less than 5 m, like a fishing vessel. A grounding involving a small commercial vessel is expected to occur once every 5 years and a grounding of a large commercial vessel is expected to occur once every 29 years.

Table 4-7 identifies that a grounding is expected to occur within the sub area annually. The likeliest vessel to run aground is a non-route bound vessel with a draft of less than 5m. A grounding involving a small commercial vessel is expected to occur once every 13 years and a large commercial vessel is expected to run aground once every 32 years.

The 2030 scenario is outlined in **Table 4-8** for both types of groundings, all three drafts, and route and non-route bound vessels. Future results for the sub area are outlined in **Table 4-9**.

Table 4-8: Return Period (in years) of a Vessel Grounding within the Study Area for 2030 Scenario

Draft of Vessel	Ramming			Drifting			Total		
	Route Bound Vessels	Non-Route Bound Vessels	Total	Route Bound Vessels	Non-Route Bound Vessels	Total	Route Bound Vessels	Non-Route Bound Vessels	Total
Draft <5m	8.2	0.4	0.4	24.0	3.4	3.0	6.1	0.4	0.3
5-10 m	2.1	-	2.1	12.6	-	12.6	1.8	-	1.8
>10 m	29.6	-	29.6	481.6	-	481.6	27.9	-	27.9
Total	1.6	0.4	0.3	8.1	3.4	2.4	1.3	0.4	0.3

The overall likelihood of groundings is calculated to be similar in the 2030 scenario as it is in the 2018 scenario (**Table 4-6**). What is notable is the likelihood of a groundings from small commercial vessels (draft 5-10 meters) changes from once every 5 years in the 2018 scenario to once every 1.8 years in the 2030 scenario. This is due the projected increase in commercial traffic transiting throughout the study area.

Table 4-9: Return Period (in years) of a Vessel Grounding within the Sub Area for 2030 Scenario

Draft of Vessel	Ramming			Drifting			Total		
	Route Bound Vessels	Non-Route Bound Vessels	Total	Route Bound Vessels	Non-Route Bound Vessels	Total	Route Bound Vessels	Non-Route Bound Vessels	Total
Draft <5m	9.7	1.5	1.3	51.0	12.3	9.9	8.1	1.3	1.1
5-10 m	11.4	-	11.4	92.2	-	92.2	10.1	-	10.1
>10 m	31.7	-	31.7	1,117.2	-	1,117.2	30.8	-	30.8
Total	4.5	1.5	1.1	31.9	12.3	8.9	3.9	1.3	1.0

The future results for the groundings in the sub area, as presented in **Table 4-9**, identify an overall risk of a vessel grounding once every year. The likeliest vessel is one with a draft less than 5 meters which is to be expected since there was no increased projection in the number of these vessels in the future scenario. A mid-sized commercial vessel is expected to run aground once ever y10 years and a large commercial vessel once every 31 years.

The grounding results were also broken down by commercial ship type to provide some increased analysis. The results below in **Table 4-10** include overall grounding risk by ship type, therefore it includes both groundings by ramming and drifting. The biggest increases in risk for the future scenario are with the LNG-LPG category of vessels which climb from zero risk to once in 3-6 years. This is not totally unexpected as this is the category with the most significant growth. These Study Area results also include the large increase in LNG traffic transiting from Kitimat which should be considered when interpreting these results. However, it should be noted that the Kitimat traffic was used in the model but no detailed assessment to account for preventative measures related to each project was done. There is also a marked increase in risk of chemical and oil tankers running aground in this time. This increase is likely most associated with the VOPAK terminal opening and the increase in Methanol and Clean Petroleum Products being transported.

Table 4-10: Grounding Results by Ship Type for Study Area (return period)

Ship Category	2018	2030
GDC – Bulker	13	13
Container	19	19
Tanker – Chemical	432	78
Tanker – Oil	12,562	244
LNG-LPG	-	3[3]
Passenger – Ferry – Roro	4	4
Fishing	3	3
Uncategorized	0.4	0.4

Table 4-11 below shows the results by ship type for the Sub Area instead of the full study area. The results show that the biggest increase risk in the Sub Area for groundings would be with Chemical tankers, oil tankers and LNG-LPG vessels. However, we can see that within the Sub Area, the 2030 risk of a LNG-LPG vessel running aground is lower than in the full Study Area.

Table 4-11: Grounding Results by Ship Type for Sub Area (return period)

Ship Category	2018	2030
GDC – Bulker	24	24
Container	22	22
Tanker – Chemical	2,720	111
Tanker – Oil	14,664	307
LNG-LPG	-	151
Passenger – Ferry – Roro	7	7
Fishing	13	13
Uncategorized	1	1

[3] Kitimat traffic was used in the model but no detailed assessment to account for preventative measures related to each project was done. Therefore, the risks may be overestimated for the Study Area.

5.0 Anchorage Area Assessment

An anchorage area assessment was conducted for the Port's anchorage areas. This was done to update the previous anchorage study done in 2012 (Moffatt & Nichol, 2012), as well as determine what impacts the future projected growth may have on the anchorage areas.

The assessment included:

- An assessment of current anchorage utilization;
- An assessment of future anchorage utilization with a traffic increase forecast provided by the Port and collected through the HAZID workshop;
- An assessment of holding capacity for the current anchorages;
- An assessment of the anchorage area swing circles;
- An overview of previous anchor dragging incidents; and
- A risk assessment of current traffic flow around the anchorages to identify any increased risk for transiting ships striking a ship at anchor.

5.1 Limitations

Anchorage Utilization Limitations

- Future projected growth within the port is not certain to occur as predicted. Therefore, 2030 results may vary from the results of this assessment.
- Estimates of future anchorage utilization are provided by a theoretical simulation model of anchorage assignment practice. The model is developed to provide a high-level view of future trends; and, is based on multiple assumptions and approximations due to lack of detailed process information.
- The anchorage utilization simulation excludes intermodal traffic as intermodal vessels only require to anchor on an occasional basis. The simulation was conducted under the assumption that this will not be affected by the increasing intermodal traffic over the next decade, and will be compensated by the planned increase in the service capacity of Fairview Container Terminal.

Anchorage Holding Capacity Limitations

- Limitations were determined based on the bathymetry of the port as provided by BCMCA (2008). The bathymetry data was for all of BC and may not adequately represent the conditions within the confines of the Port of Prince Rupert.
- Holding capacity calculations were based on theoretical calculations based on standard anchors, cable and vessels. Individual vessels vary in how they are constructed which means that the theoretical calculations may not directly represent a vessel.

Swing Circle and Diameter Limitations

- Swing circle and diameter limitation calculations were based on BCMCA bathymetry data, and theoretical calculations that my not represent all vessels that call upon the Port.

Anchorage Area Risk Assessment Limitations

- Future projected growth is not certain to occur as predicted. Therefore, 2030 results may vary from the results of this assessment.
- The SAMSON model utilizes AIS; therefore, does not capture vessel movements for ships that are not required to utilize AIS.
- The SAMSON model does not model the additional risk of ships dragging anchor while other ships transit.

5.2 Anchorage Utilization

As described in **Section 2.2.2**, the Port is expected to experience an increase in commercial vessel traffic over the course of the next decade. **Figure 2-11** illustrates forecast of commercial vessel traffic from 2019 to 2030. The increasing traffic results in a higher future demand for anchorage areas and/or adjustments to the anchorage assignment policies.

5.2.1 Current Anchorage Utilization Modelling

The anchorage assignment by the Port is shown below in **Figure 5-1.** As shown in the figure, historical trends of anchorage assignment from 2015 to 2018 shows an overall surplus of available time at all anchorage areas. Furthermore, the data illustrates that anchorage areas 3a, 11-14, 30 and 31 were not used during the time period). However, this overall view does not account for anchorage availability in real time and in accordance to cargo type and LOA specifications. Therefore it does not necessarily imply that there is currently an operation without bottle-necks and difficulties in the anchorage assignment process.

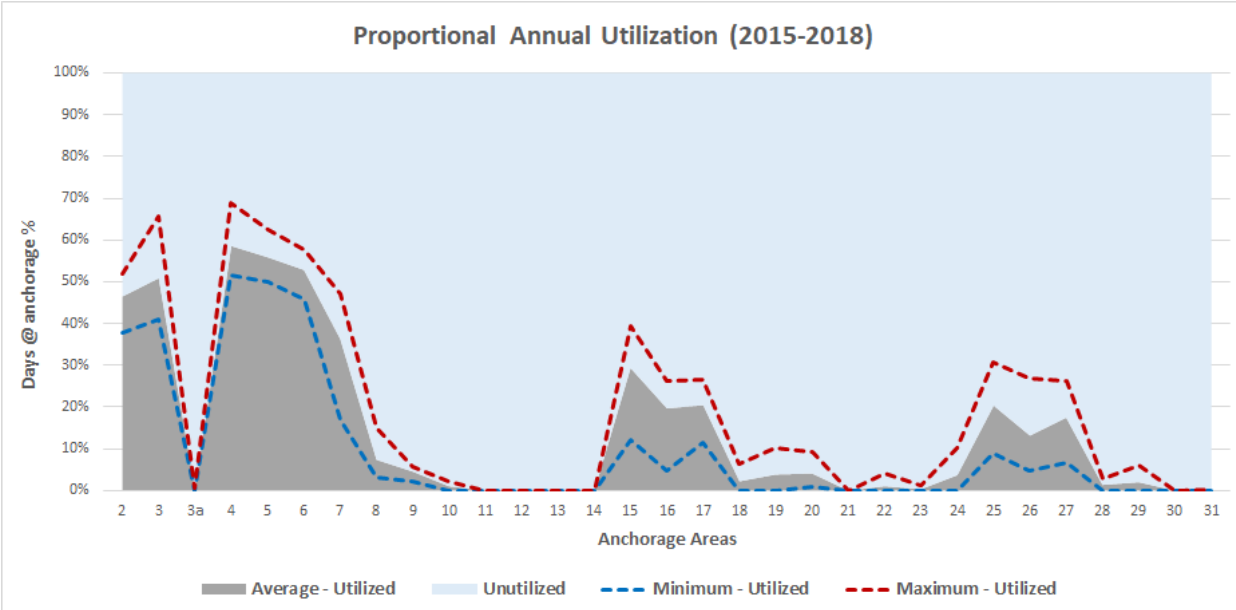


Figure 5-1: Annual Anchorage Utilization Rate 2015-2018

Figure 5-2 provides a statistical overview of anchorage assignments from 2015 to 2019. As shown in the figure, inner harbour anchorage areas, anchorages 2-7, and anchorage areas 15-17 are the most, high demand anchorage areas. This is not only because of the high proportional volume of grain traffic, but also likely due to log ships. The relocation is caused by the requirement of inner harbour area for docking and inspection purposes. Anchorage areas 25-27 that are usually allocated to coal and LPG vessels.

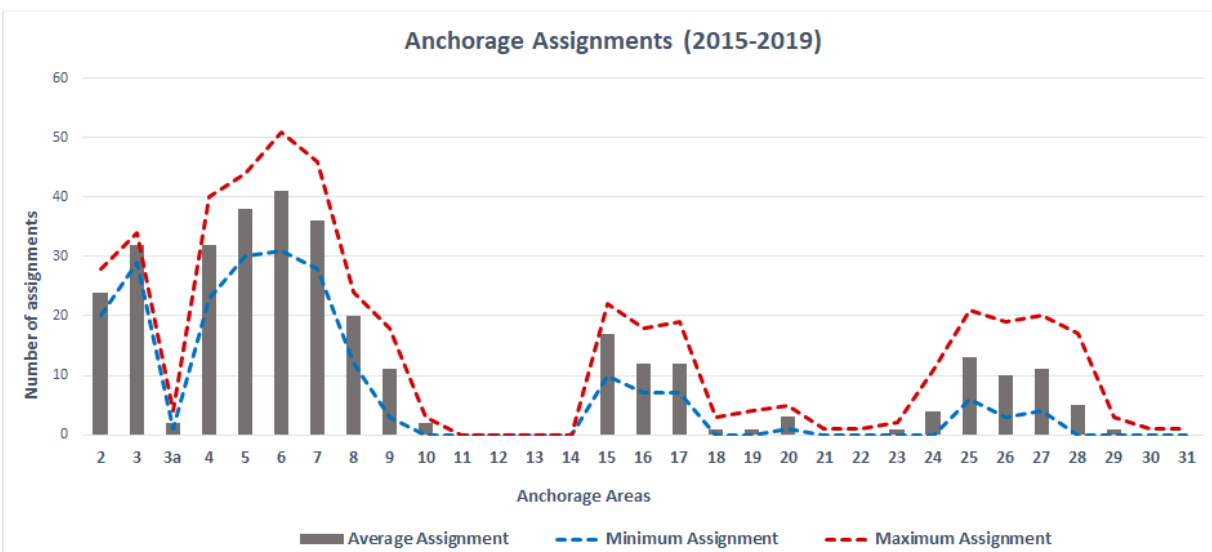


Figure 5-2: Annual Anchorage Assignments 2015-2018

Seasonality trends were also examined in the study and found to be of minor importance. As presented in **Figure 2-11** the number of grain vessels are not expected to increase, but the expected increase in future traffic is mostly due to the increase in LPG and methanol ships. Therefore, significant changes in utilization level is expected in anchorages 9, 10, 25, 26, 27, 30, and 31 anchorages with LPG and methanol cargo allocation specifications, in comparison to inner harbour anchorage areas. This is further explored in the next section.

5.2.2 Future Anchorage Utilization Modelling

Lack of capacity to meet future anchorage demand is an operational risk; but it can also be viewed as a safety hazard as attempting to meet an unexpected demand may dictate lower safety margins in the anchorage allocation practice. The management of the anchorage areas needs a proactive approach especially when a larger number of vessels of larger size are anticipated. Thus, an analysis of future anchorage efficiency has been conducted to shed light on the future demand and the efficiency of current anchorage areas in accordance with the forecasted traffic figures.

The initial steps of the analysis included an overall statistical review of the anchorage assignments and durations based on the 2015 to 2019 data provided by the Port. The initial analysis included examining historical trends, anchorage policies and procedures, as well as constraints and concerns through a review of port documents, past studies, data sets provided by the Port, MARIN, and information collected at the HAZID workshop.

Analysis of future anchorage utilization and capacity requires complex analysis since the behavior of the anchorage system is tied to variable factors such as environmental conditions, vessel traffic volume, specifications of different fleets, and the corresponding arrival patterns. Therefore, a top-down approach to the analysis based on historical trends may not be a valid approach as the behavior of the system is subject to change and old patterns may not hold.

In the case of the Port, as shown in **Figure 2-11**, ships of different cargo types are anticipated to follow different vessel traffic trends in the next 10 years. The increasing traffic volume is one of the variables in future trends, but the analysis of the system needs an effective approach to handle further complexities which are outlined below:

- An analysis of anchorage utilization and capacity is not solely dependent on vessel traffic rate. Factors such as the availability of terminal berths at arrival, and anchorage availability upon requirement play major roles in such a forecast. These factors are subject to a high level of uncertainty, and are functions of underlying factors such as vessels arrival patterns and terminal service rates.
- The underlying factors such as the expected interarrival times and service times are also factors of stochastic nature and also differ in accordance to different fleets.
- Characteristics of the expected traffic is subject to change as a result of new projects such as Alta Gas, Pembina, and Vopak; and the new jetties mentioned in **Table 2-4**. As a result, not only the

traffic volume is subject to variation, a change in the proportional distribution of ships of different cargo types and sizes is expected. Prediction of system behavior is complex as it depends on traffic characteristics, and the availability of terminal jetties and anchorage areas with certain requirements.

The effect of changes in rates and patterns, policies, constraints, and procedures cannot be easily incorporated in a top-down statistical analysis. Therefore, Discrete Event Simulation was employed as an effective technique and a bottom-up approach to model the system based on current specifications and observing the outcome of imposed variations to the system.

A discrete-event simulation system is a probabilistic model that consists of an algorithmic simplified model of reality; and, a computation engine capable of regenerating snapshots future scenarios based on probability distributions. The simulation engine generates a number of simulation entities, assigns determinant attributes to each entity, and examines a number of possible combinations of attributes through a number of iterations. Adequate number of iterations help to analyze the variability of results due to the randomness of system variables.

The simulation system enables handling complex analyses but it should be expressed that the simulation model is a simplified model of reality and that the validity of output is closely dependent on its accuracy in modeling the reality of processes and constraints. A detailed simulation model requires access to detailed information on the determinant attributes, and extensive observation and modeling efforts that are beyond the scope of this project. However, in order to provide insight to future trends and needs at high-level, a discrete event simulation model was developed under certain assumptions and a level of approximation, and ran for 200 iterations for each year. **Figure 5-3** is a schematic presentation of the process simulation model.

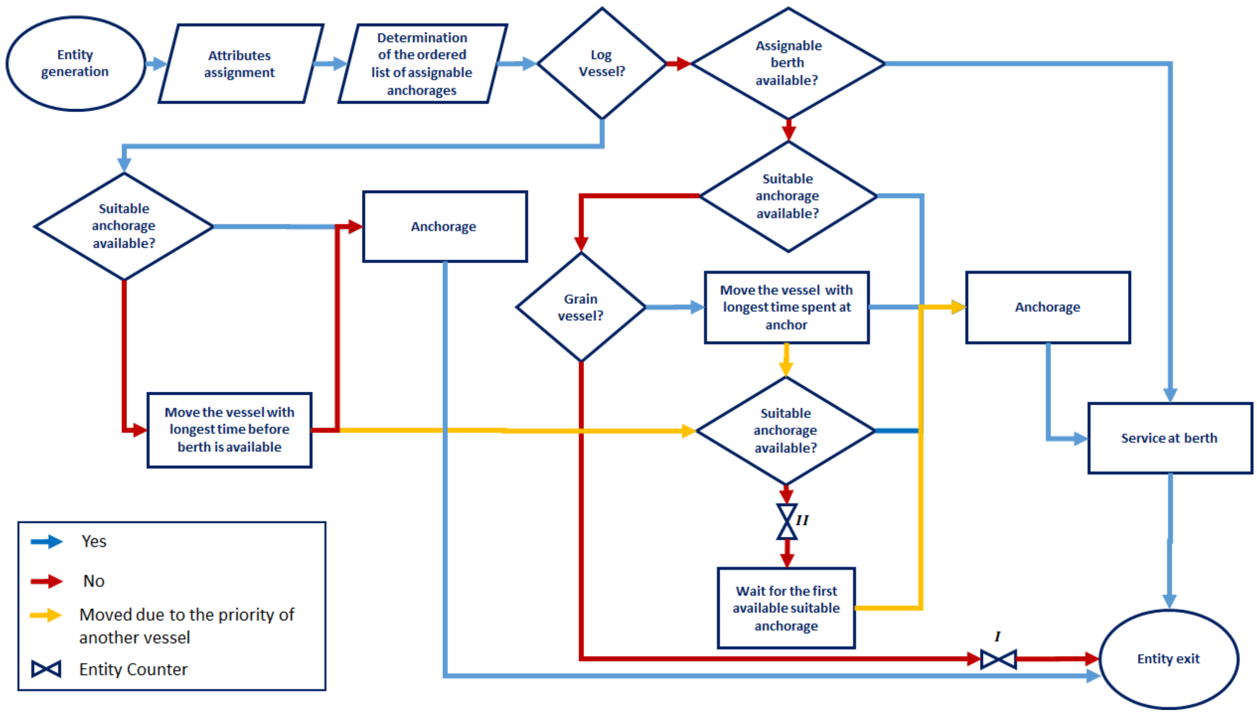


Figure 5-3: Schematic Presentation of the Process Simulation Model

In this simulation, each simulation entity is equal to a vessel, and the determining attributes to the anchorage process were identified to be the cargo type, LOA, arrival time, and terminal service times. These attributes were randomly assigned to each entity based on their historical patterns modeled as probability distribution functions as presented in **Appendix E**.

The presented simulation model provides a high level estimate of anchorage utilization trends by modeling service and traffic factors and is developed under a number of limitations and assumption as explained below:

1. Arrival Times

The arrival times of ships are usually modelled by the use of historical interarrival patterns. The interarrival intervals of all traffic could be obtained from AIS data; however, information on the schedule or arrival patterns of ships of different cargo types were not available from the Port and AIS databases. As a workaround, interarrival intervals were simulated based on the arrival pattern of all marine traffic based on 2018 AIS data.

Exponential distribution is a distribution class that is suggested for modeling random arrival times, and as shown in **Figure 5-4**, the 2018 AIS data closely fits an exponential function. Therefore, an exponential distribution was used to simulate the arrival patterns.

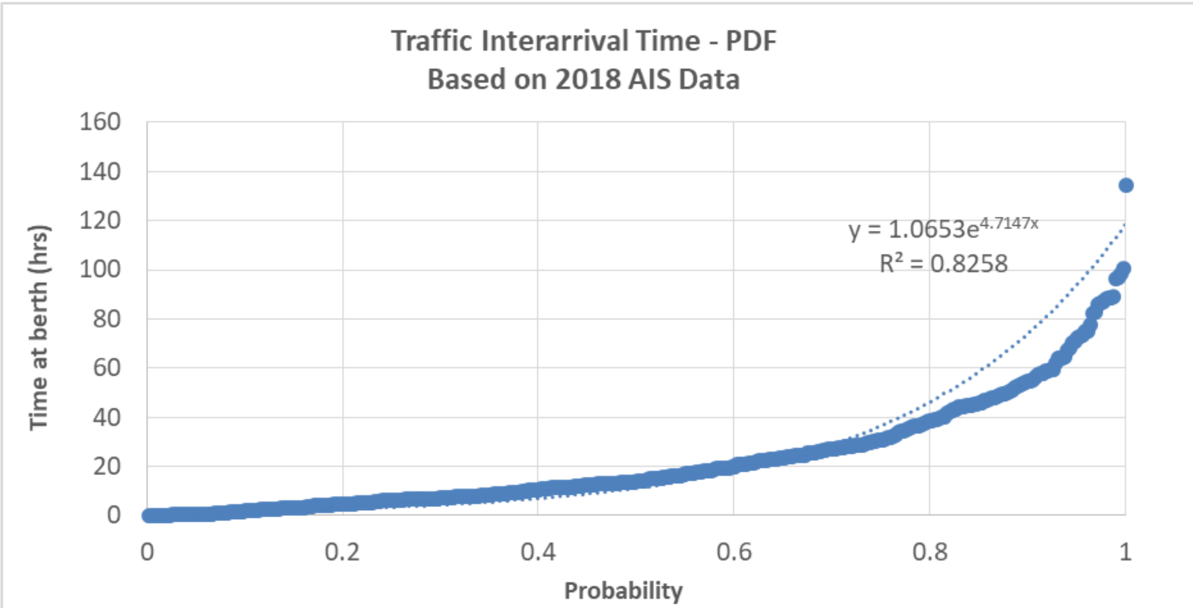


Figure 5-4: Traffic Interarrival Time based on 2018 AIS Data

The mean parameter of the exponential distribution was set equal to the expected mean for each year based on the predicted number of vessels for each year. In other words, interarrival times were randomly assigned based on the 2018 arrival pattern, but adjusted to the number of ships expected in each year. **Table 5-1** shows the number of vessels forecasted for each simulation year and the average interarrival time that is calculated as number of hours in one year (8,760 hrs) over the number of forecasted arrivals.

Table 5-1: Number of Vessels Forecasted for Each Year

Simulation Year	Number of Vessels (Including Intermodal)	Average Interarrival Time (hours)
2019	577	15.18
2020	661	13.25
2021	697	12.57
2022	761	11.51
2023	883	9.92
2024	953	9.19
2025	996	8.80
2026	1120	7.82
2027	1170	7.49
2028	1225	7.15
2029	1229	7.13
2030	1233	7.10

An individual modeling of arrival rates for each fleet would be ideal to attain a higher level of accuracy but such detailed information was not available.

2. Cargo Types and LOAs

Cargo types were attributed to each simulated vessel based on the traffic proportional probability for each cargo type for each simulated year based on the base case forecast.

Assigning LOAs based on the typical for each cargo type would be ideal for the purpose of simulation. However, Information on the typical range and proportion of different vessel LOAs with reference to each cargo type was not available for this study, and AIS databases did not possess category type data to estimate these factors. As a workaround, LOAs were randomly attributed to each simulated vessel based on the arrival probability of a vessel under each LOA category. The probabilities were assumed equal to the proportion of vessels in each LOA category to the total number of ships that anchored in the port area based on 2018 AIS Data as provided in **Table 5-2**.

Table 5-2: Probability of LOA for Vessels based on 2018 AIS Data

	Count	Percentage	LOA Category Probability Cut-offs
LOA=<225	262	70.4%	70.4%
LOA=<250	73	19.7%	90.1%
250<LOA<=270	4	1.1%	91.2%
270<LOA<=325	26	7.0%	98.2%
325<LOA<=350	4	1.0%	99.2%
350<LOA<=400	3	0.8%	100%

Due to the mentioned limitation, cargo types and LOAs are assigned as separate probabilities, and the simulation system assumes all cargo types are equally likely to include vessels with different LOAs.

3. Terminal Service Times

Ideally the service time or the time that each vessel spends at berth, is modelled as a function of its size and cargo type based on empirical data. However, in the absence of such information, the simulation system is programmed to assign a random duration based on the distributions fitted to historical data received from the Port. However, the data does not include information on LOA and cargo type of ships but only contains time at berth for all ships at each berth from 2017 to 2019. Thus, the simulation of berth cycles lacks accuracy at the individual entity level but remains reliable at high level.

Data on terminal berth cycles showed close fits to logarithmic and exponential distribution patterns. Hence, after eliminating a few outlier points, empirical distributions were used to model service times on a stochastic basis. Data on time vessels spent at anchorage areas 2 and 3 were utilized to approximate the load/unload activities of log vessels in a similar manner. The empirical probability distribution functions fitted to the historical data are presented in **Appendix E**.

4. General Assumptions

As previously mentioned, a simulation model is a simplified model of the reality of processes. In this project, several assumptions were needed to scope the simulation model to the project requirements and fill gaps where information was not available. General assumptions are outlined below:

- Grain ships inspection and fumigation processes are excluded from the simulation model. However, with an assumption that all grain vessels require inspection, inner harbor anchorage priority has been incorporated in the model.
- Intermodal vessels do not typically anchor. Therefore, Intermodal traffic is excluded from the simulation model.
- Anchorages number 11 to 14 have not been utilized since 2015 and are unlikely to be used in the near future. Therefore, the simulation system excludes them from entity assignment.
- The simulation model records unavailability if a ship does not find an anchorage that is specified for its class. While this may not be the case as anchorages are often managed by rearrangements, the recorded cases of unavailability serve as an indicator of system performance.

The level of accuracy of simulation outputs depends on two aspects of the simulation system: its level of accuracy in following the reality of processes and the validity of computation functions. With regard to the former aspect, the clarity of the method in modeling system inputs is an advantage that serves as an indicator to determine the estimation level and the degree to which outputs are accurate. A higher level of reliability often requires rounds of verification and validation to ensure the model mimics reality to a suitable level. Statistical tests and sensitivity analysis are methods that can be employed to determine the validity of computations. **Appendix E** shows the input modeling and **Appendix F** provides the anchorage assignment graphs based on the average number of anchorage assignments outputted from simulation iterations and, the simulation output summary table that provides more details on output statistics respectively.

Python programming language was used to handle the complexity of computations in this application, and the simulation was conducted by 200 iterations for every year from 2020 to 2030.

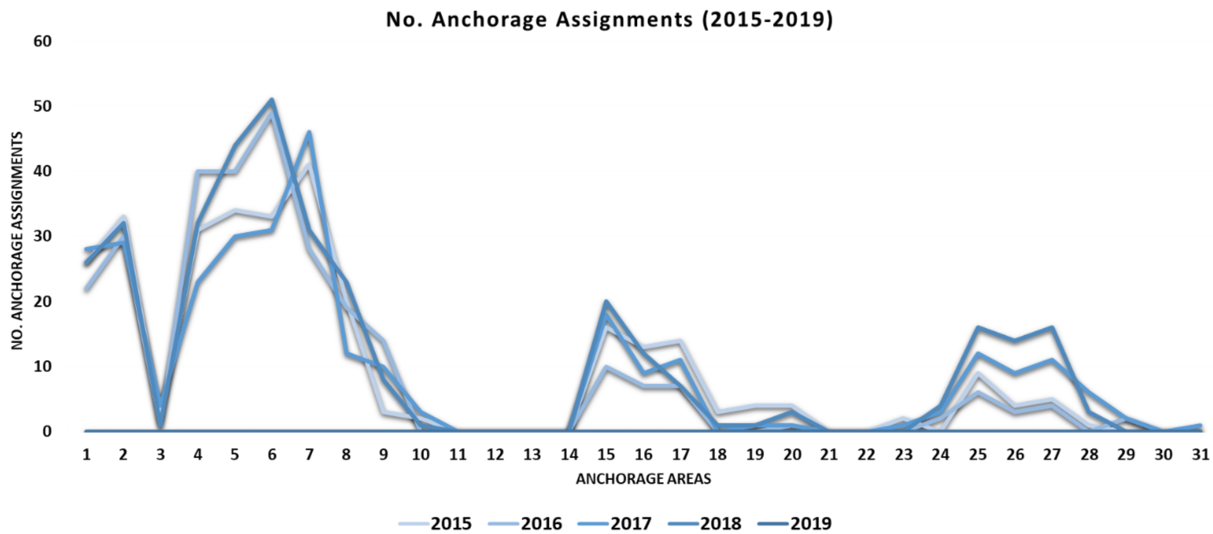


Figure 5-5: Anchorage Assignments based on Data from 2015-2019

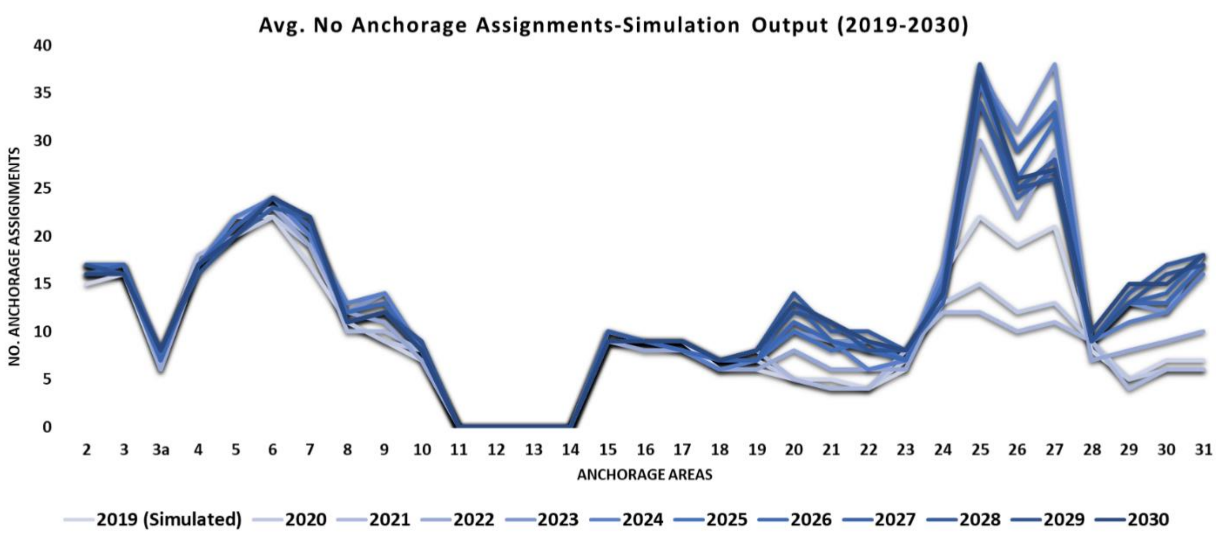


Figure 5-6: Anchorage Assignments 2019-2030 Modelled

As illustrated in **Figure 5-6**, the anchorage assignments are expected to increase as the traffic increases over time. This is to be expected as more ships will inevitably require more anchorage assignments due to waiting for berth, inspections, etc. The results show an increase in utilization of anchorages 24, 25, 26, 27, 29, 30, and 31 over ten years as it was expected due to the projected growth in LPG and methanol vessel traffic.

Figure 5-6 may not show the anchorages at a maximum capacity, however, the model is able to identify when a suitable anchorage (based on the anchorage guidelines from the Port) is unavailable. This is outlined in **Figure 5-7**, below. In the figure we can see that a suitable anchorage is available to be assigned in most cases (blue) or is not required (yellow), however, there will be times when a suitable anchorage is unavailable upon vessel's arrival that is presumably handled on a case by case basis. The orange bars in the figure show the percentage of times such an issue is expected to happen. The level of unavailability of anchorage area upon arrival increases until the expansion of Ridley Island Terminals in 2022[4]. The expansion of the terminal will result in a decline in number of anchorage requirements; and, therefore, a significant decrease in the anchorage unavailability rate. However, we can see that as of 2027 as traffic continues to increase, there will also be an increase in the unavailability of an anchorage area upon ship arrival.

With the rise of traffic volume in consecutive years, this rate will increase again but does not reach it's the peak it did in 2021/2022. A similar trend, is foreseen for the level of anchorage unavailability when vessels that anchored in the Inner Harbour need to be relocated to clear space for a newly arrived grain ship requiring inspection. The relocation anchorage availability is presented in **Figure 5-8**.

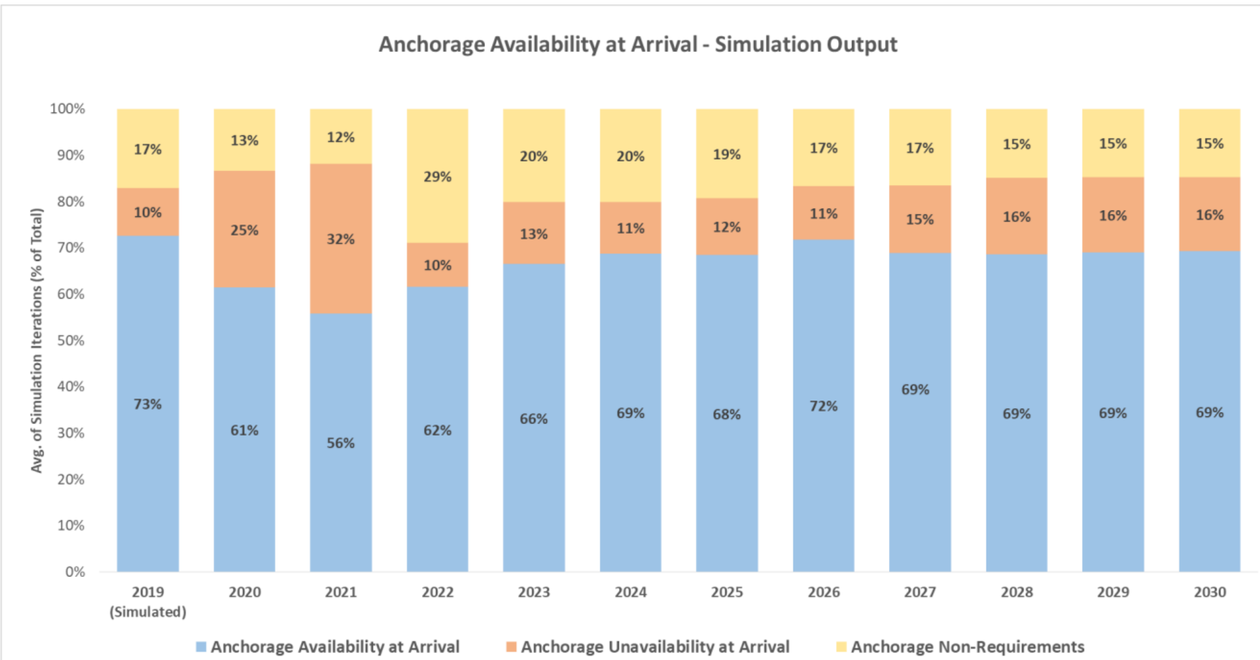


Figure 5-7: Anchorage Availability at Arrival as per Model Outputs

[4] The exact opening of this expansion is TBD, but was modelled as 2022 for the purposes of this assessment.

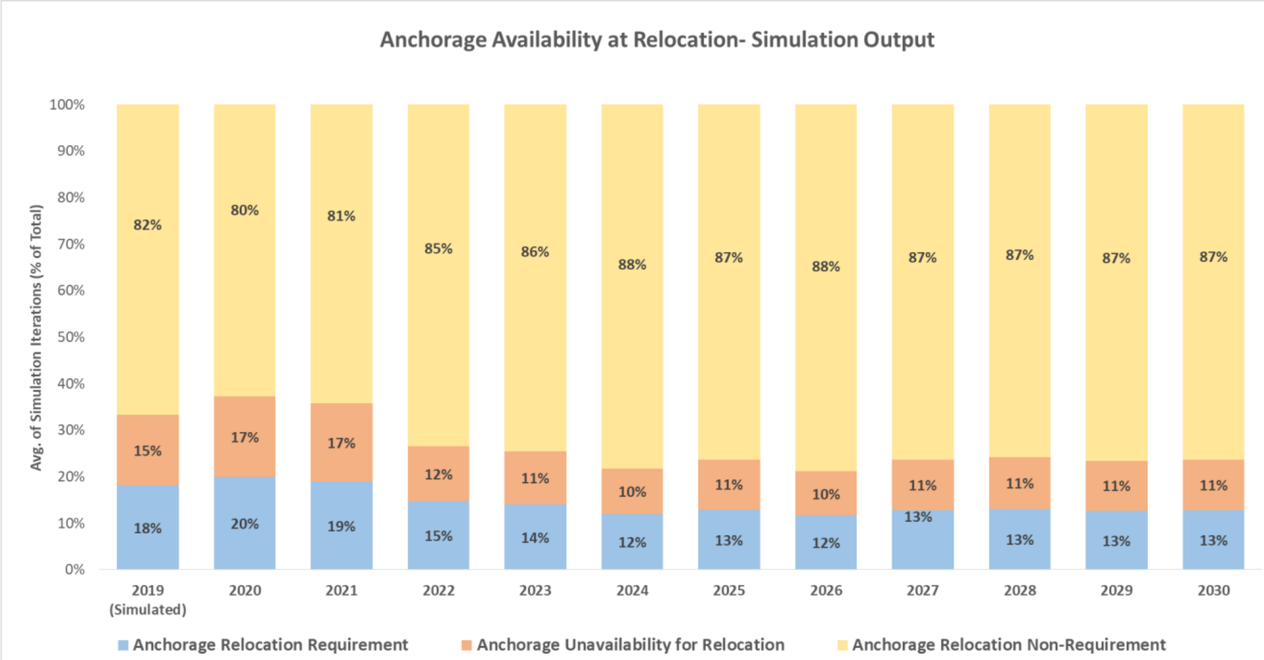
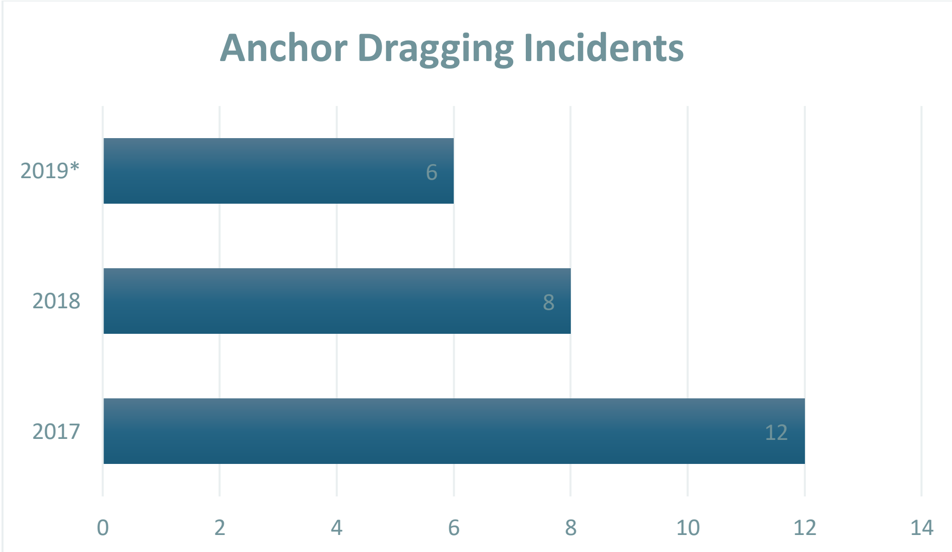


Figure 5-8: Anchorage Availability at Relocation as per Model Outputs

5.3 Historical Anchor Dragging Statistics

The PRPA has recorded a number of anchor dragging incidents in since 2017. This increase in reporting is mainly due to the installation of additional radar coverage within the Port, which has allowed for better vessel monitoring. It is also believed that in the past there was likely a lack of reporting from vessels when they were dragging anchor, leading to what appears to be a jump in incidents. However, it still remains that the Port has experienced a number of annual anchor dragging incidents since 2017. **Figure 5-9**, provides the number of confirmed anchor dragging incidents from 2017 to October 2019.



*2019 data is for 10 months, not the full year.

Figure 5-9: Overview of Anchor Dragging Incidents by Year

Anchor dragging can be caused by a number of factors. The root cause of anchor dragging is external forces exceeding holding power of the anchor and chain. This is typically caused by winds and currents, but can also be caused by a combination of milder environmental factors and the ship being in ballast condition.

Considering the fact that Prince Rupert is primarily an export port, vessels staying at anchorage will be in ballast condition (e.g., light displacement and higher windage area); therefore, more likely to get affected by inclement weather conditions.

When the ship is in ballast condition, it has a far greater exposed windage area. Ships at anchor typically ride along the tide or wind, depending on which one is stronger. However, during changes of tide the vessel will swing 180 degrees, and during this swing if the wind catches the ship's hull sideways, the windage area becomes significantly larger. This can cause the anchor and chain to become loose and result in the ship dragging.

The individual anchor dragging incidents reported to the PRPA are highlighted below in **Table 5-3**.

Table 5-3: Anchor Dragging Incidents as Recorded by the Port

Date	Anchorage Area	Date	Anchorage Area
10/22/2019	27	02/17/2018	20
10/22/2019	18	10/23/2017	07
10/11/2019	16	07/11/2017	N/A
10/11/2019	15	04/05/2017	04

Date	Anchorage Area	Date	Anchorage Area
10/21/2019	18	03/31/2017	N/A
10/22/2019	27	03/31/2017	07
12/11/2018	04	03/07/2017	06
12/10/2018	17	02/12/2017	06
11/13/2018	08	02/07/2017	07
10/29/2018	08	01/26/2017	04
10/24/2018	24	01/16/2017	04
04/10/2018	N/A	01/15/2017	03
04/05/2018	26	01/15/2017	09

A graphic which illustrates the locations of the anchorages with anchor dragging incidents (blue dots), and the reported wind speed during the incident, is located below in **Figure 5-10**.

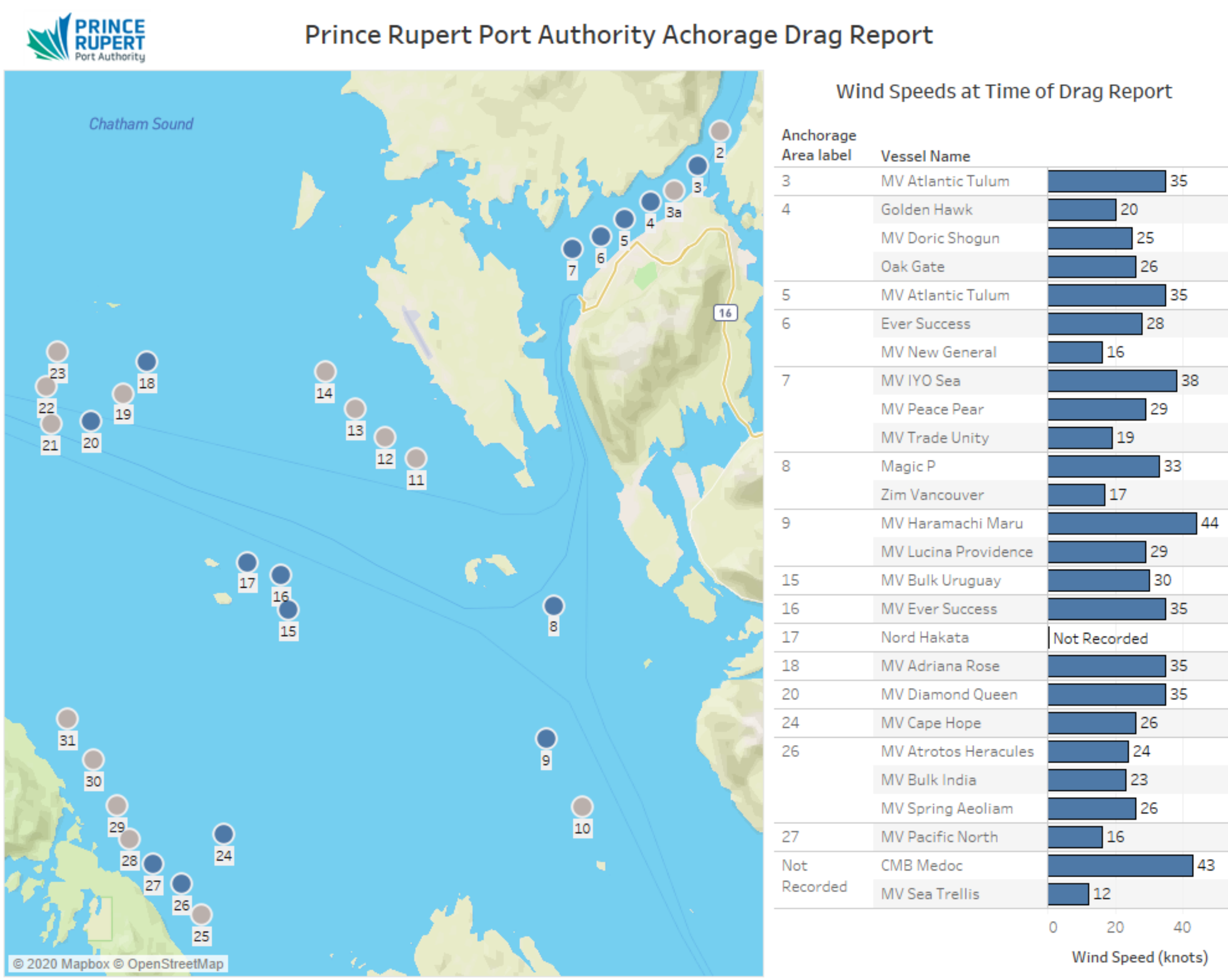


Figure 5-10: Anchor Dragging Incidents Table

As can be seen in **Figure 5-10**, there are a variety of locations and wind speeds associated with the anchor dragging incidents. The dataset is limited, so drawing any conclusions as to what factors may cause a ship to be susceptible to anchor dragging from the data is not possible. However, inner harbour anchorages, except for 2 and 3a, have all had anchor dragging incidents, which is of concern due to the limited availability of navigable water within the inner harbour. There is limited space for ships who are dragging to regain control before grounding or having an allision with another vessel. These incidents also demonstrate that the anchor dragging incidents are not limited to non-sheltered areas.

There are also important observations that can be highlighted from the analysis of the anchor dragging events.

- Bulk carriers in ballast condition made up the majority of ships that dragged anchor.
- Roughly 70% the majority of incidents took place with wind conditions above 25 knots.
- 30% of incidents also took place with wind conditions below 25 knots.

It is difficult to draw conclusions from a small dataset; therefore, we recommend that the Port continues to collect detailed data on anchor dragging incidents, including wind direction, and that they also started to record the condition of the ballast for the ships who are dragging. This could help to identify if ships with a minimum ballast condition have higher rates of anchor dragging within the Port.

More information on anchor dragging and preventative measures can be found in the Other Jurisdiction Anchorage Analysis in **Section 6.0**. Recommendations that can help reduce the number of anchor dragging incidents are presented in **Section 7.0**.

5.4 Anchorage Area Holding Capacity

One of the key factors in assessing the risk of anchor drags, is the holding capacity of the anchorage systems in use. Anchorage holding capacity is calculated as the amount of force that an anchor can hold without dragging; and, provides a basis for assessing the risk of dragging incidents. This can be done by estimating the magnitude of anchor loads, and comparing it with the maximum anchorage holding capacity in order to inform the possibility of anchorage drag incidents.

To determine this, assumptions are made to develop likely scenarios. These scenarios need detailed information on factors such as vessel's shape, size, and anchorage equipment. Using multiple assumptions and approximations, this study has determined a high level estimate of holding capacity.

The holding capacity for the anchorage areas was determined for each anchorage area. The main factors which impacts the anchorage holding capacity are the type of seafloor, depth of the anchorage, type of anchorage, size of ships and environmental conditions such as wind. An overview of the seafloor types around the anchorage areas can be found below in **Figure 5-11**.

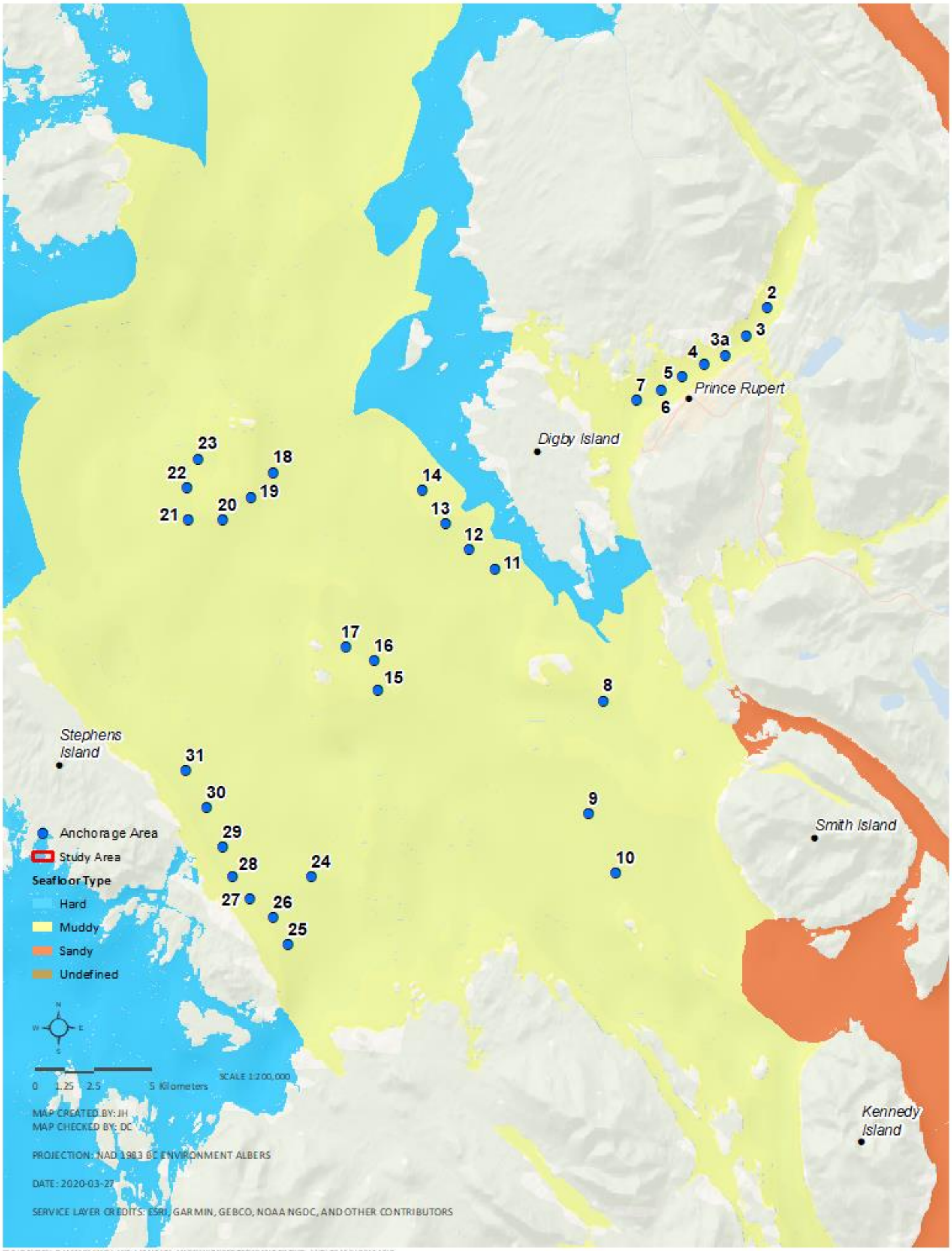


Figure 5-11: Seafloor Type – Anchorage Areas

A precise determination of anchorage system holding capacities requires detailed and complex studies and modeling. However, US Navy UFC4-159-03 report (Department of Defense, 2005) provides empirical formulas to estimate holding capacities based on the type of anchors carried by vessels, and the seabed geological condition at the anchorage location. Equation 1 is suggested as an estimate of ultimate anchor system static holding capacity where:

$$H_M = H_R \left(\frac{W_A}{W_R}\right)^b \quad (1)$$

Where:

- H_M: ultimate anchor system static holding capacity (kN)
- H_R: reference static holding capacity
- W_A: anchor weight in air, suggested as 4,536 kg (Department of Defense, 2005)
- W_R: reference anchor weight in air
- b: exponent

In order to calculate a generic holding capacity for the anchorages, Reference static holding capacity (H_R) and exponent (b) were based on **Table 5-4** by US Navy UFC 415903, i.e. 0.92 and 107. These factors are provided based on the type of anchors and the seabed condition. Standard stockless anchors with moveable flukes was selected for the calculation as it was reported to be the most common type of anchor applicable to the study (Moffatt & Nichol, 2012). Further, the referenced holding capacity of this type of anchors is minimal in comparison to other types and results in a conservative estimation of anchorage holding capacity. In order to maintain a conservative assessment, soft soil (soft clays and silts) have been assumed as seabed condition for all the anchorage areas.

Table 5-4: Drag Anchor Holding Parameters U.S. Customary (UFC-4-159-03, 3 Oct 2005)

Anchor Type (*a*)	SOFT SOILS (Soft clays and silts)		HARD SOILS (Sands and stiff clays)	
	H_R (kips)	b	H_R (kips)	b
Boss	210	0.94	270	0.94
BRUCE Cast	32	0.92	250	0.8
BRUCE Flat Fluke Twin Shank	250	0.92	*(c)*	*(c)*
BRUCE Twin Shank	189	0.92	210	0.94
Danforth	87	0.92	126	0.8
Flipper Delta	139	0.92	*(c)*	*(c)*
G.S. AC-14	87	0.92	126	0.8
Hook	189	0.92	100	0.8
LWT (Lightweight)	87	0.92	126	0.8
Moorfast	117	0.92 *(i)*	60 100 *(d)*	0.8 0.8
NAVMOOR	210	0.94	270	0.94
Offdrill II	117	0.92 *(i)*	60 100 *(d)*	0.8 0.8
STATO	210	0.94	250 *(e)* 190 *(f)*	0.94 0.94
STEVDIG	139	0.92	290	0.8
STEVFIX	189	0.92	290	0.8
STEVIN	139	0.92	165	0.8
STEVMUD	250	0.92	*(g)*	*(g)*
STEVPRIS (straight shank)	189	0.92	210	0.94
Stockless (fixed fluke)	46	0.92	70 44 *(h)*	0.8 0.8
Stockless (movable fluke)	24	0.92	70 44 *(h)*	0.8 0.8

Determining the range of anchor weights is a task of more complexity, as such detailed data were not found in the various marine databases reviewed. Design criteria are also based on detailed design characteristics of vessels that are not easily attainable. Therefore, an empirical projection by Germanischer Lloyd (Lloyd, 2011) was used to estimate the anchor weights (kg) for vessels of different size based on their deadweight tonnages (DWT); and DWTs were obtained from a query of 2018 AIS data utilized by MARIN for anchorage areas located at the Port of Prince Rupert. **Figure 5-12** shows the projection (Harkes, 2013).

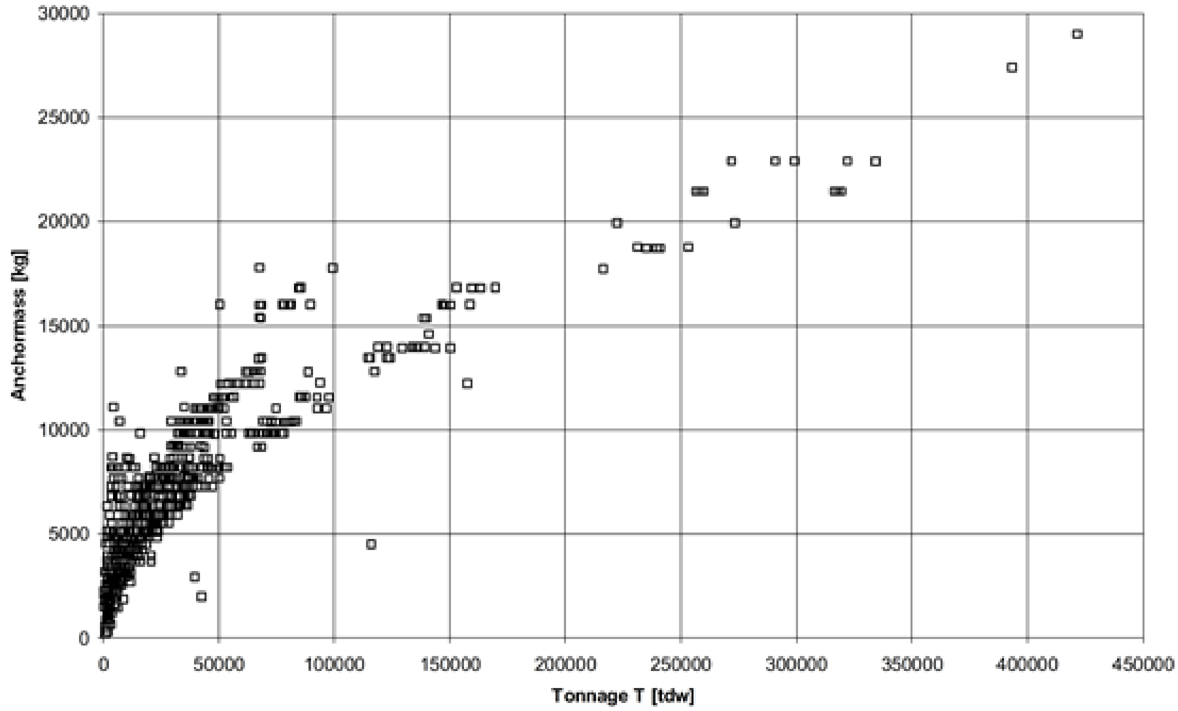


Figure 5-12: Anchor Mass vs. Tonnage (Harkes, 2013)

AIS data does not possess data on DWTs for anchorage areas of rare and emergency use; therefore, DWTs for those anchorages were estimated based on a fitted curve to map LOA values to DWTs based on the 2018 AIS data as presented in **Figure 5-13.**

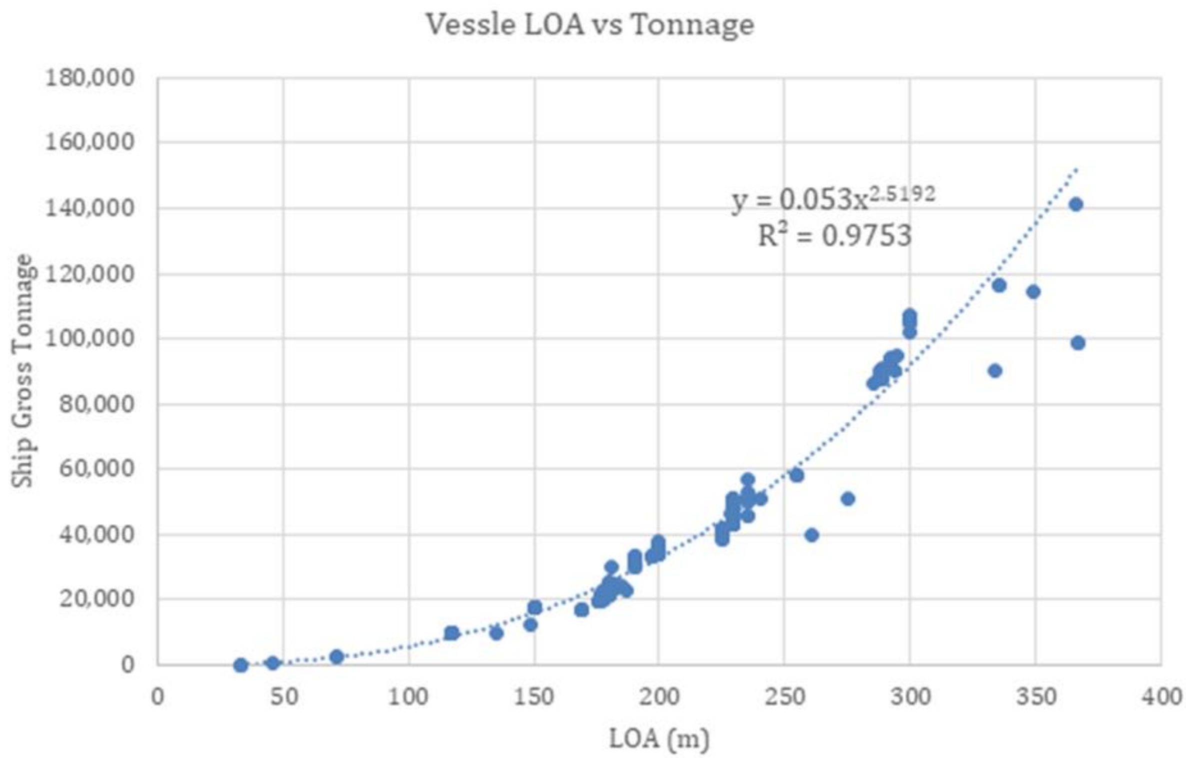


Figure 5-13: Vessel LOA vs. Tonnage

Appendix F presents maximum anchorage holding capacities calculated for each anchorage area; a threshold for wind speed at each anchorage area, above which can be considered a high risk zone for anchorage drag incidents assuming a ship of 270 meters LOA. The threshold is defined as the point at which anchor load, which is caused by wind, equates maximum anchorage holding capacity; therefore, a wind speed over the determined threshold level is believed to lead to an anchor drag. The figure also provides 90th percentile wind velocities to be compared against the threshold as a basis for anchor drag risk analysis. However, the analysis does not take into consideration wind gusts, only sustained wind speeds. **Figure 5-14** is a visual illustration of the wind speed safety thresholds and the 90th percentile wind velocities.

Estimating wind driven anchor load is a complex process that requires dynamic modeling of wind and current forces applied to anchorage systems. In this study, estimates of wind driven anchor loads have been used to provide a high level estimate of the wind speed safety thresholds. Anchor loads are approximated based on fitted curves (provided in **Appendix F**) to the simulation results provided by Moffatt & Nichol (2012, p 30-32) for a 270 LOA vessel with a close fit (r-square= 0.94 to 0.99). It is not representative of all situations, but does provide a baseline to estimate the level of drag incident risk associated with each of the anchorage areas.

As seen in **Figure 5-14**, inner harbor anchorages are the ones at high risk as the 90th percentile wind velocities exceed the safety threshold (for 270 LOA) in these anchorage areas. This might not be the case for anchorage areas with lower LOA allowances (such as those in the inner harbour), and may differ in accordance to the size and shape of vessels. The figure, however, indicates the degree to which anchor drags are possible at each anchorage area under same assumption of LOA. Chatham Sound anchorage areas are not found to be at similar risk level in this case.

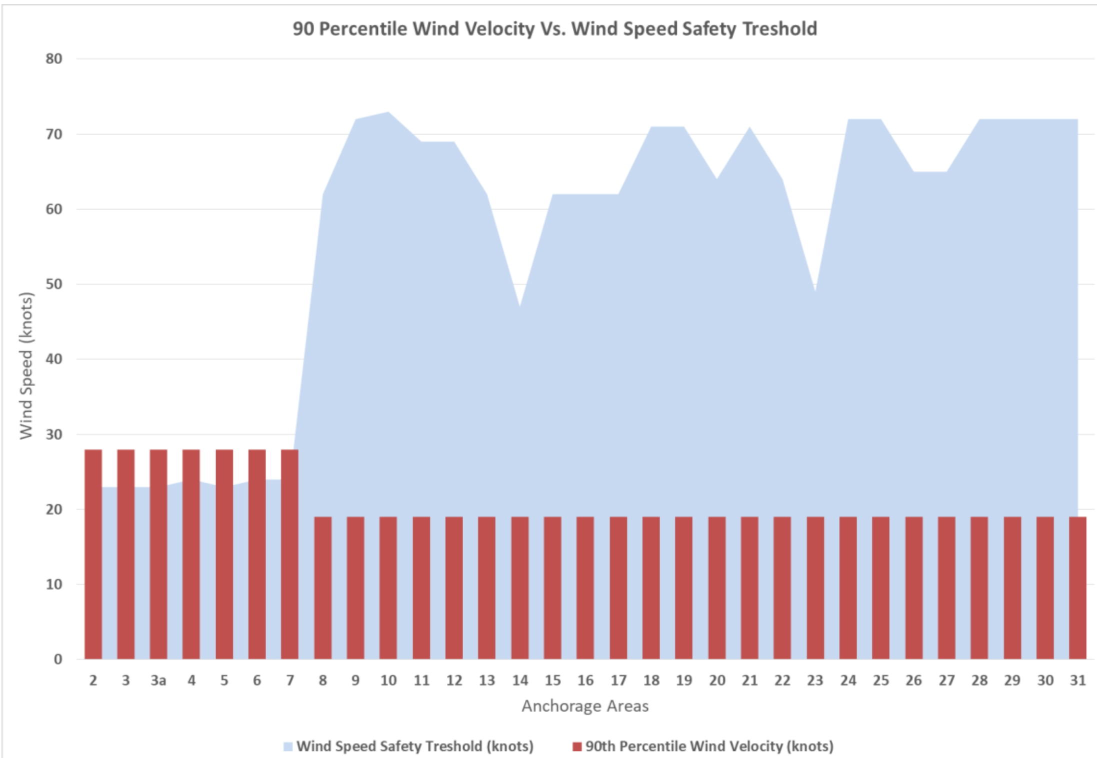


Figure 5-14: Wind Speed Threshold vs. 90th Percentile Wind Velocity for Anchorage Areas

5.4.1 Swing Circle and Diameter

When ships are at anchor, there is a swing circle that has to be determined to ensure safety. Since ships at anchor are subject to influence by currents, tides and winds, some movement expected. Therefore, there must be an appropriate distance maintained between the ship at anchor and other vessels. In addition, the swing circle for ships also needs to incorporate an appropriate safety distance to account for the potential dragging of anchor that can occur due to environmental conditions. A vessel that is dragging its anchor if not mitigated could lead to a collision or allision with another vessel.

The swing circle of ships; therefore, need to include an extra safety margin in response to an anchor dragging hazard. A detailed examination of safe swing radius requires modeling of several factors such as the seabed holding capacity, wind, current, traffic, and proximity to other ships or structures.

However, general guidelines and best practices are also provided in the literature to estimate a safety margin in the allowable swing radius.

Report the Maritime Navigation Commission (Martime Navigation Commission , 2014) provides guidelines to determine a suitable swing radius for anchored vessels. In addition to the consideration of vessels' LOA, the total length of available anchorage chain should be considered in the calculation to cover the chance of a complete stretch due to heavy weather conditions. Further, an additional safety margin is required to reduce the risk of an accident in the event of an anchor drag.

As a minimum measure, the report suggests a 30 meters anchor drag margin, and an anchor chain length of five times the water depth (h) as a general rule, in addition to the ship's LOA. The minimum radius requirement of a free weather-vaning anchorage can be calculated using the equation below:

$$R_A = LOA + 5h + 30$$

Where:

R_A: minimum swing radius (m)
LOA: Length Overall of Vessel (m)
h: water depth (m)

While this equation determines a minimum swing radius, a higher level of protection is advised (Intertanko, 2019) (Martime Navigation Commission , 2014). The following safety margins are suggested to be added to the LOA and chain length to determine a swing radius with a higher level of safety:

1. An additional distance to compensate for issues such as positioning inaccuracies, human errors, and time elapsing between anchorage order and complete anchorage of a vessel. This margin is advised to be between 25% and 50% of the vessel's LOA.
2. A suitable prior notice margin for a possible anchor drag that can be determined in accordance to wind velocity and the resistance of the holding ground as presented in **Table 5-5**.
3. An additional safety clearance of 10% of the vessel's LOA.

Table 5-5: Wind Velocity and Anchoring Resistance Safety Scale

Wind Velocity	Good Anchoring Resistance Seabed	Bad Anchoring Resistance Seabed
≤ 10 m/s	0 m	30 m
20 m/s	60 m	90 m
30 m/s	120 m	150 m
≥ 30 m/s	180 m	210 m

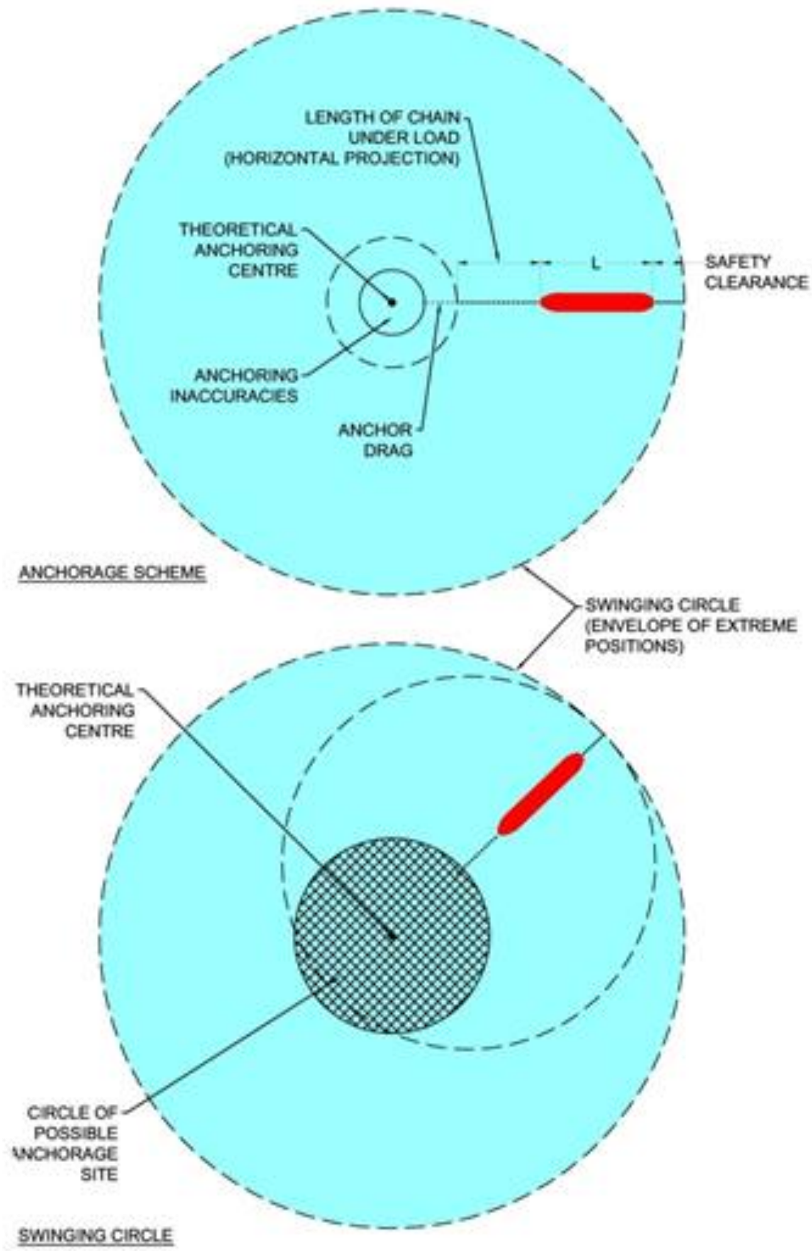


Figure 5-15: Illustration of the Suggested Safety Margins (Martime Navigation Commission , 2014)

Using these guidelines, a minimum swing radius and an advisable swing radius are calculated for each of the anchorage areas, the result of which are provided in **Table 5-6**. The length of anchorage chain is assumed to be five times the depth of the anchorage area to provide a minimum swing radius as a minimal safety measure. As explained previously, this number is based on a theoretical assumption on the anchorage chain length, and should only be used as a minimal safety measure in case a larger swing circle is constrained by natural and/or operational constraints.

The last column on the right of **Table 5-6** presents advisable figures that are based on an assumption of 12 shots (about 329 meters) of chain length on-board, that is based on a conservative estimate provided by the 2012 study (Moffatt & Nichol, 2012) Maximum LOAs determined for each anchorage and maximum safety distance (50% of LOA) are used in the calculations and poor holding ground condition is assumed to maintain a conservative approach. The 90th percentile wind velocities have been used based on the data from closest station to the anchorage areas provided by Tetra Tech.

Table 5-6: Swing Circle Radius

Anchorage Area	Depth (m)	Wind Velocity - 90th Percentile (m/s)	Max LOA (m)	Chain Length (≈ depth*5)	Safety Distance	Prior Notice Margin	Safety Clearance	Minimum Swing Radius (m)	Advisable Watch Radius (m)[5]
2	56	14.24	225	280	112.5	150	22.5	535	839
3	48	14.24	225	240	112.5	150	22.5	495	839
3a	48	14.24	225	240	112.5	150	22.5	495	839
4	39	14.24	225	195	112.5	150	22.5	450	839
5	42	14.24	225	210	112.5	150	22.5	465	839
6	37	14.24	250	185	125	150	25	465	879
7	55	14.24	250	275	125	150	25	555	879
8	38	9.64	270	190	135	150	27	490	911
9	66	9.64	350	330	175	150	35	710	1039
10	60	9.64	400	300	200	150	40	730	1119
11	53	9.64	270	265	135	150	27	565	911
12	54	9.64	270	270	135	150	27	570	911
13	43	9.64	270	215	135	150	27	515	911
14	30	9.64	270	150	135	150	27	450	911
15	41	9.64	270	205	135	150	27	505	911
16	39	9.64	270	195	135	150	27	495	911
17	42	9.64	270	210	135	150	27	510	911
18	60	9.64	325	300	162.5	150	32.5	655	999
19	65	9.64	325	325	162.5	150	32.5	680	999
20	52	9.64	325	260	162.5	150	32.5	615	999
21	54	9.64	325	270	162.5	150	32.5	625	999
22	42	9.64	325	210	162.5	150	32.5	565	999
23	30	9.64	325	150	162.5	150	32.5	505	999
24	60	9.64	350	300	175	150	35	680	1039

[5] This number is based on a theoretical assumption on the anchorage chain length, and should only be used as a minimal safety measure in case a larger swing circle is constrained by natural and/or operational constraints

Anchorage Area	Depth (m)	Wind Velocity - 90th Percentile (m/s)	Max LOA (m)	Chain Length (≈ depth*5)	Safety Distance	Prior Notice Margin	Safety Clearance	Minimum Swing Radius (m)	Advisable Watch Radius (m)[5]
25	53	9.64	350	265	175	150	35	645	1039
26	50	9.64	350	250	175	150	35	630	1039
27	38	9.64	350	190	175	150	35	570	1039
28	54	9.64	350	270	175	150	35	650	1039
29	66	9.64	350	330	175	150	35	710	1039
30	80	9.64	350	400	175	150	35	780	1039
31	72	9.64	350	360	175	150	35	740	1039

5.5 Anchorage Area Risk Assessment Results

As a part of the Marine Navigational Risk Assessment, special attention and analysis was brought to the anchorage areas to determine if there were any anchorages which had a higher risk of incidents. This was done through the SAMSON model and run by MARIN.

The SAMSON model examined the data from the anchorage areas where there were enough signals to be able to determine the risks posed by vessel movements. Therefore, anchorages which are not as active were not reviewed. The SAMSON model was able to determine the risk of a transiting ship striking a ship at anchor either through ramming (with engine power) or drifting (without engine power). The results are presented for both the present and future scenarios by anchor.

5.5.1 Analysis of Ship Movements

A first analysis of the anchor areas consists of visually analysing the AIS-data. **Figure 5-16** to **Figure 5-18** show the tracks plots of the AIS-data for the route bound traffic. The colour indicates the heading of the vessels but also the speed. Brown (west and south) and Black (east and north) indicate the heading of vessels with a speed higher than 1knot (kt). The other colours indicate the speed; red below 0.01, pink less than 0.2 1kt, yellow less than 0.41 and blue less than 1.0 kt. The pink circular tracks indicate clearly the areas where the vessel anchor.

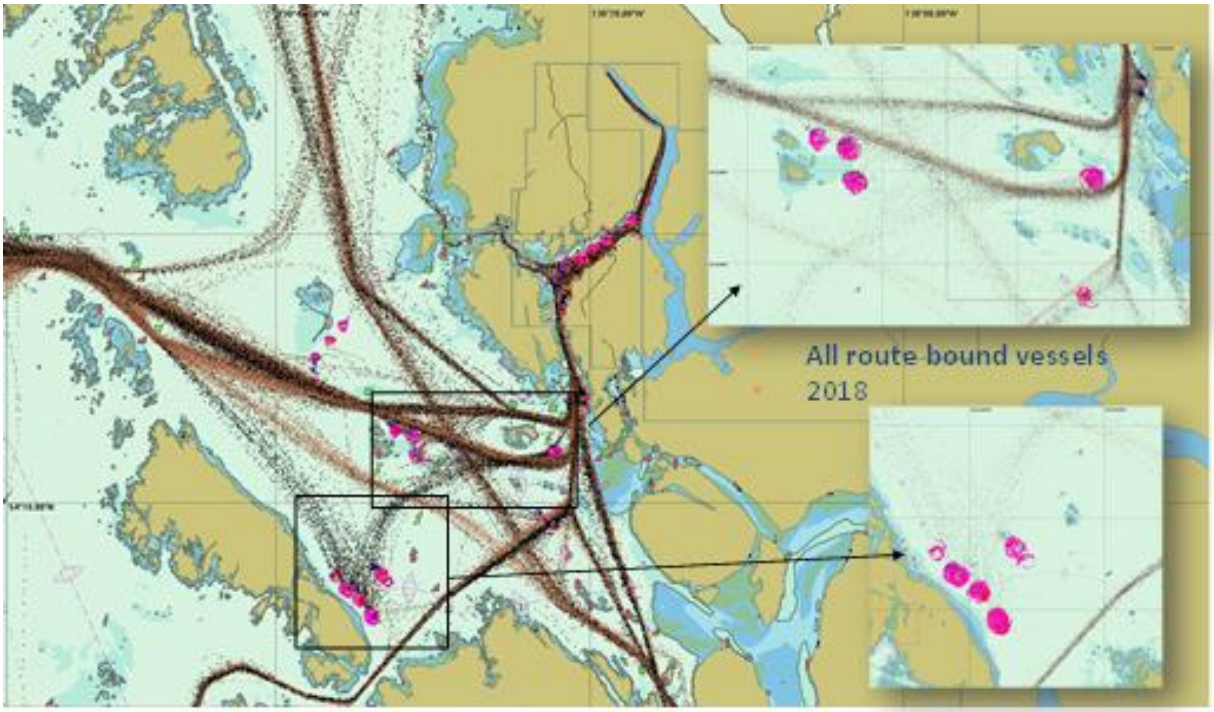


Figure 5-16: Overview of Ship Traffic near the Anchorage Areas

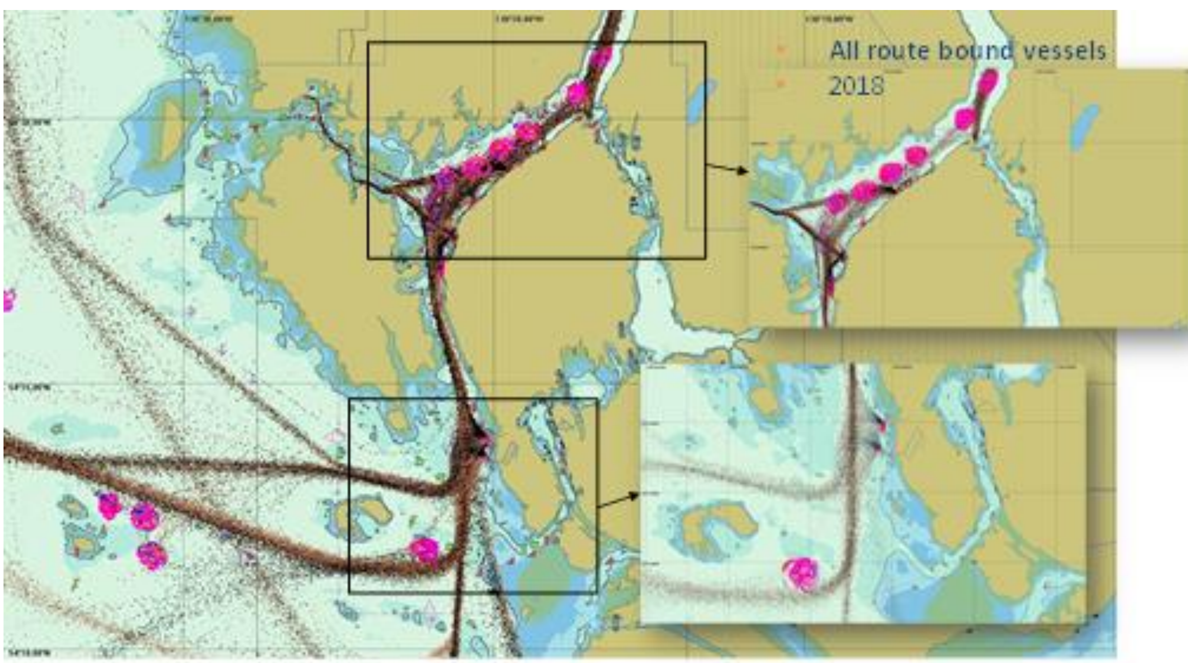


Figure 5-17: Overview of Ship Traffic near the Anchorage Areas Closer to the Port

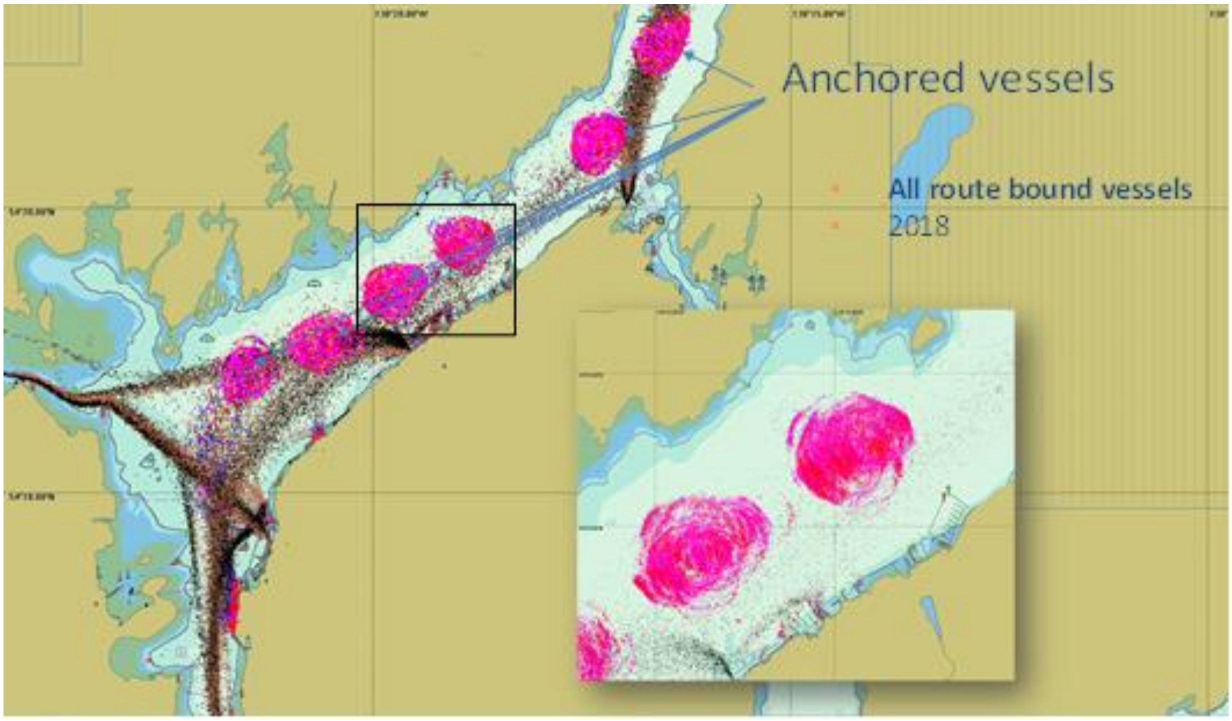


Figure 5-18: Overview of Ship Traffic near the Anchorage Areas in the Inner Harbour

Figure 5-19 illustrates the vessels transiting to anchorage 2 (numbered Anchor20) in the MARIN figure. This traffic illustrates the traffic patterns of this anchor area and how the vessels must transit by the other busy anchorage areas in the inner harbour. Anchorage area 7 (numbered Anchor 15) is an area of concern as all ships entering the inner harbour must transit by it and must execute a turning maneuver at the location of the anchorage. Furthermore, container vessels proceeding to the DP World Container Terminal must execute a 180 degree turn near the anchorage area prior to proceeding to their berth.

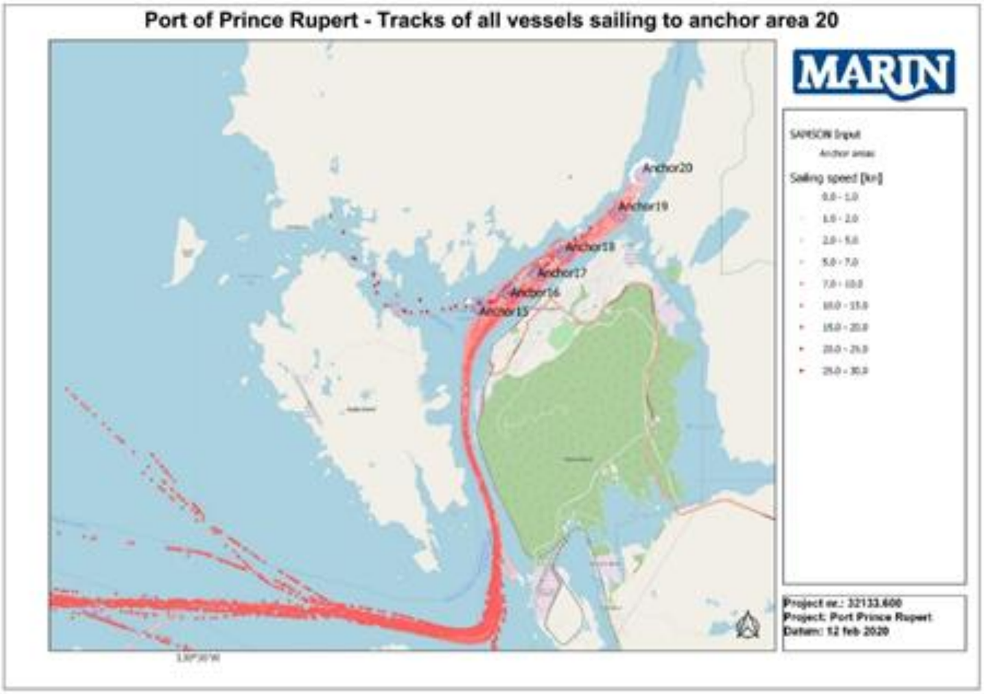


Figure 5-19: Tracks of all Vessels Heading to Anchorage 2

5.5.2 Analysis of Incidents involving Ships at Anchor

Utilizing the SAMSON model, MARIN analyzed the risk of ships transiting, having an incident with a ship at anchor. As previously mentioned, this was done for anchorage areas where there were enough AIS signals in 2018 to complete modelling. The model included the anchorage areas presented in **Table 5-7**.

Table 5-7: Anchorage Areas Analyzed by SAMSON

Anchorage Areas Included	Anchorage Areas Not Included
3	2
4	3a
5	11
6	12
7	13
8	14
9	17
10	21
15	22
16	23
18	29
19	30
20	31

Anchorage Areas Included	Anchorage Areas Not Included
24	
25	
26	
27	
28	

Results were run based on the 2018 AIS data as well as the 2030 traffic database that was created based on future traffic projections. More information on the 2030 traffic database can be found in **Section 4.1.1.2.**

5.5.2.1 Present Scenario

The 2018 analysis showed that there are a number of anchorages where there is a higher risk of an incident. The inner harbour anchorages were identified as the highest risk anchorage areas within the port with an incident from ramming expected to occur once every 72 to 220 years as can be seen in **Figure 5-20**. Drifting strikes are expected to occur significantly less often than ramming within the inner harbour as seen in **Figure 5-21**. Anchorages number #15-16 are the next highest risk of ramming and drifting with either expected to occur once every 325 and 362 years respectively. Anchorage #8 is the last of the higher risk anchorages with a ship strike from ramming of drifting expected to occur once every 404 years. Overall there is expected to be an anchorage incident once every 67 years for the highest risk anchorage area, anchorage #6 as seen in **Figure 5-22**.

The risks to the anchorage areas are clearly associated with the traffic movements. It is the anchorage areas which are closest to the movement of ships which have the highest risks, as expected. However, the inner harbour is significantly higher in risk than other areas. The ships which anchor there are subject to ships transiting past them and tight quarters which does not leave for much response time. A ship to ship incident with an anchorage in the inner harbour has a 1% chance of happening each year, this includes all ships within the area and not just commercial vessels.

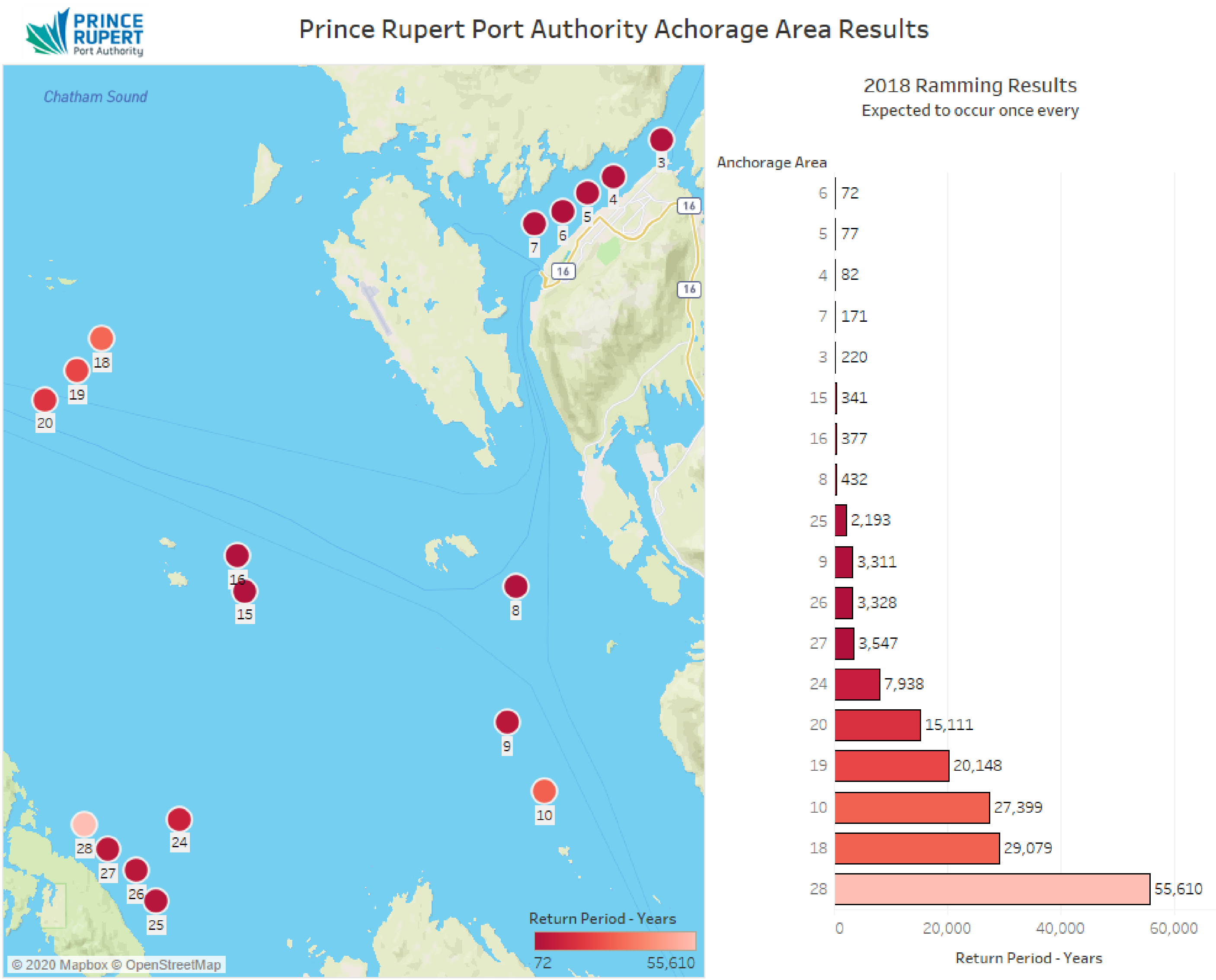


Figure 5-20: Anchorages Risk of Ramming Incident 2018

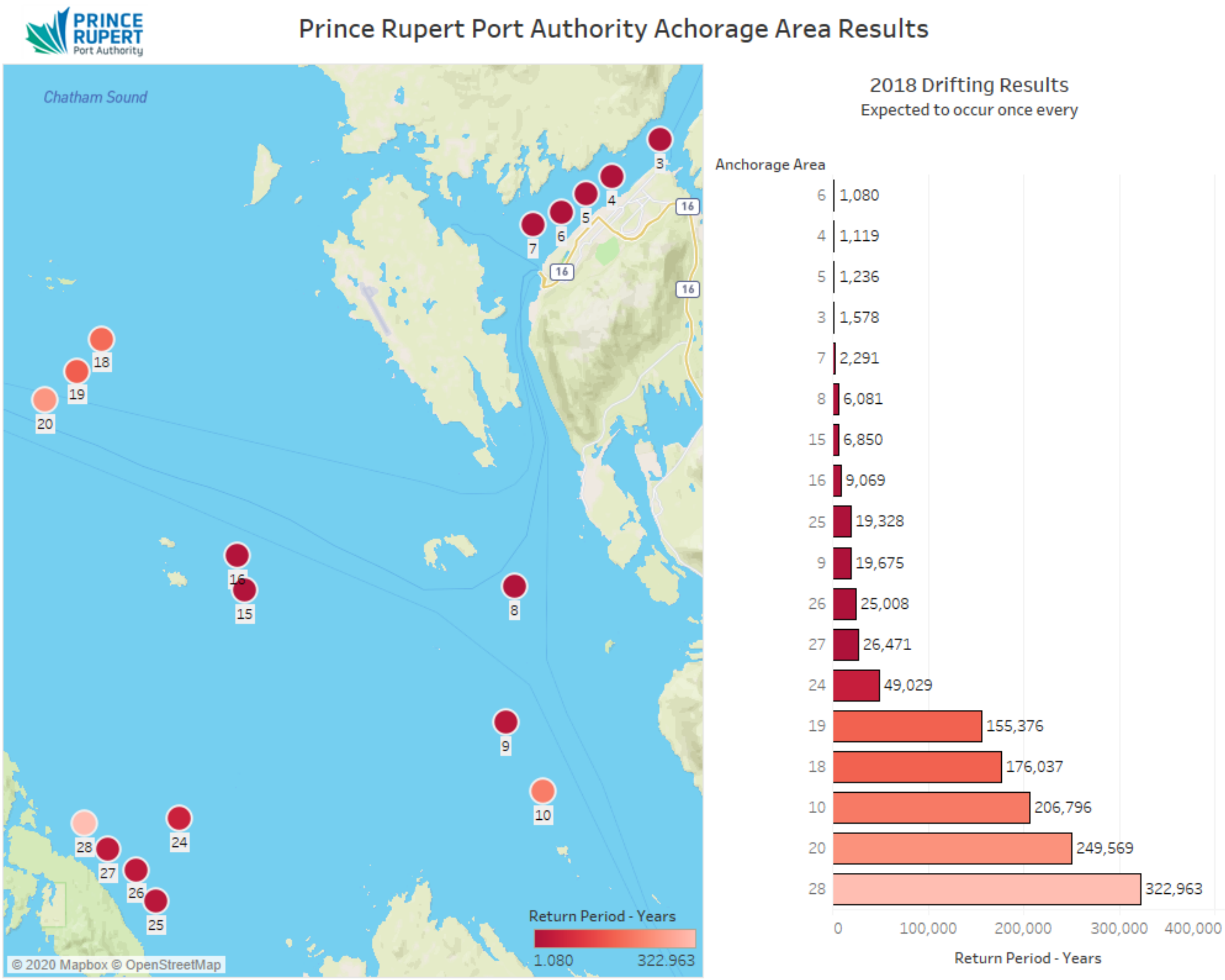


Figure 5-21: Anchorages Risk of Drifting Incident 2018

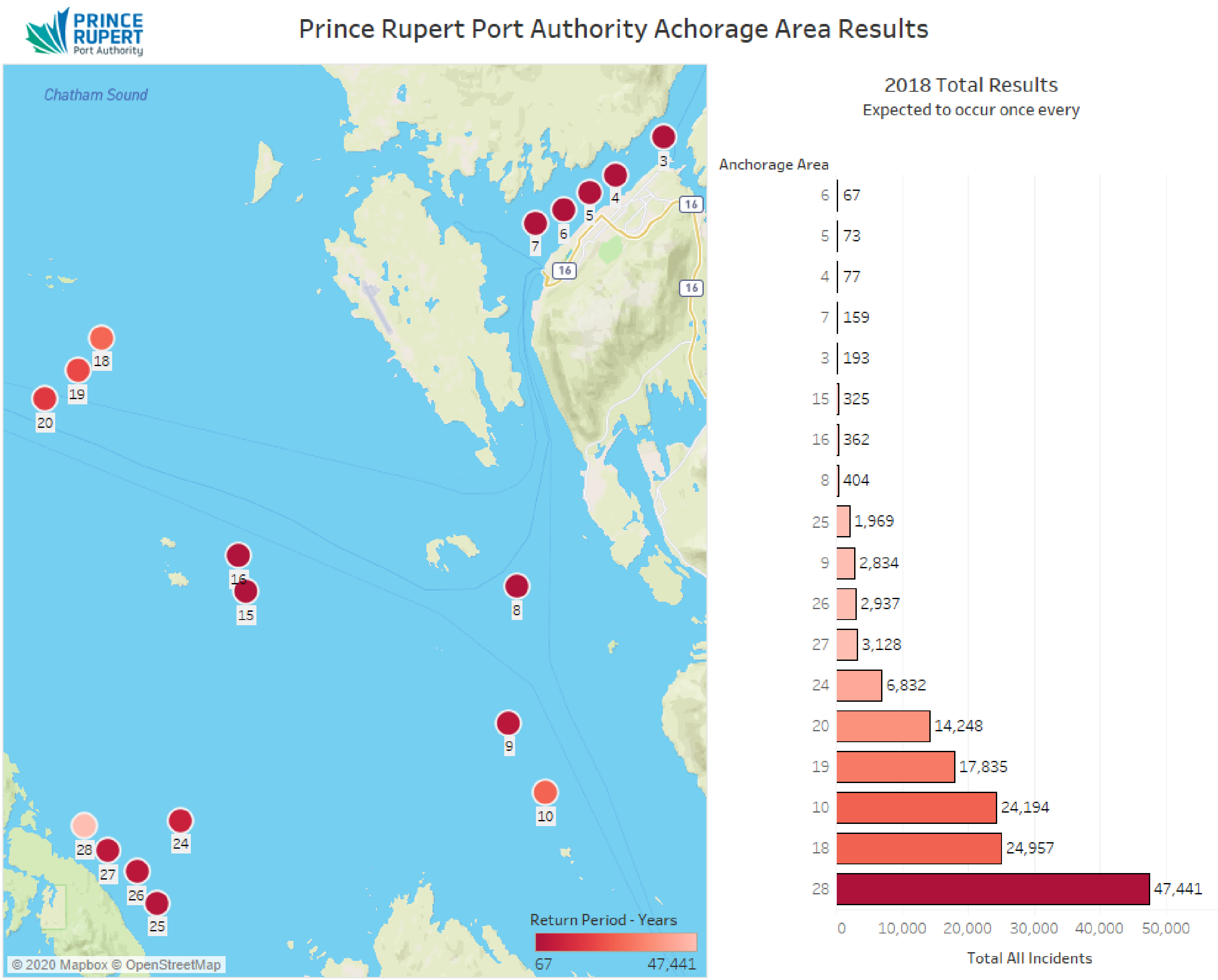


Figure 5-22: Anchorages Risk of Incidents 2018

5.5.2.2 Future Scenario

The 2030 analysis showed that there are a number of anchorages where there is a higher risk of an incident. The inner harbour anchorages were identified as the highest risk anchorage areas within the port with an incident from ramming expected to occur once every 71 to 218 years as seen in **Figure 5-23**. Drifting strikes are expected to occur significantly less often than ramming within the inner harbour as seen in **Figure 5-24**. Anchorages number #15-16 are the next highest risk of ramming and drifting with either expected to occur once every 281 and 311 years respectively. Anchorage #8 is the last of the higher risk anchorages with a ship strike from ramming of drifting expected to occur once every 383 years. Overall there is expected to be an anchorage incident once every 67 years for the highest risk anchorage area, anchorage #6, as seen in **Figure 5-25**.

The risks to the anchorage areas are clearly associated with the traffic movements. It is the anchorage areas which are closest to the movement of ships which have the highest risks, as expected. However, the inner harbour is significantly higher in risk than other areas. The ships which anchor there are subject to ships transiting past them and tight quarters which does not leave for much response time. A ship to ship incident with an anchorage in the inner harbour has a 1% chance of happening each year.

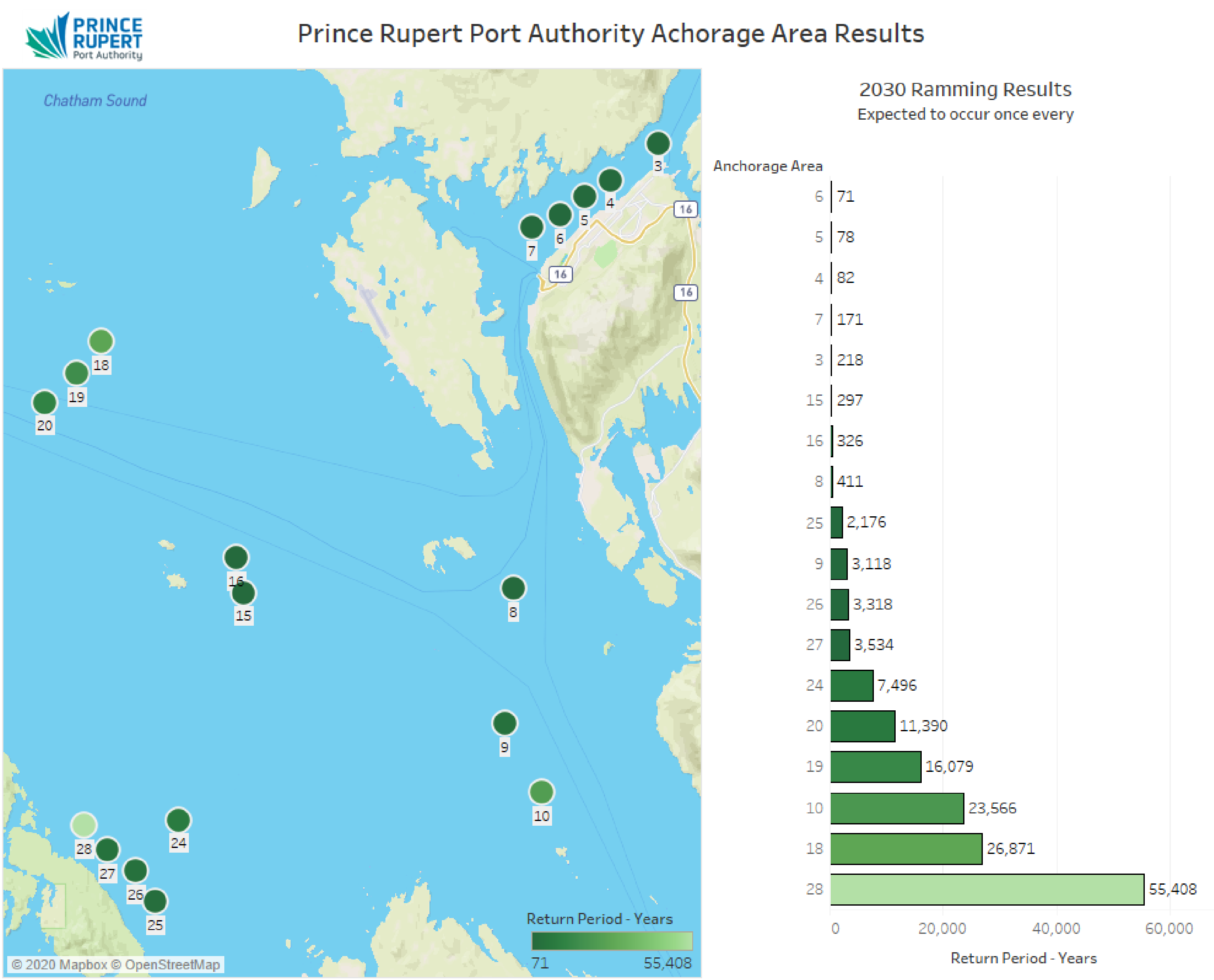


Figure 5-23: Anchorages Risk of Ramming 2030

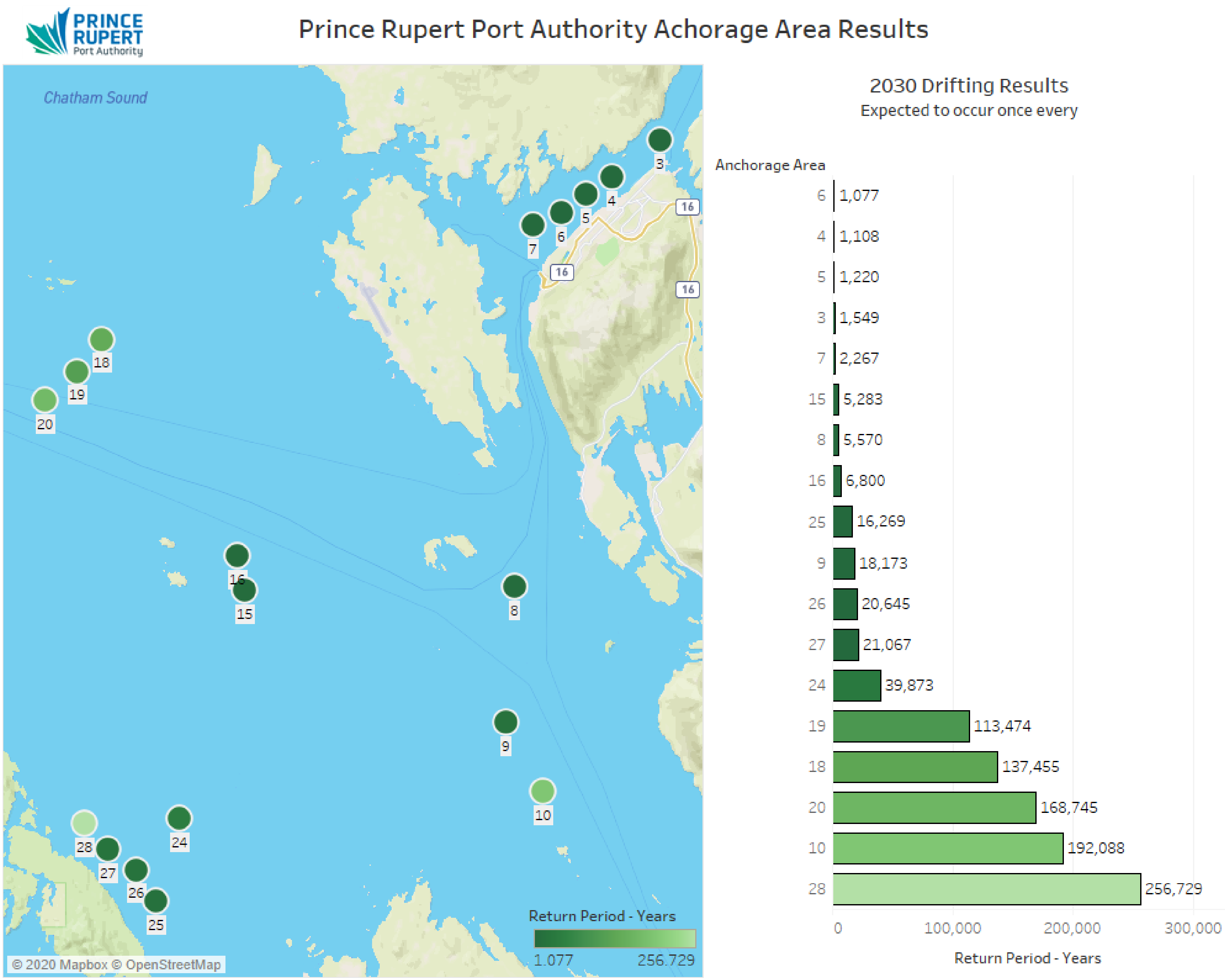


Figure 5-24: Anchorages Risk of Drifting Incident 2030

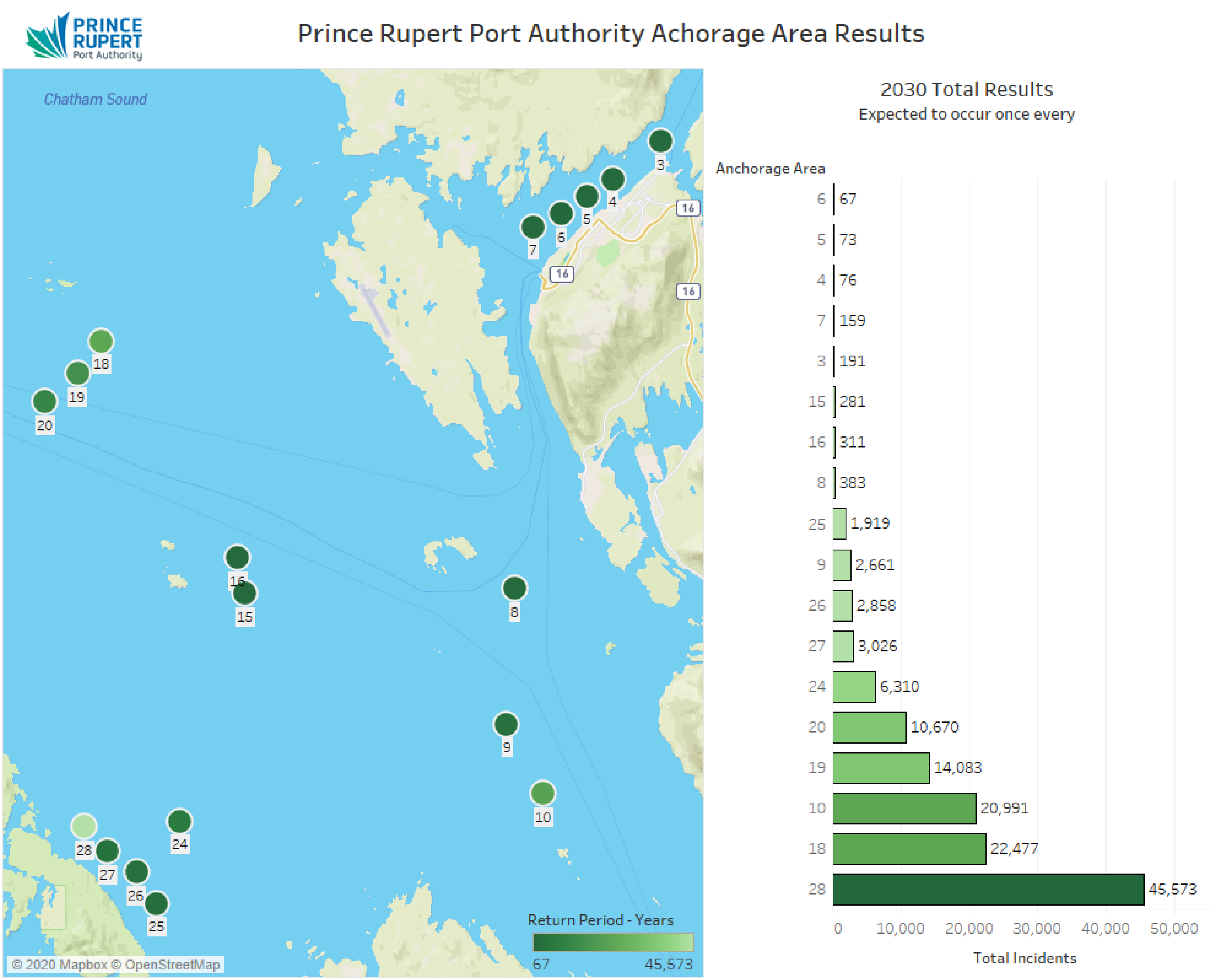


Figure 5-25: Anchorages Risk of Incidents 2030

5.5.2.3 Change in Risk from 2018 to 2030

When comparing the results from 2018 and 2030, we can see an increase in risk, however it is minor. **Figure 5-26** provides a comparison of the results by anchorage for all incidents. The overall increase to all risks within the anchorage areas modelled by SAMSON showed an increase of 2.2%. Some anchorage areas saw a higher increase in risk (35% for anchorage #20) however the risk for these anchorages was already quite low. The inner harbour anchorages are expected to only see a minor increase in risk, less than 1% in most cases, and this is likely due to the fact that the increased traffic will not transit through the anchorage areas but instead are intended for other terminals.

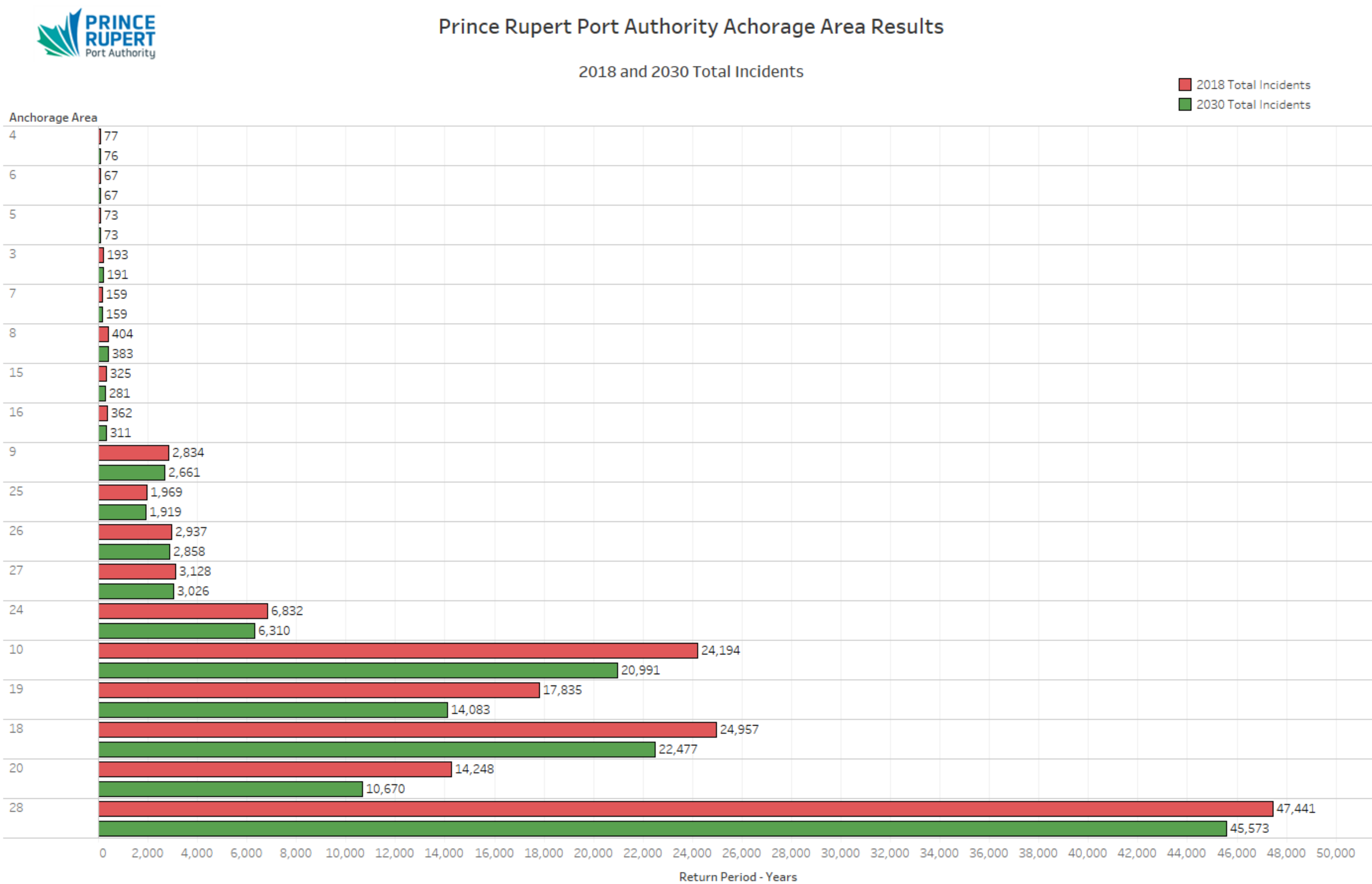


Figure 5-26: Anchorage Risks – Total Incidents 2018 vs. 2030

5.5.2.4 Limitations

It is important to note that this analysis has limitations. Therefore, the future scenario modelling for the risk assessment may not fully capture the risks to anchorages.

- The future may not fully mimic the future scenario that was modelled with SAMSON.
- This risk assessment does not capture any changes to the Port's operations or anchorage assignment guidelines.
- The SAMSON model does not account for the risk of anchor dragging in its modelling.

5.6 Findings

The overall capacity of the anchorage areas is not currently at capacity. Future scenario modelling showed that as traffic increases in the future, there may be instances where an anchorage is not available for a ship upon arrival. This trend should be reduced upon the opening of the expansion of Ridley Island Terminals. This is based on the anchorage assignment guidelines from the Port and therefore, there may be an opportunity to address this issue through operations or changes to the guidelines. Changes to the guidelines should only be done with a risk assessment which would look to address risks such as changes to anchorages where ships carrying dangerous goods as cargo are allowed to anchor.

The anchorage holding capacity were calculated for each anchorage area. Based on this analysis the swing circles were reviewed to ensure that the anchorage areas are safe for future projected traffic. The swing circle assessment brought forward an analysis of swing circle diameter and recommendation for larger swing circle diameters to account for human error and anchor dragging response time.

The inner harbour anchorages were identified as having a higher likelihood of anchor dragging incidents with high wind events. Although the calculations could only be completed for vessels with a higher LOA than the maximum LOA for these anchorages, they do identify that this area may be at higher risk in general.

The anchorage area risk assessment found that the inner harbour anchorages have the highest risk of a transiting ship ramming or drifting into a vessel. In addition, anchorage #8 and #15-16 were also higher risk. The overall change in risk from the 2018 analysis to the 2030 scenario was not significant with an overall increase in risk of 2.2%.

6.0 Other Jurisdiction Analysis

In order to validate the effectiveness of practices and procedures in use by the Port an analysis of and comparison with several major international ports was conducted. While the practices in individual ports may be influenced by local weather, regional and national regulatory requirements and unique layout, some activities are common and considered as best practices irrespective of uniqueness of the port.

6.1 Marine Navigational Risk Analysis

This assessment focused on marine navigation accidents and specifically estimates the likelihood of collisions, groundings and allisions. The SAMSON model, which is the acronym for Safety Assessment Model for Shipping and Offshore on the North Sea, was first developed over 40 years ago and since then has been refined, validated and improved by MARIN in various studies performed for Rijkswaterstaat, within European projects and other commercial parties (Creber et al., 2017; Koldenhof and van der Tak, 2006; Koldenhof and van der Tak, 2007; Koldenhof and van der Tak, 2010; and de Jong et. al., 1998). The SAMSON model was developed for marine risk assessments to determine the probabilities, locations and consequences of various marine accidents within a defined study area taking into consideration various mitigation measures that could be used to reduce the likelihood of a marine accident (e.g.: pilotage, use of TSS, speed reduction, VTMS monitoring of traffic). The parameters of the casualty models are derived from the worldwide Information Handling Services (IHS) Fairplay casualty data of 1990-2012. The IHS Fairplay database only contains casualty information involving marine vessels greater than 100 gross tonnes.

A direct comparison of the results of this MNRA with similar studies completed in other ports and with national and international accident databases is not an easy or straight forward task. Marine accident models rely on a number of inputs in order to determine the likelihood of a marine accident occurring. Each model utilizes different inputs and has different limitations associated with them which makes comparison of their results difficult. Accident characteristics were reviewed within the literature to identify trends in marine accident models and best practices. The key aspects of marine navigation accident models are illustrated in **Figure 6-1**.

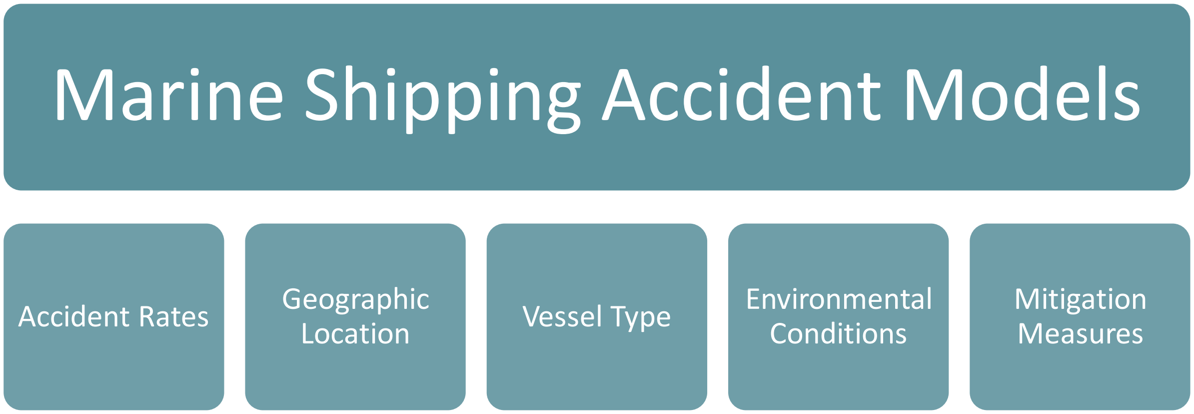


Figure 6-1: Key Aspects of Marine Shipping Accident Models

Accident rates are influenced by a variety of parameters. As such, accident rates and trends should be compared between similar geographic areas, regimes, and time periods. Geographic factors, policy and procedures, weather conditions, and vessel traffic density, can influence the rates of a marine accident occurring. Historical data illustrates that marine accidents are more common in high traffic areas than in low traffic areas. Vessel type is important to consider because different vessel types have different accident rates due to maneuverability and size. Environmental conditions including tides, currents, winds, poor visibility and extreme weather events all influence marine accident rates. However, weather conditions are generally poorly recorded or not included in marine accident databases. Mitigation measures that are used to help reduce the rates of marine accidents vary. Mitigation measures include, but are not limited to, the use of pilots, traffic separation schemes, escort and tethered tugs, VTMS and detailed weather and current information. The location and availability of mitigation measures vary by region. As an example, a large portion of the study area falls within the mandatory Pilotage, while the North Sea area, even though very busy, with significantly higher traffic, does not require mandatory Pilotage.

In Canada the Transportation Safety Board (TSB) maintains the database of marine accidents that occur in Canadian Waters (TSB, 2020). As part of their annual reporting TSB publishes the number of marine accidents within Canada along with calculated accident rates. According to TSB data there were 282 marine accidents in Canadian waters in 2018 (TSB, 2019). The TSB also provides an accident rate for commercial vessels in Canadian waters, where the TSB defines commercial vessels as cargo vessels, ferries, passenger vessels tugs and barges. The calculated TSB accident rate is determined per thousand ship movements, where a ship movement is a defined travel segment between ports, with at least one port within Canada, or movement within a Canadian port of 1 km or more. Using the TSB data a ten year average accident rate for all commercial vessels in Canada was determined to be 2.1 accidents per thousand ship movements (TSB, 2019).

One of the main limitations of the accident rate determined for all of Canada based on ship movements is that it assumes that the accident rate is the same for all waters in Canada. However, historical data illustrates that 77% of all marine accidents within Canadian waters occur in restricted waterways (harbours, rivers and canals/locks) (Council of Canadian Academies, 2016). In the Canadian context, the total number of reported shipping accidents in Canadian waters or involving Canadian ships shows a 40% decrease in marine accidents from 1998 to 2014 (Council of Canadian Academies, 2016). Furthermore there is significant variations in the types of accident and their locations in different regions of Canada. Allisions accounted for 12% of all accidents in BC waters while they account for nearly 20 % of accidents in the St. Lawrence River between 2004 and 2015 (Council of Canadian Academies, 2016).

Creber *et al.,* (2017) published accident rates for four areas in Canada using TSB marine accident database from 2004 until September 2015 and 2014 AIS data. The accident rates are presented in **Figure 6-2.** The casualty rates in the four Study Areas deviate, but the incident and accident rate for the St. Lawrence Study Area at 15.5 incidents and accidents per million nm, is 1.6 times greater than the next closest Study Area. The rate is the lowest in Port Hawkesbury, with 2.5 incidents and accidents per million nm sailed. The rate for Bay of Fundy and Southern BC are close at 7.8 and 9.8 respectively, per million nm sailed. Caution should be used when interpreting these results as it was assumed that the AIS data used for 2014 is representative for the years 2004 until 2015.

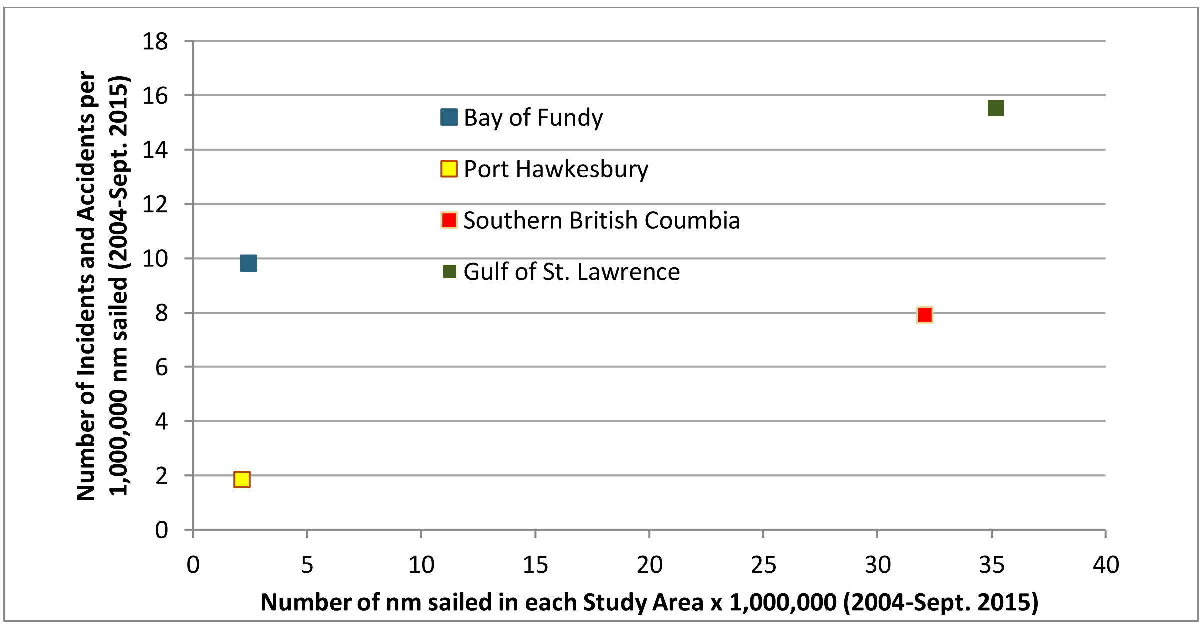


Figure 6-2: Calculated Accident Rate based on TSB data from 2004 until Sept. 2015 and 2014 AIS Data

Accident rates vary based on vessel types (e.g.: Container ship versus bulk carrier) and ship sizes (small coastal container ship versus large container ship) as well as by geographical area (e.g.: relatively open coastal waters vs. confined/narrow channels and approaches to ports). International statistics obtained from the IHS Fairplay database were used to determine the accident rates within SAMSON model based on the accidents that occurred on the North Sea from 1990 to 2012. North Sea statistics were used as these accidents were comprehensively analyzed and the North Sea is one of the busiest shipping lanes with similar safety regimes as Canada. Using North Sea statistics from the IHS Fairplay database is an industry standard for completing marine risk assessments and this data has been used in several previously completed marine risk assessment studies completed in Canada (DNV, 2013; DNV, 2016; Dillon 2017a,b,c,d; Dillon 2019a, Dillon 2019b).

Dillon has previously used the SAMSON model and the IHS Fairplay database to complete marine navigation risk assessments for five areas in Canadian waters: the Bay of Fundy, Port Hawkesbury, St Lawrence River, Southern British Columbia and Northern British Columbia (Creber et al., 2017; Dillon 2017a; Dillon 2017b; Dillon 2017c; Dillon 2017d and Dillon, 2019b). Dillon used these previous completed marine navigational risk assessments to determine accident rates for Canada as part of a Ship-Source Hazardous and Noxious Substance Release Risk Assessment in Canada (Dillon, 2019a).

It was determined that there were large variations in the accident rates over different geographical areas (e.g., Northern BC versus Southern BC) as well as between the accident types (e.g., collision versus grounding). This is due to traffic densities, environmental conditions, and in particular, the layout of shipping channels. Narrow shipping channels, like those present in the St. Lawrence area increase the probability of an accident for several reasons including the narrowness of the channel in which vessels have to pass (i.e., vessels are closer to each other increasing the risk of collision). Furthermore, if a vessel loses power or steering within these narrow channels there is very little time for the vessel to recover prior to it causing an incident.

Globally, a review of vessel losses from 2007 to 2016 indicates a declining trend in over 50% per decade with an average of 118 total loses per year over a 10-year period for vessel (Allianz Global Corporate and Speciality, 2017). A vessel loss can be defined as the actual total loss of the vessel (i.e., it sinks) or is declared as 'constructive total loss' (i.e., estimated repair cost higher than the value of the vessel). This decline in shipping losses occurred despite an increase in seaborne trade over the same temporal period (UNCTAD, 2018 and Dillon, 2019).

There are significant variations in the types and number of vessels involved in marine accidents across Canada and the world. This is further complicated by different navigational challenges, mitigation measures and environmental factors in each area. This makes it very difficult to compare marine accident data and outputs from marine navigational risk assessments from one area to another.

The MNRA calculations provided in **Section 4.0** are forward looking predictions based on the international model but with local geographical layout, historical local meteorological and oceanographic conditions, known preventive measures and anticipated traffic density over the next decade. The scope of the project did not include similar modeling for other regions in the world for comparison purposes. Without using the same model and modelling approach a comparison of the results from the analysis completed for Prince Rupert with other jurisdictions is not possible.

6.1.1 Accident Rates in Canadian Ports

In order to try and provide more context on where the Port stands amongst other ports in Canada, we have provided some overviews of the number of marine accidents from 2004-2011 in select Canadian Ports is presented in **Figure 6-3** (Council of Canadian Academies, 2016). It's important to note that although more recent data exists, the Council of Canadian Academies data included below, provides a thoroughly screened data set and is therefore more accurate than the publicly available data sources.

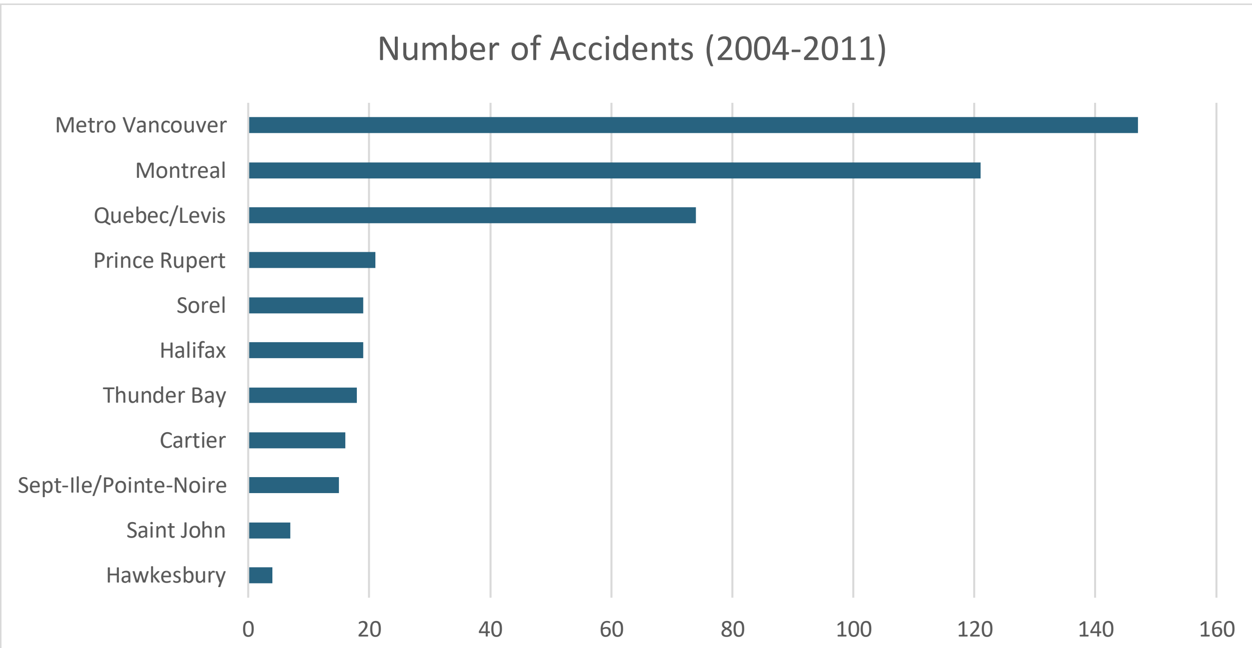


Figure 6-3: Number of Accidents between 2004 and 2011 in select Canadian Ports as reported by the TSB (Council of Canadian Academies, 2016)

Using the accident data as well as the volume of cargo (in 1,000,000 of tonnes per year) handled within each port from 2011 (Stats Canada, 2012), the number of annual accidents per million tonnes of cargo handled were calculated for each port and is presented in **Figure 6-4**. Caution should be exercised when reviewing these numbers for the following reasons:

- It is assumed that accident data from 2004-2011 is still representative of current accident numbers within Canadian Ports.
- It is assumed that cargo data from 2011 is still representative of current cargo volumes.
- A marine accident is defined as an accident resulting directly from the operation of a ship other than a pleasure craft and includes an accident aboard a ship (a person is killed or injured) or a shipping accident (vessels sinks, collides, goes aground, strikes, sustains a fire/explosion or

founders (TSB, 2018). The SAMSON model results reported in this document do not consider accidents aboard a ship.

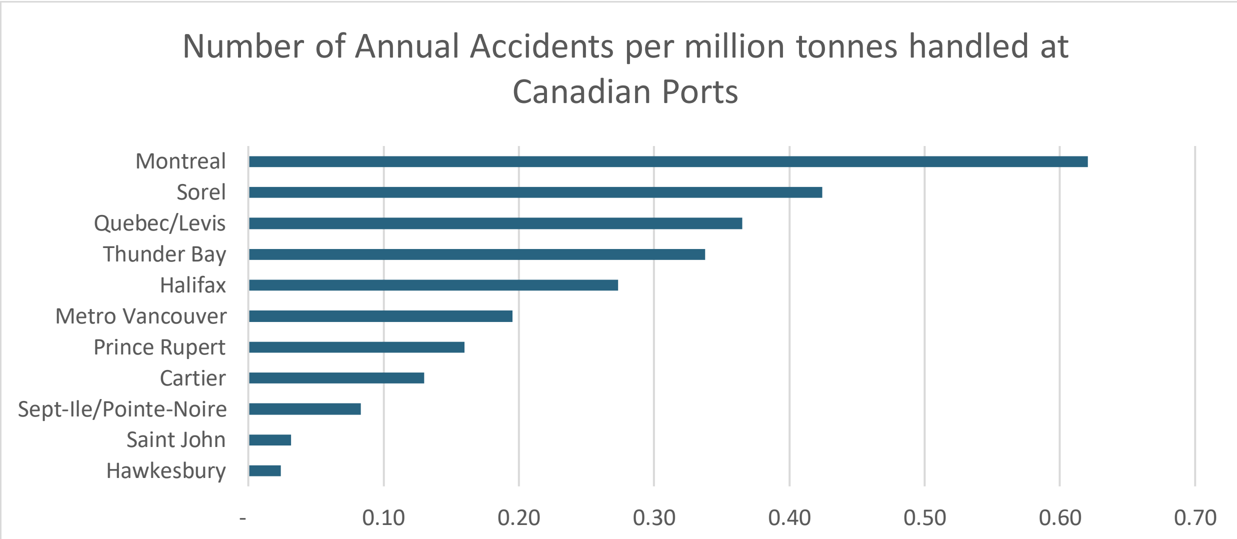


Figure 6-4 Number of Annual Accidents per million tonnes handled at Canadian Ports (Council of Canadian Academies, 2016)

Based on the data presented in **Figure 6-4** Prince Rupert is in the middle of the group, at 0.16 accidents per million tonnes of cargo handled. Furthermore, while Sorel, Thunder Bay and Halifax have higher accident rates than Prince Rupert they all handle less than half the annual cargo that Prince Rupert does. Montreal, Quebec/Levis and Metro Vancouver all handled significantly more cargo per year than Prince Rupert.

6.1.2 International Accident Rates

The direct comparison of accident rates from one port to another is not easy for reasons that were explained in **Section 6.1**. However, in order to provide additional context to the results of the MNRA an attempt was made to review accident data from five international ports and compare them to the results of Prince Rupert. The five ports and the rationale for including them in the analysis is presented in **Table 6-1**.

Table 6-1: List of International Jurisdictions Reviewed

Port	Rationale
Brisbane	Port similar size to Prince Rupert, located in Australia
Hong Kong	Large Asian port that handles multiple types of cargo
Hamburg	Large multi-modal port in Europe. Handles 5 times the volume of cargo as Prince Rupert.
Rotterdam	Largest Port in Europe and one of the best studied ports in the world. Has multiple different types of ships and cargo, including significant barge traffic.
Singapore	Large container ship port where the largest container ships call, good to examine potential increased risk from container vessels.

Collision and grounding/stranding data for each of the five ports was obtained from the IMO, Global Integrated Shipping Information System (GISIS) marine accident database (IMO, 2020). The database contains historical information of marine accidents that were submitted to the IMO. It must be stressed that the IMO does not collect the data itself but instead the data is provided to the IMO by member organizations or states. The IMO does not guarantee the accuracy of the data and some member organizations and/or states are likely to be better at reporting than other states. There was no data on collisions and stranding/groundings in the GISIS database for Prince Rupert. Therefore, the TSB Database for marine accidents was used and a geographic search was completed for collisions and groundings/strandings that occurred within the Port of Prince Rupert from 2004 until 2018 (TSB, 2018). A yearly average number of collisions and groundings/stranding were calculated for each of the ports.

The collisions and groundings/strandings that occurred in the 5 listed ports from the last 20 years (2000-2020) were extracted from the GISIS database (IMO, 2020). The volume of cargo handled at each port for the year 2018 was extracted from each port authority (Brisbane Port Authority, 2020; Hong Kong, 2020; Port of Hamburg, 2019; Port of Rotterdam, 2019, Port of Singapore, 2020).

Finally, collisions and groundings/strandings per million tonnes per year were calculated for each port as presented in **Figure 6-5**.

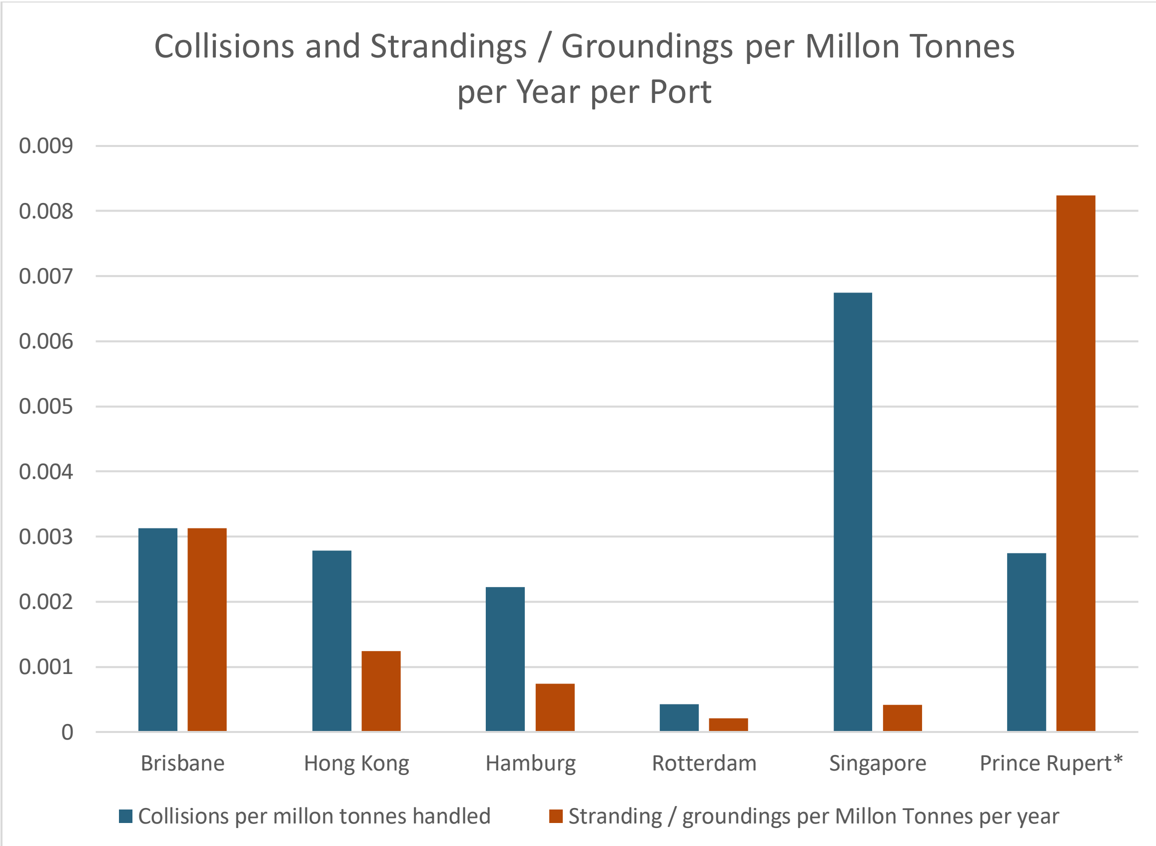


Figure 6-5: Collisions and Strandings/Groundings per year per million tonnes of cargo handled at the Port

As can be seen in **Figure 6-5** above, Prince Rupert has a lower collision accident rate than the Port of Brisbane which has a similar volume of cargo. However, Prince Rupert has a higher strandings/groundings accident rate than that port. Prince Rupert also has a higher accident rate than Hamburg and Rotterdam, which are all larger ports.

Drawing clear conclusions from this data is challenging because the GISIS database had no records of collisions and groundings/standings in Prince Rupert over the past 20 years. Therefore, we had to use the TSB database. Comparing two incident databases can be misleading due to reporting requirements. The reporting requirements and what is considered a reportable incident may vary per jurisdiction and therefore incidents which are reported to the TSB in Canada may not be reported in these other jurisdictions, lowering their incident rates in the GISIS database.

This analysis illustrates the challenges in comparing accident data and rates amongst different jurisdictions.

6.2 Anchorage Analysis

All major ports have to contend with anchorage area designation. Designating an anchorage area requires a great deal of analysis which can include the nature of the sea bottom (geotechnical analysis), anchoring demands on the Port, typical ship sizes, calculations to determine anchorage holding capacity, swing circle calculations, and many more factors.

The international standard for anchorage development is the PIANC Harbour Approach Design Guidelines (Martime Navigation Commission , 2014). In addition, standards from the US Department of Defense (Department of Defense, 2005) and other international standards are often utilized for determining the appropriateness of anchorage areas. Aside from the design and technical specifications for anchorage area designation, determining environmental impacts and appropriateness is also addressed by several international jurisdictions.

Review and analysis of several major international ports anchorages is provided for consideration and comparison against practices used by the Port.

6.2.1 Port of Los Angeles / Long Beach

The Port of Los Angeles / Long Beach have inner and outer anchorages. The inner anchorages are within the confines of the port protected by the breakwater which provides good protection from the swell and seas but limited protection from the wind. The inner anchorage spots are numbered with defined swinging circle radius, the largest being 457 metres (500 yards). The inner anchoring spots are assigned by the Pilot bringing the vessel within the inner anchorage. The outer anchorages are similarly numbered and are somewhat larger in size with larger swinging circle radius of 548 metres (600 yards). The anchoring spots at the outer anchorage are assigned by the VTS, however no Pilot is required to anchor at outer anchorage unless the vessel has departed from one of the berths within the port and already has the Pilot onboard.

The port guide (The Port of Los Angeles, 2020) makes reference to 33 CFR (Coast Guard Department of Homeland Security, 2010) 210.110 Anchorage Regulation which requires vessels to ensure their propulsion plant is placed in immediate standby and a second anchor is made ready to let go if wind conditions exceed 40 knots which is much higher wind speed threshold than that of PRPA, however, they do provide guidance on the effects of the wind and the force necessary to counter lateral wind pressure as per **Figure 6-6** which is useful information, for the Pilot when deciding whether tug assistance will be required to move the vessel and for the Master to assess whether his anchor and chain are capable of holding his vessel in position.

As an example, the typical Bulk Carrier in ballast with LOA of 250 metres will have 4,000m^2 of windage area while a 13,100 TEU container vessel with LOA of 365m and 80% loaded with containers will have 10,500m^2 windage area.

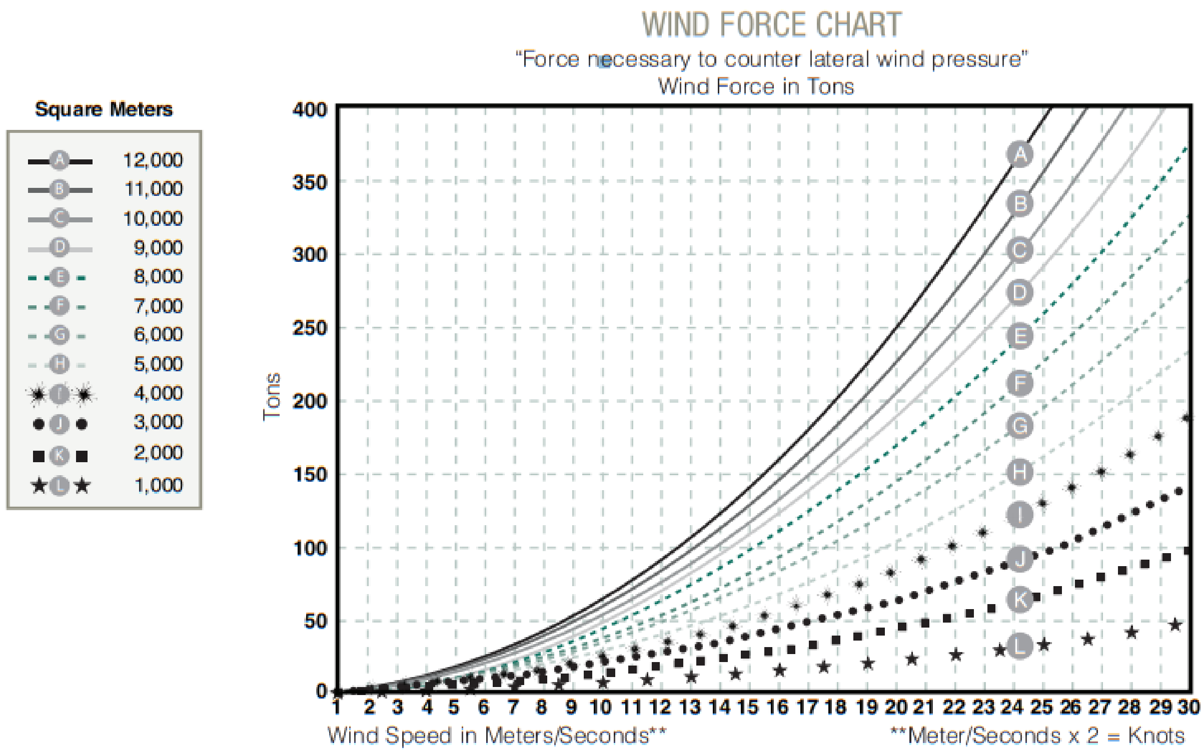


Figure 6-6: Force necessary in tons to counter lateral wind pressure in m/s extracted from Port of Los Angeles, Mariners Guide (The Port of Los Angeles, 2020)

6.2.2 Port of Rotterdam

As indicated in Notes section on the navigational chart for approaches to the Port of Rotterdam and the Port Information Guide, there are several anchorages outside the port, on each side of the TSS leading to the Hook of Holland and port entrance (Port of Rotterdam, 2020). Approach to and departure from these anchorages is without Pilot onboard. Generally, there are only a couple of factors that play a role in determining where a vessel should anchor, these are the size of vessel and type of vessels. The general anchorage areas are bounded by the lines between the specified coordinates (usually in rectangle or polygon shape), however individual vessel anchorages and the size of swinging circles are not defined.

The deep draft vessels (irrespective of type) require a larger under keel clearance (UKC) during their anchor-period, giving them an anchorage further out to sea. Due to their deep draft they are also required to follow the Deep Water traffic route into Rotterdam. LNG Vessels haven their own designated anchorage away from other vessels due to cargo type.

The VTS that oversees the anchorages does not assign specific positions for vessels to drop their anchor. They may offer advice but the ultimate decision lies with the Master of the vessel where he decides to anchor his or her vessel. Some of the factors the Master may take into considerations are the depth, current, expected weather for the duration of stay at anchorage and available space to employ minimum scope of chain and resultant swinging circle.

Located in North Sea with no protection from the elements, the vessels at Rotterdam anchorage are very exposed to winds and waves especially in the late fall and winter months when wave height may exceed 6 meters. Despite relatively good holding ground, it is common practice for vessels to pick up anchor and head out to open seas when winds are expected to exceed 25 knots to prevent anchor dragging and potential damage to its equipment. This is easily achieved by the Master as there is no compulsory pilotage requirement to approach or leave anchorage. Since the anchorage areas are not under pilotage, the Port authorities do not provide guidelines and instructions regarding anchoring and anchor watch keeping as it is assumed that vessels will adhere to IMO STCW.7 Circ. 14 – Guidance for Masters on keeping a safe anchor watch (found in **Appendix G**).

6.2.3 Port of Hong Kong

The Port of Hong Kong has 24 inner anchorages, 16 of which can be used for cargo vessels and handling of cargo. Most of these are located in the protected bays of Hong Kong and neighbouring islands and are providing protection during typhoon season. The sixteen anchorages are designated as Government Mooring Buoys (GMB) (Port of Hong Kong, 2020). These serve ocean-going vessels calling on the Hong Kong Port to transfer their cargo to and from barges secured to the ships' sides. The GBMs, illustrated in **Figure 6-7** are single steel floating buoys of approximately 3.6 metres diameter anchored to the sea bottom by a length of approximately 40 metres of chain. The vessel uses her anchor chain to secure to the buoy’s swivel shackle. GMBs can also serve as typhoon moorings for vessels during extreme weather conditions however they are restricted in vessel sizes they can accommodate up to maximum of 183m LOA. Arrival and departures to and from these anchorages is done with a Pilot onboard. HKMD (Hong Kong Marine Department), as the regulatory body, does not provide specific guidelines regarding anchoring and anchor watch keeping but are making reference to the IMO STCW.7 Circ. 14 – Guidance for Masters on keeping a safe anchor watch, **Appendix G**.

Figure 6-7: Hong Kong Harbour Government Mooring Buoy

As per 'Berthing Guidelines' (issued by Hong Kong MARDEP- Marine Department) the VTS will issue wind warning when the sustained wind speed reaches 25 knots and Pilotage will be suspended when the sustained wind speed of 33 knots is recorded.

Considering the number and size of the vessels calling to the Port of Hong Kong, the vast majority of vessels actually anchor south of the Lamma Island and further south in the waters under the jurisdiction of PRC (People's Republic of China). These are relatively open waters which provide little protection from the elements especially during typhoon season. It is usually the practice for these ships to go out to sea during typhoons. Pilotage is not required to approach or depart from these anchorages. These anchorages are adjacent to multiple TSS (Traffic Separation Scheme) with extremely heavy traffic and are often very crowded although closely monitored by the VTS.

6.2.4 Port of Singapore

The Port of Singapore is the world's second busiest port in terms of total shipping tonnage and is situated next to the world's busiest transit lanes, the Singapore Strait and the Strait of Malacca. The MPA (Maritime and Port Authority) of Singapore has designated 32 anchorages (Maritime and Port Authority of Singapore, 2020) along the Southern coast of Singapore island as illustrated in **Figure 6-8**. The individual anchorage areas are usually defined based on vessel type (LNG, LPG, Oil Tanker, General Cargo, Navy, etc.) and vessel size such as VLCC (Very Large Crude Carrier), Small Craft etc. Being strategically located, Singapore is also a major bunkering port with five dedicated bunkering anchorages.

Approach to and departure from all of these anchorages is done with the Pilot onboard. The anchorage areas are bounded by the lines between the specified coordinates (usually in rectangle or polygon shapes), however individual vessel anchorage spots and the size of swinging circles are not defined. Pilots, together with VTS, make decisions for individual vessel anchoring location. Vessel's size, expected time at anchor and available space are defining factors in this decision making process.These anchorages are adjacent to multiple TSS with extremely heavy traffic and are often very crowded although closely monitored by the VTS, as illustrated in **Figure 6-9**. Due to its location, the area is exposed to strong ocean currents which may have significant effect on the vessels during anchoring operations. The weather conditions in the area are typically benign with light to moderate winds. However, during the Monsoon Season (June to September) frequent squalls with localised strong winds and severe reduction in visibility, pose significant challenges to vessels at anchor by creating the conditions which cause most of the anchor dragging incidents to occur.

The Singapore VTS keeps continuous watch, not only on the vessels that are moving but anchored vessels as well and often warn vessels when they are observed dragging anchor and endangering other vessels in the vicinity. The MPA Singapore does not provide specific guidelines regarding anchoring and anchor watch keeping but are making reference to the IMO STCW.7 Circ. 14 – Guidance for Masters on keeping a safe anchor watch, located in **Appendix G**.

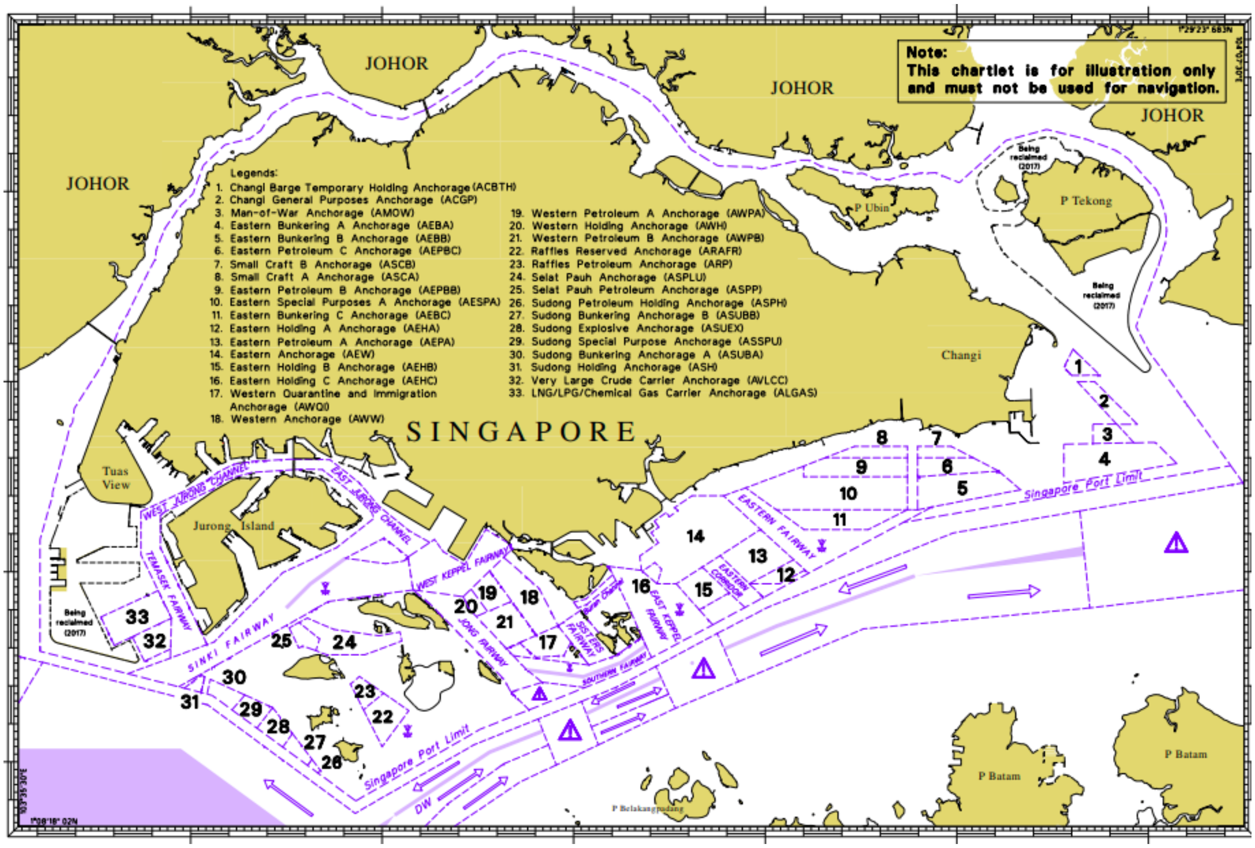


Figure 6-8: Chartlet depicting Singapore's 33 Anchorages (Maritime and Port Authority of Singapore, 2020)

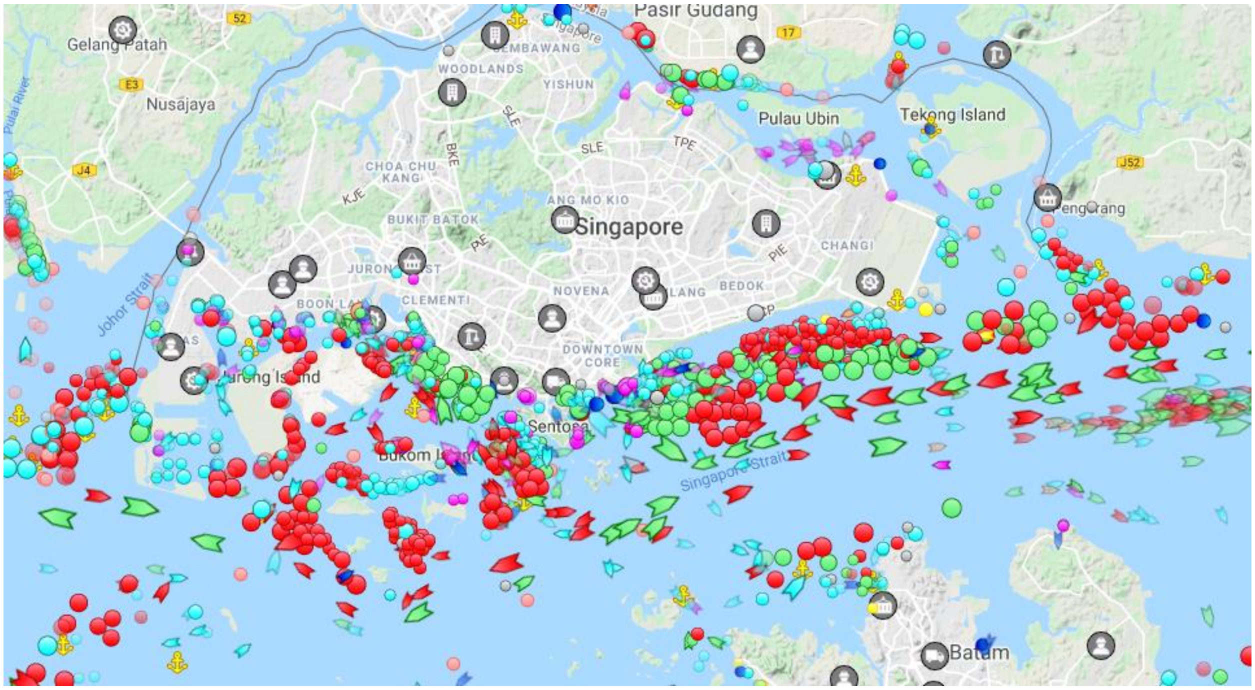


Figure 6-9: AIS image illustrating the number of vessels at anchor and those transiting in and out of the port of Singapore. Vessels at anchor, docked or not underway are depicted by the dots. Vessels underway are depicted by the arrows. Image courtesy of (Marine Traffic, 2020)

6.2.5 Port of Yokohama

Port of Yokohama, Japan has a total of 20 anchorages as illustrated in **Figure 6-10**, there is a mixture of single anchorage spots with a defined swinging radius, and varying size anchorage areas which are bounded by the lines between the specified coordinates (usually in rectangle or polygon shapes). Individual anchor spots and general anchorage areas are grouped as per vessel type and size as applicable. The 'Port Entry Manual-Port of Yokohama' contains only brief information regarding the need to maintain proper anchor watch and lookout and monitor radio watch for latest weather information.

Anchoring spot is assigned by the Captain of the Port (Harbour Master). Pilotage is compulsory even for the approach and departure to an anchorage area in Tokyo Bay. Tokyo Bay, where the Port of Yokohama is located, falls under mandatory Pilotage for all vessels over 10,000 GT and over 300GT for vessels carrying dangerous cargo. Port of Yokohama (Port of Yokohama, 2017), has a policy which requires vessels to go out to open sea to weather the major storm events instead of sheltering in place at anchor or within the confines of the harbour.

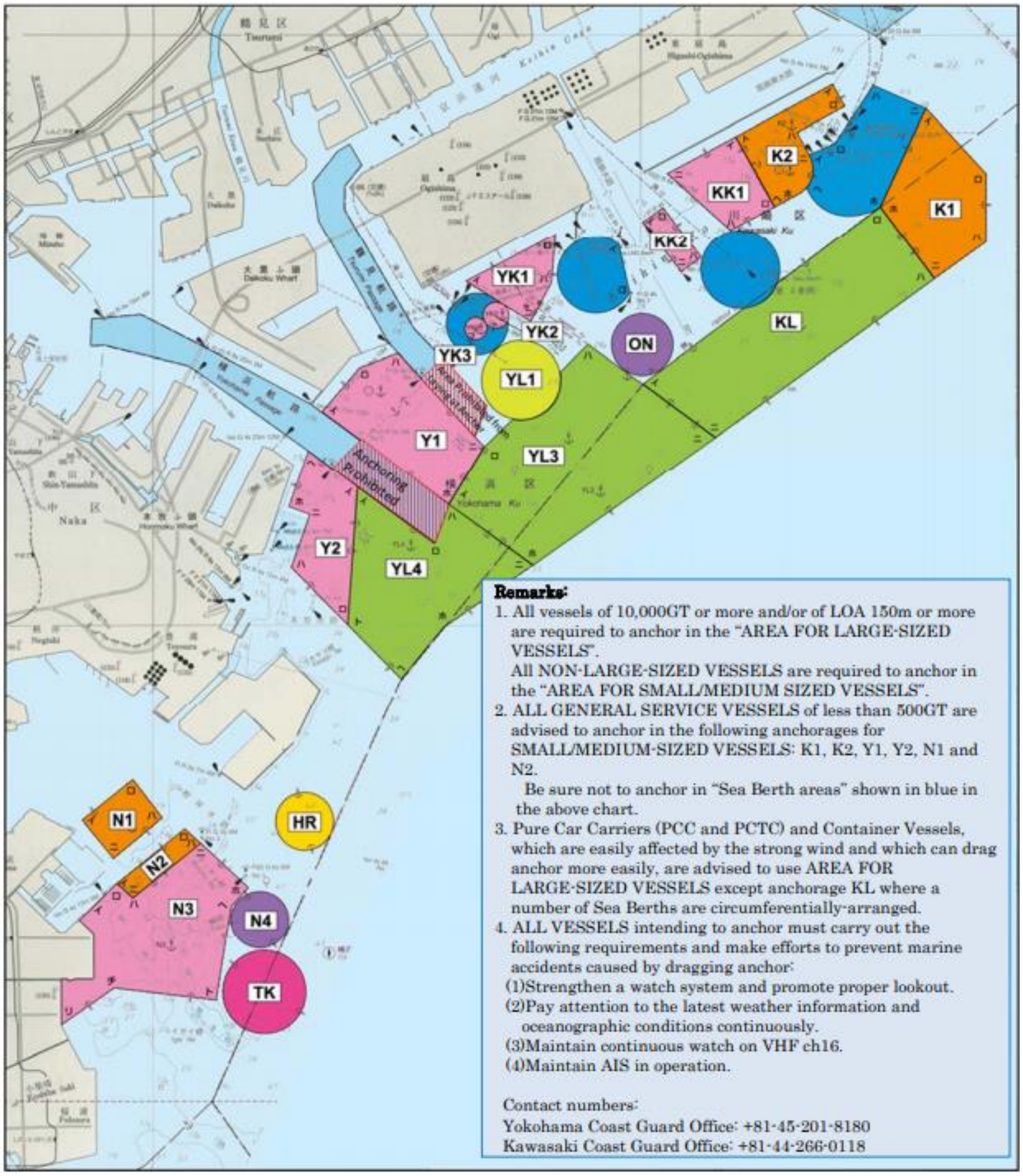


Figure 6-10: Port of Yokohama Anchorage Areas (image courtesy of Port Entry Manual (Port of Yokohama, 2017))

6.2.6 Port of Halifax

The Port of Halifax has two inner harbour anchorages with a total of 13 anchoring spots with defined Latitude & Longitude however no swinging radius are defined (Port of Halifax, 2020). Both of these inner anchorages are within the compulsory pilotage area, therefore vessels arriving to and departing from inner anchorages have the Pilot onboard and while the anchorage spot is authorized by the MCTS through prior contact and request, the pilot will identify the most appropriate anchorage spot according to: the prevailing conditions, scheduled vessel arrivals and departures, other vessels at anchor and any other scheduled operations for the port.

Two short term anchorages outside the compulsory Pilotage area are meant to be used only in fair weather conditions due to their exposure.

MCTS will monitor vessels at anchor by radar for early signs of dragging anchor and inform vessels of any detected movement. MCTS advises them via VHF radio of the potential risk when sustained wind speed has reached or is predicted to exceed 25 knots.

Port of Halifax PIG provides some specific guidance for vessels at anchor:

- No vessel at anchor, within the jurisdiction of the HPA, may immobilize its main propulsion machinery without the explicit authorization of the HPA.
- If repairs or maintenance to the main engine or steering gear prevent the ship from manoeuvring under its own power, the services of a standby tug will be required. Consequently, if a standby tug cannot be acquired, a suitable berth will be assigned by the HPA.
- When sustained winds of 25 knots are encountered the main propulsion must be on standby and capable of responding within five (5) minutes.
- When sustained winds of 30 knots or more occur, the main propulsion must be capable of responding as if the vessel was berthing, i.e. shortest possible response time.
- Vessels deemed by to be at high risk of dragging anchor (e.g. vessels with an excessively high freeboard, unusual trim and/or damage, etc.) may be instructed by the HPA to engage pilots and/or tugs and/or shift to an available berth.
- The above mentioned vessels must also rig a line from the bow to within one (1) meter from the water to enable a tug to quickly secure should it be necessary. This line is to have a breaking strain of 165 tonnes and be rigged in a manner similar to the attached drawings.

6.2.7 Common Anchoring Practices

Common anchorage safety practices in other international ports include requirements for ships to call ahead and request an anchorage, as is standard in most ports. In many ports, tugs are required for movements within the harbour including dock-to-anchor and anchor-to-dock movements. MCTS / VTS usually monitors all vessels at anchorage and provide timely notification of inclement weather and when vessels are observed dragging their anchor.

A common issue between other international ports and the Port is anchor dragging. Anchor dragging occurs typically when environmental factors exceed the holding capacity of an anchor. Anchoring equipment is designed for temporary mooring of a vessel within a harbour or sheltered area and is not designed to hold a vessel in fully exposed rough weather or to stop a ship that is fast-moving or drifting. An analysis of anchor dragging incidents, as recorded by the Port, and preventative measures endorsed by international jurisdictions was conducted as this is currently the main issue the Port is experiencing with its anchorage areas.

6.2.8 Discussion

From the above information describing various international port's anchorage practices and regulations, a common theme is that the onus on ensuring the vessel is safely anchored and holding its position is vested on the Master of the vessel. Therefore, it is recommended that PIG contains this information and preferably makes reference to IMO STCW.7 Circ. 14 – Guidance for Masters on keeping a safe anchor watch (**Appendix G**).

In addition, the VTMS clearly plays a vital role in maintaining close watch on all vessels including those that are anchored. In addition to broadcasting weather warnings if gale winds are forecasted and when sustained wind speeds exceeds 25 knots, timely notification is required to any vessel suspected of dragging anchor as well as those in their vicinity.

Some of the above ports analysed have PIG booklets which contain less information and guidance than that of the Port. It is assumed that the reason for that is that most of the information and guidance is readily available through navigational charts and publications (sailing directions, etc.) which are mandatorily carried onboard all ocean going vessels.

Port statistics on anchor dragging are difficult to find in a publicly accessible format; however, the marine insurance industry reviews incidents resulting from anchor dragging and other anchorage instances, known contributing factors to anchor dragging are identified below:

- Ballast condition is identified as a major contributor to anchor dragging incidents. Ships have run aground due to weather changes when the ship is in light ballast condition. The increase in windage area when a ship is in light ballast condition ads additional force to the cable. In some cases, the light ballast contributed to the captain failing to steer the ship from running aground since the conditions and ballast meant the propellers were not fully submerged. This factor was identified as especially important when ships are anchored close to shore and do not have much time to regain control in an anchor dragging situation (The Standard, 2008).
- Engine readiness was also identified as a contributing factor to losses from dragging anchor. Some incidents resulted from ships which started to drag anchor and the engine was not able to come online quickly enough to avoid running aground (The Standard, 2008).
- An inappropriate anchor watch has also been identified as a contributing factor. Good watch keeping and observation by the duty officer, can help to identify quickly if a vessel is dragging anchor and timely action by the Master can avoid potential incidents. (The Standard, 2008).

To help prevent future anchor dragging incidents, the Port should consider the application of the following preventative measures based on our international review:

- The Port's PIG identifies that ships should maintain "safe ballast" that keep the ships' propeller and rudder below the water line while at anchor. This should be examined more closely by the Port to determine if keeping just enough ballast to keep the propeller and rudder below the water line would be sufficient in an unexpected wind event. It may be more appropriate to require ships to maintain maximum ballast until a confirmed loading time has been arranged.
- The Port does require that ships at anchor keep their engines on standby. This can reduce the likelihood of an event from a ship dragging anchor and this practice should be maintained.
- The PIG should make reference to the STCW.7 Circ. 14 – Guidance for Masters on keeping a safe anchor watch.
- Currently, the Port does not require ships to weather storms at sea; however, if a large storm was to come in, and ships would begin to drag anchor, a pilot is required to move ships out of the harbour area. The availability of pilots could; therefore, contribute to incidents from anchor dragging if the pilots are unable to move the vessels quickly enough. Therefore, the Port should consider adopting a policy that would require vessels at anchor in the inner harbour anchorages to leave anchorage early if inclement weather is predicted and proceed out to weather a storm at sea, especially since there is limited space for them to maneuver should they drag anchor. Considering that the entire anchorage area for the Port falls within mandatory pilotage requiring a Pilot onboard for every vessel movement on and off the anchorage, a review and risk assessment in conjunction with BC Pilots / Pacific Pilotage Authority is recommended to ascertain the adequacy of the number of Pilots available for timely attendance should the vessels be ordered to leave anchorage due to inclement weather conditions.
- The risk assessment should consider a deviation from the mandatory pilotage policy that would determine the risk of allowing vessels at anchorages outside the confines of the Port (i.e. #8 and higher) for the Master to depart anchorage without a Pilot, if Pilot is not readily available in emergency situations or where extreme weather is forecasted.

7.0 Recommendations

Based on the results of the MNRA and AARA, we have provided some recommendations for the Port to consider which could improve the safety margins. It is important to note that some of these changes would need to be studied further prior to implementation.

7.1 Holding Ground

The physical composition of the seafloor in an anchorage is critical for providing a safe and effective anchorage. A ships anchor needs to be embedded into the seafloor so the anchor chain can lay out providing effective holding capacity for the ship. Seafloor composed of mud or sand or sand/shell provide good holding material as the anchor can readily embed into the seafloor.

Seafloor made up of rocks and compacted sand are regarded as being quite poor holding grounds, with anchors often failing to hold in inclement weather conditions. As such these seafloors should be avoided.

The information about the nature of the seafloor should be provided in the Port Information Guide (in addition to the information provided in the nautical charts).

7.2 Weather and Tides/Currents

Wind, squalls, currents and tidal variations, all need to be taken into consideration when deciding where to anchor. Anchorages that are exposed to strong winds and/or high seas will impact on a ship's ability to safely manoeuver to and from the anchorage as well as the ability of the anchor to hold the ship in position. Ship at anchor will swing around its anchor under the force of tide and wind. As the ship swings the anchor chain will drag along the seafloor and may weaken the holding force; therefore, particular attention has to be paid by the Officer on Watch during change of tide and increased wind speed.

The port issues a warning to vessels when winds exceed 25 knots. However, 30% of the anchor dragging incidents took place in winds under 25 knots Therefore, it may be worthwhile for the Port to explore the possibility of issuing a wind warning when winds are expected to exceed 20 knots for a sustained period.

The Prince Rupert port information guide requires the vessel to use at least 10 shackles (275 m) of chain during winter months when there is more likelihood of higher wind speed. It is unclear if this practice is being followed and enforced by Pilots who are onboard at the time of vessels anchoring. The scope of the chain to use is not mentioned in the port guide.

7.3 Depth and Available Space

Considering the size of the vessels calling anchorages in the Prince Rupert port, the fact that majority of them are in ballast condition and available depth at anchorages, it can be safely said that available depth is more than adequate, and on some anchorages even too deep rendering anchoring ineffective due to inability to achieve adequate scope of anchor (anchor chain length to depth ratio).

The 'scope of chain' is the ratio of the length of cable from the hawse pipe to the anchor 'D shackle'; divided by the depth of water from the hawse pipe to the seabed. Good seamanship, and industry best practice when anchoring the vessel calls to use the scope of 6 to 10.

With the length of 11 shackles of chain being 302.5 metres (the most any vessel would pay out practically) and the minimum scope of 6 as per above mentioned best practice , this would mean that anchoring at a spot with depth over 38 metres, the minimum scope of 6 would not be achieved on most of the anchoring spots. Looking at the available depths at designated anchorages and the typical hawse pipe height of 12 metres above water level on most vessels calling Prince Rupert Port in ballast condition, the minimum scope of 6 would be achievable only on 7 out of 31 anchorages, i.e., #4, 6, 8, 14, 16, 23 & 27, and that only if vessels do pay out 11 shackles of chain. The records of dragging incidents did not provide the number of shackles vessels have paid out when first anchored.

7.4 Anchorage Size

The size of anchorage has to take into consideration the swing arc of one vessel versus the adjacent ships in order to avoid collisions due to potential of ships swinging in the opposite direction rather than in unison.

The PIANC guideline provides good guidance on how to determine the size of individual anchorage positions. These calculations generally result in an anchorage circle of a determined radius based on a vessel anchoring roughly at the centre, an allowance for length of anchor chain deployed based on predominate water depth, weather conditions, the length of the vessel and a safety margin.

With the latest technology and navigational equipment onboard ocean going vessels, including PPU (Portable Pilot Unit) tablets that BC Pilots are using, dropping the anchor at the centre of the designated anchoring spot is easily achievable.

An anchorage area may contain individual anchorage sites with different swing radius to cater for different size vessels, which is the way Port has defined for their anchorages. Smaller ships can safely anchor in shallower water which will require less anchor chain to be deployed, while large ships will need deeper water to safely anchor resulting in more anchor chain being deployed. By utilising a mix of anchorage swing circle sizes to match the expected ship sizes, a smaller overall anchorage area footprint can be achieved.

Current practice of defining individual circular shape anchorage spots with specific Latitude & Longitude and swinging circle radius is much better and safer than defining general anchorage area bounded by a number of coordinates in rectangular or polygon shapes as practiced in some ports, because these may entice the Master & Pilot to crowd the anchorage and use shorter lengths of anchor chain.

However, as shown in **Table 7-1** below, the swinging circle radius provided in the Port Information Guide indicate that the radius for anchorage 4,6,10, 14, 23, 26, 27 and 28 may not be sufficient if the stipulated LOA of the vessel is at its limit and 10 shackles of chain is used as recommended for winter months by the Port Information Guide. This was ascertained by using the allowed LOA, depth and assumption of hawse pipe being 12 metres above sea level. Industry recognized formula was used to calculate the maximum swinging circle.

Table 7-1: Anchorage Swing Radius Comparison

Anchorage Area	Depth (m)	Max LOA (m)	Hawse pipe above seabed (m)	Maximum swinging circle Radius if 10 shackles of chain paid out (m)	Swing radius provided in the Port Guide(m)	Difference (m)
2	56	225	68	503	550	47
3	48	225	60	535	550	15
3a	48	225	60	535	550	15
4	39	225	51	571	550	-21
5	42	225	54	559	600	41
6	37	250	49	604	600	-4
7	55	250	67	532	650	118
8	38	270	50	620	725	105
9	66	350	78	588	870	282
10	60	400	72	662	600	-62
11	53	270	65	560	600	40
12	54	270	66	556	600	44
13	43	270	55	600	600	0
14	30	270	42	652	650	-2
15	41	270	53	608	650	42
16	39	270	51	616	650	34
17	42	270	54	604	700	96
18	60	325	72	587	700	113
19	65	325	77	567	700	133
20	52	325	64	619	700	81
21	54	325	66	611	700	89
22	42	325	54	659	700	41

Anchorage Area	Depth (m)	Max LOA (m)	Hawse pipe above seabed (m)	Maximum swinging circle Radius if 10 shackles of chain paid out (m)	Swing radius provided in the Port Guide(m)	Difference (m)
23	30	325	42	707	700	-7
24	60	350	72	612	725	113
25	53	350	65	640	700	60
26	50	350	62	652	600	-52
27	38	350	50	700	650	-50
28	54	350	66	636	600	-36
29	66	350	78	588	675	87
30	80	350	92	532	675	143
31	72	350	84	564	675	111

It is therefore recommended that the Latitude and Longitude of the anchorages #4, 10, 14, 26, 27 and 28[6] be revised in order to accommodate the swinging circle size which will results with use of 10 shackles of chain.

It is the PRPA requirements to use minimum 10 shackles of chain during winter months on deep sea ships. This requirement needs to be enforced through Pilots at the time of anchoring and in arrival instructions to all vessels. Using a minimum of 10 shackles of chain throughout the year, and not only during winter months, should be considered for added safety. This information to be highlighted in the Port Information Guide.

In order to better understand the reason for anchor dragging incidents, every future anchor dragging incident report from individual vessels should have information on:

- Number of shackles of chain paid out when initially anchored;
- Scope of chain based on the depth of water at the anchorage;
- Nature of the seabed as per navigational chart information;
- Maximum wind speed observed around the time the anchor started dragging;
- Wind direction; and
- Vessel loaded condition (ballast/ laden) and windage area if available.

7.5 Anchorage Locations

There are some anchorage areas which stood out throughout the analysis of the various risks they may be exposed to.

[6] Anchorages 6 and 23 are not listed since the discrepancy is less than 10 meters.

Anchorage #8 is located next to the main shipping lanes where the ships transit and execute a turn to head to the terminals or the inner harbour. This location is a high traffic location. This means that ships at this anchorage are more exposed to the risk of ships striking it either through mechanical failure or human error. In addition, it was flagged as one of the higher risk anchorage areas in the anchorage area risk assessment.

Anchorage #7 is located at the entrance to the inner harbour. All vessels transiting through the inner harbour or to and from other anchorages in the inner harbour, must pass by anchorage area #7 while executing a turn. This increases the risk of a ship at this anchorage area, being involved in an incident with a transiting vessel. In addition, there were three anchor dragging incidents reported at this anchorage.

Anchorages #11-14 should be considered for decommissioning. They are currently identified as emergency anchorage only and are located near aquaculture sites. If they are not to be decommissioned, then further study should be done to consider the aquaculture sites, sea bottom type (the anchorages are located near a transition from mud to hard surface), and cultural sensitivities for Indigenous communities that have identified this as an ecologically sensitive area during the HAZID workshop.

7.6 Anchorage Assignment Guidelines

One clear outcome of the future modelling for the anchorage utilization was that there will likely be situations where there is no immediately available anchorage area. This can be mitigated through changes to the current anchorage assignment guidelines. However, we recommend that the Port take an in-depth study of any changes to the guidelines which would consider the cargo of the ships, especially those carrying dangerous goods, and potential risks.

7.7 Pilot Station

The location of the current pilot station was identified as a concern during the HAZID session. Therefore, we recommend examining the feasibility of relocating it further away so that Pilots have the time to properly assess the situation and complete the Master/Pilot Information Exchange checklist before taking control of the vessel and needing to make the changes to the vessel's navigation.

7.8 AIS

The involvement of fishing vessels in the overall navigational risks in the Sub Area was brought up through the HAZID and in some of the MNRA results. The PRPA has previously had a program where it funded AIS installation on fishing vessels which are not required to have AIS. AIS reduces the likelihood of vessel collisions and increases navigational safety. We recommend that the PRPA continues to pursue this project seeking support from TC to continue improving navigational safety.

7.9 Recommendations from the International Jurisdiction Review

The Port's PIG identifies that ships should maintain "safe ballast" that keep the ships' propeller and rudder below the water line while at anchor. This should be examined more closely by the Port to determine if keeping just enough ballast to keep the propeller and rudder below the water line would be sufficient in an unexpected wind event. It may be more appropriate to require ships to maintain maximum ballast until a confirmed loading time has been arranged.

The Port does require that ships at anchor keep their engines on standby. This can reduce the likelihood of an event from a ship dragging anchor and this practice should be maintained.

The PIG should make reference to the STCW.7 Circ. 14 – Guidance for Masters on keeping a safe anchor watch.

Currently, the Port does not require ships to weather storms at sea; however, if a large storm was to come in, and ships would begin to drag anchor, a pilot is required to move ships out of the harbour area. The availability of pilots could; therefore, contribute to incidents from anchor dragging if the pilots are unable to move the vessels quickly enough. Therefore, the Port should consider adopting a policy that would require vessels at anchor in the inner harbour anchorages to leave anchorage early if inclement weather is predicted and proceed out to weather a storm at sea, especially since there is limited space for them to maneuver should they drag anchor.

Considering that the entire anchorage area for the Port falls within mandatory pilotage requiring a Pilot onboard for every vessel movement on and off the anchorage, a review and risk assessment in conjunction with BC Pilots / Pacific Pilotage Authority is recommended to ascertain the adequacy of the number of Pilots available for timely attendance should the vessels be ordered to leave anchorage due to inclement weather conditions.

The risk assessment should consider a deviation from the mandatory pilotage policy that would determine the risk of allowing vessels at anchorages outside the confines of the Port (i.e. #8 and higher) for the Master to depart anchorage without a Pilot, if Pilot is not readily available in emergency situations or where extreme weather is forecasted.

8.0 Conclusion

The MNRA and AARA were completed with an analysis of both the current traffic and anchoring volumes in the Port, and the future, 2030, scenario where future traffic levels and vessel calls were modelled.

The MNRA results showed that currently, the highest risk for the port with regards to marine navigation, exists in the inner harbour and the channel transiting to the inner harbour. The highest risk of ship to ship collisions with current traffic within the Sub Area for larger commercial vessels is with Passenger-Ferry-Roro vessels at 1 in 131 years, followed by GDC-Bulker ships at 1 in 245 years. For 2030, there is no major increase in the expected number of ship to ship collisions for larger commercial vessels of these categories. The highest risk area, the inner harbour and entrance to the inner harbour would potentially have high consequences for the area including potentially an oil spill, cargo spill, foundering of a ship, and even the closure of the Port while the ships are salvaged. This could cause a disruption to the Port's operations and the transfer of goods within Canada.

The MNRA also showed that there is a high risk of groundings within the study area. In the current (2018) results, a small vessel (such as a fishing vessel) is expected to ground annually. Small commercial vessel groundings are expected to occur once every 5 years. A grounding for a large commercial vessel is expected to occur once every 29 years. In 2030, the results were not notably higher except for the risk of a small commercial vessel grounding which is expected to increase to one every 2.3 years.

The MNRA grounding results for the sub area showed that there is expected to be a small vessel grounding annually. Small commercial vessel grounding are expected to occur once every 13 years. Large commercial vessel groundings are expected to occur once every 32 years. The 2030 results were not notably higher but did increase across the board. In 2030, the highest risk of groundings by commercial ship type will be with LNG/LPG vessels.

The AARA results showed that presently, the anchorage areas are not at capacity, however in the future, there are likely to be instances where an anchorage area is not immediately available for a ship upon arrival with an easing in this trend only coming with the expansion of the Ridley Island terminal. This may require the Port to re-examine its guidelines for assignment of anchorages. The results also found that some anchorage areas do not have an appropriate swing circle radius and this should be changed to stay in line with the most up to date safety standards.

The AARA's analysis of anchorage holding capacity found that inner harbour anchorages are at a higher risk of dragging anchor at winds in the 90th percentile.

The AARA's analysis of ship traffic near the anchorage areas found that the inner harbour anchorages are most at risk of having a transiting ship come into contact with them. This is in addition to almost all inner harbour anchorages having had anchor dragging incidents. The anchorages 8 and 7, which are both located at turning points for ships, are both at added risk because of this. The AARA also found that risk to the anchorages is not significantly increased by the increase in traffic. There was only a marginal increase in risk to anchorages between 2018 and 2030.

An international review of other ports found that the Port operates with many of the best practices required to reduce incidents.

The recommendations in **Section 7.0** outline the steps that we believe should be examined to improve the safety of navigation and anchorage practices at the Port. These recommendations are based on results of the analysis which may differ from real life outcomes. Therefore, they should be carefully considered in more detail prior to implementation.

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Appendix A

Environmental Data

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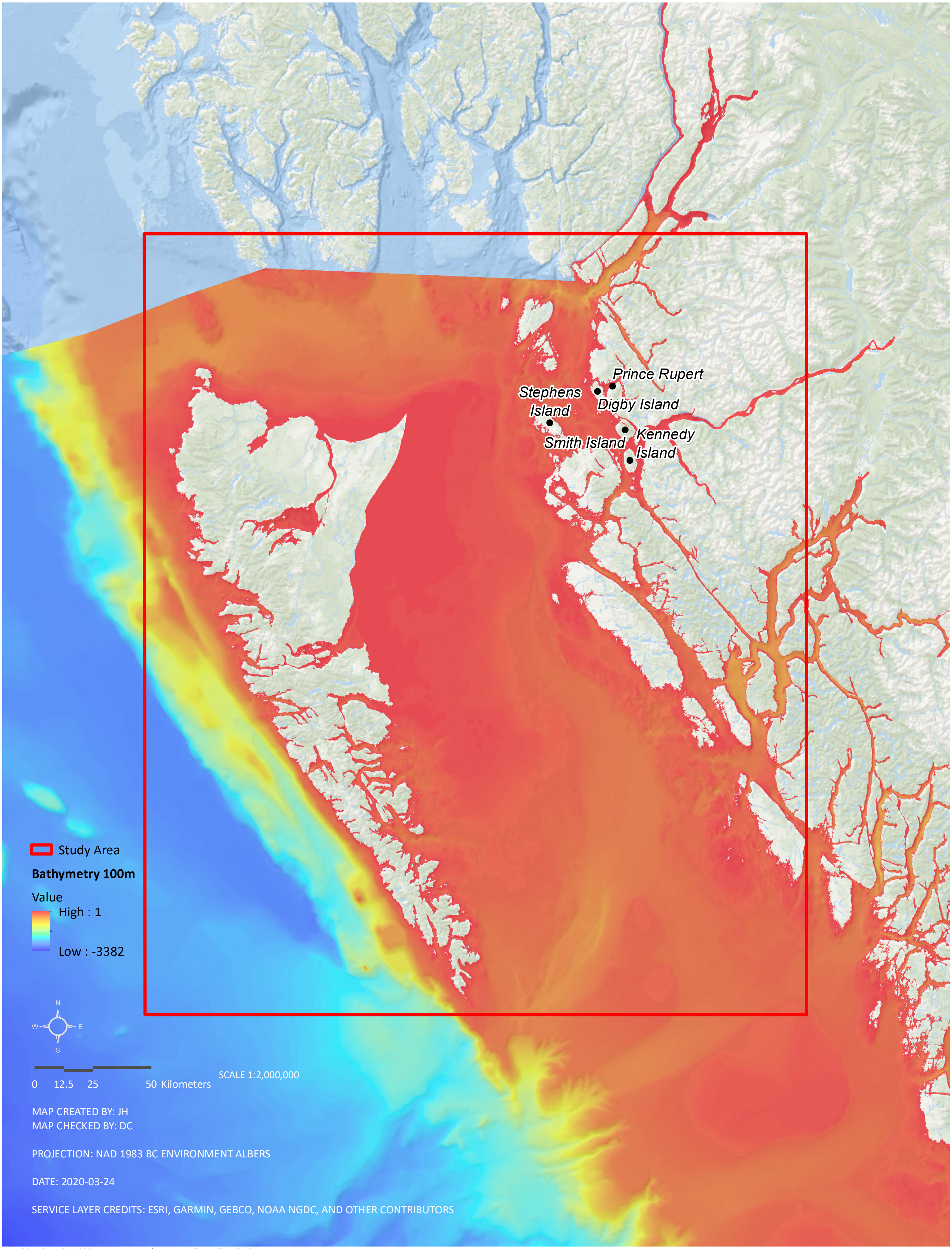

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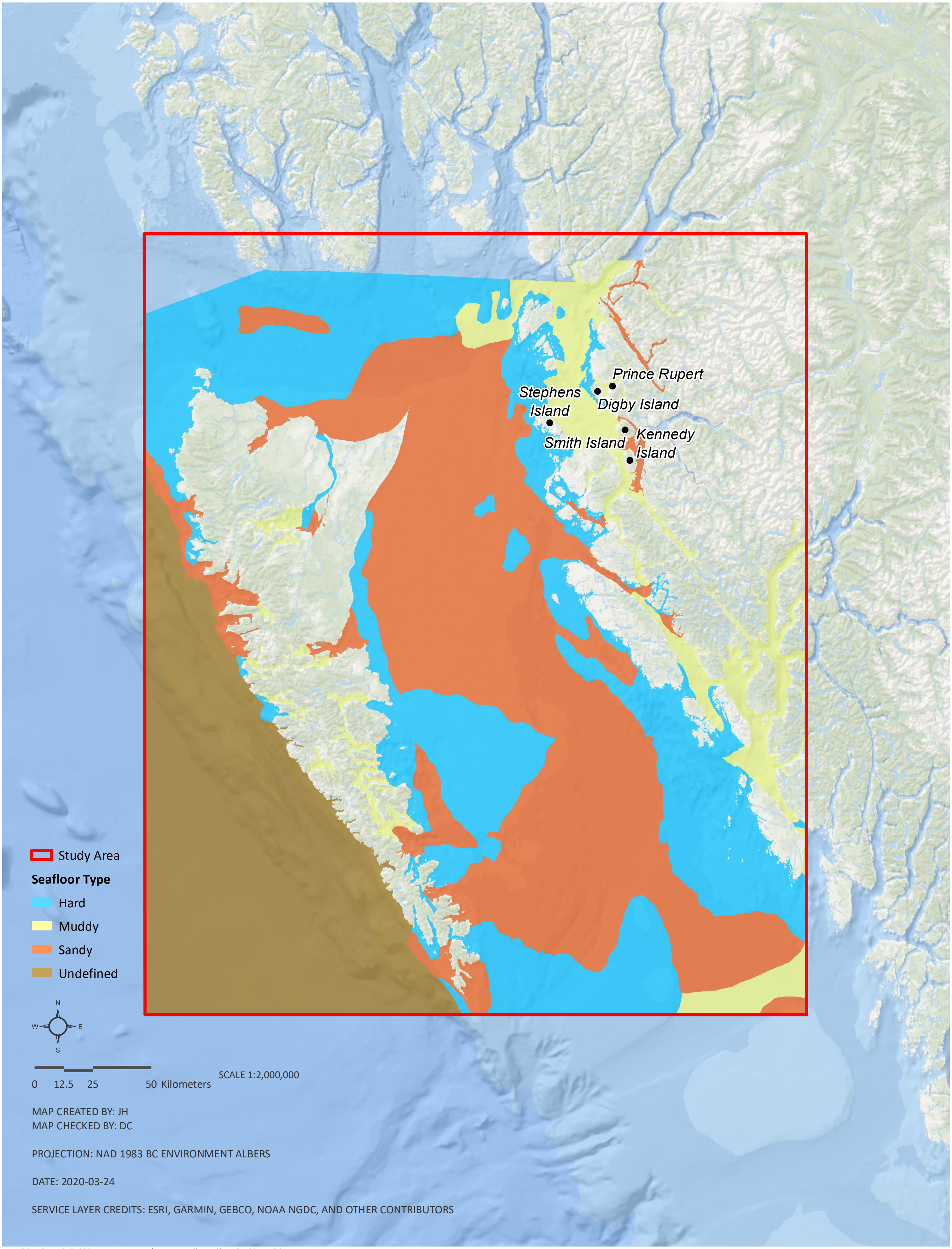

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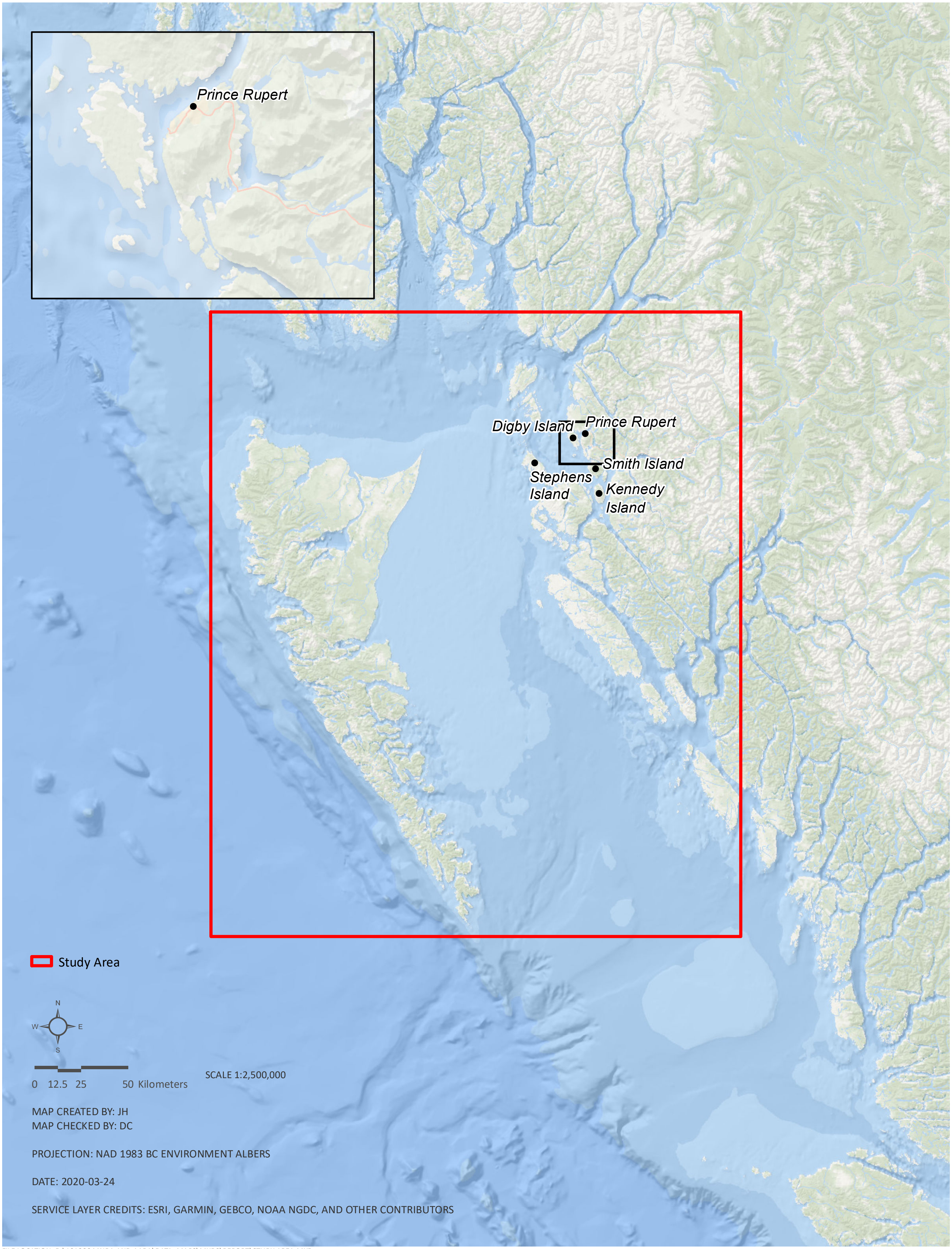

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7.0 CLOSURE

We trust this technical memo meets your present requirements. If you have any questions or comments, please contact the undersigned.

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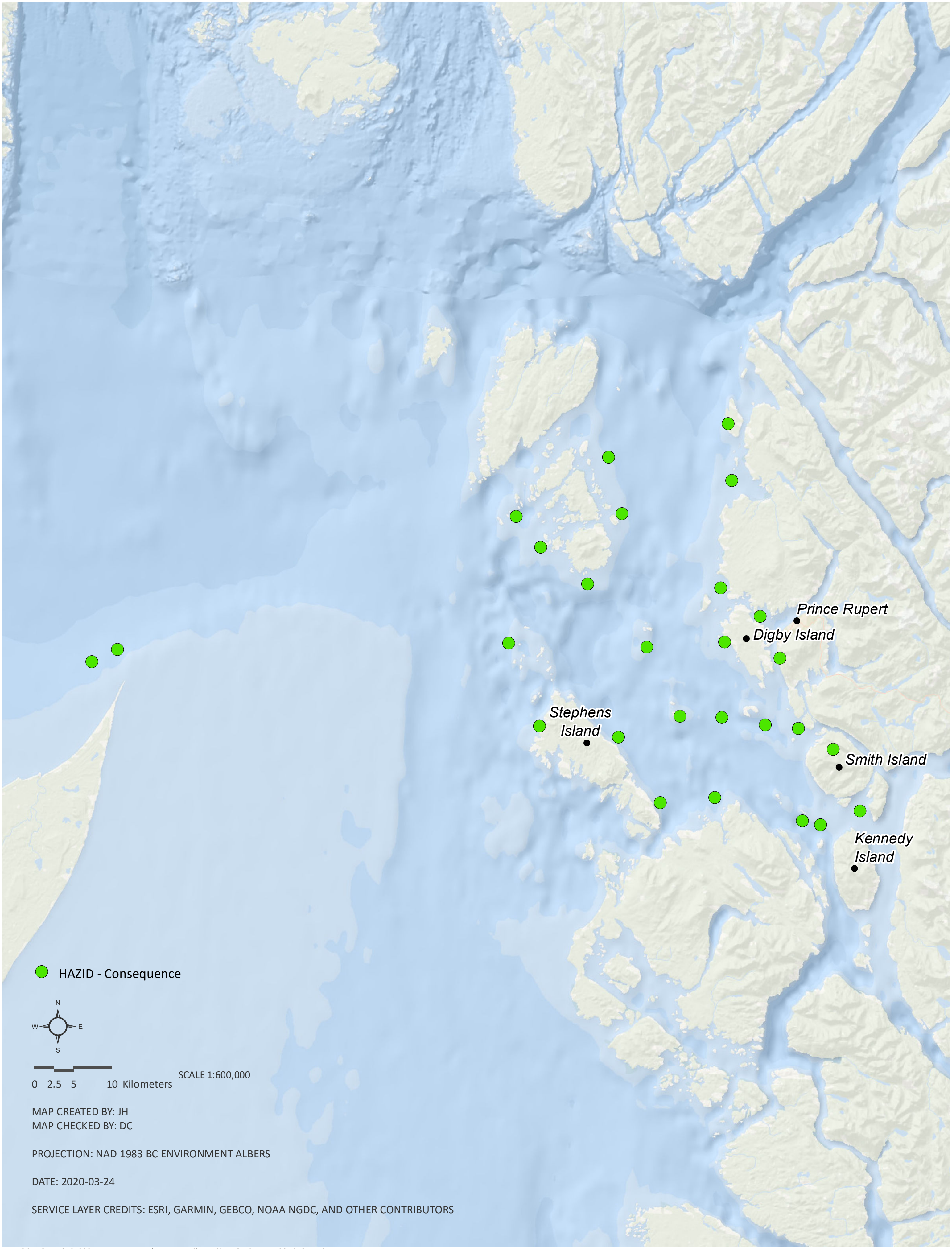
Appendix B

HAZID Maps



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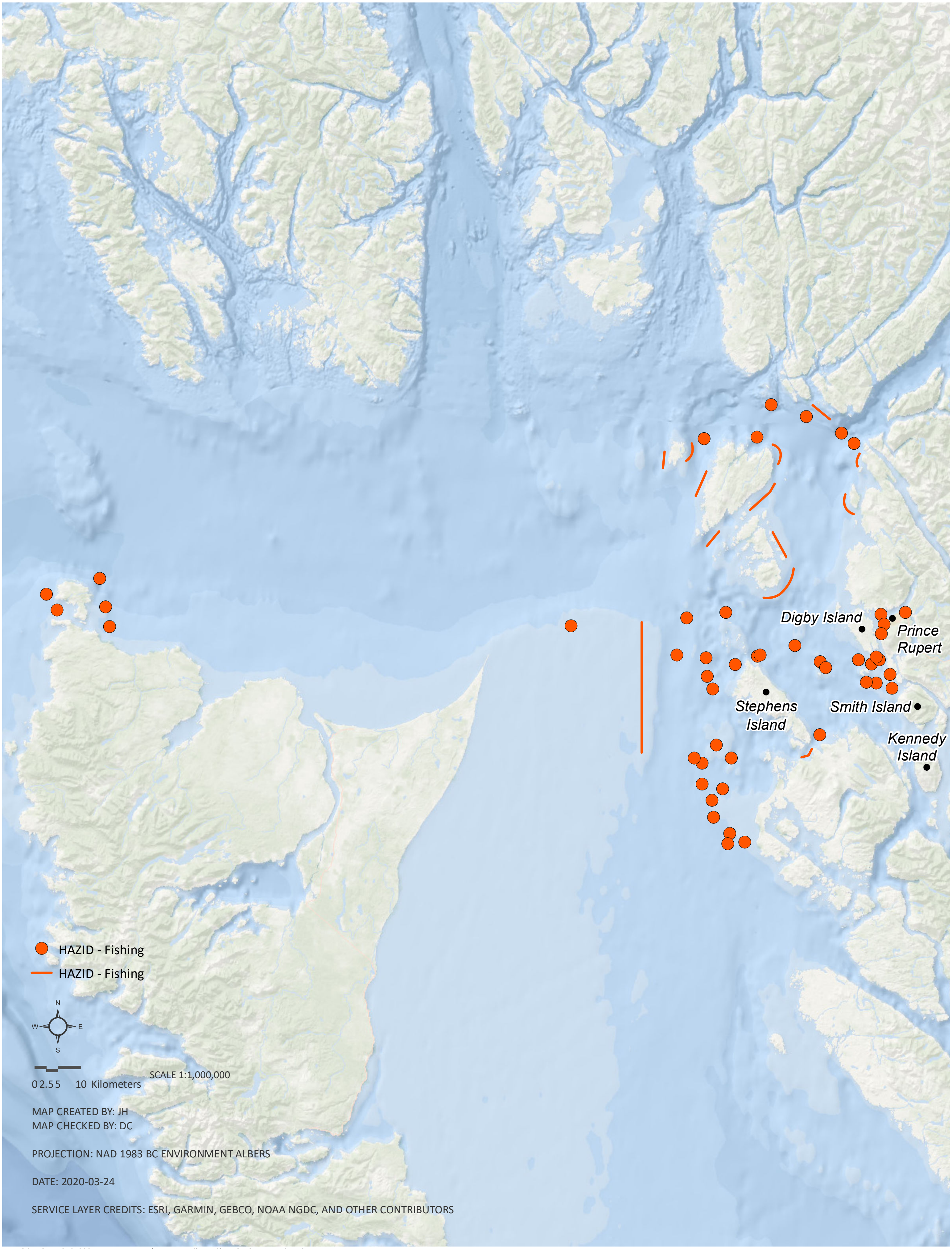

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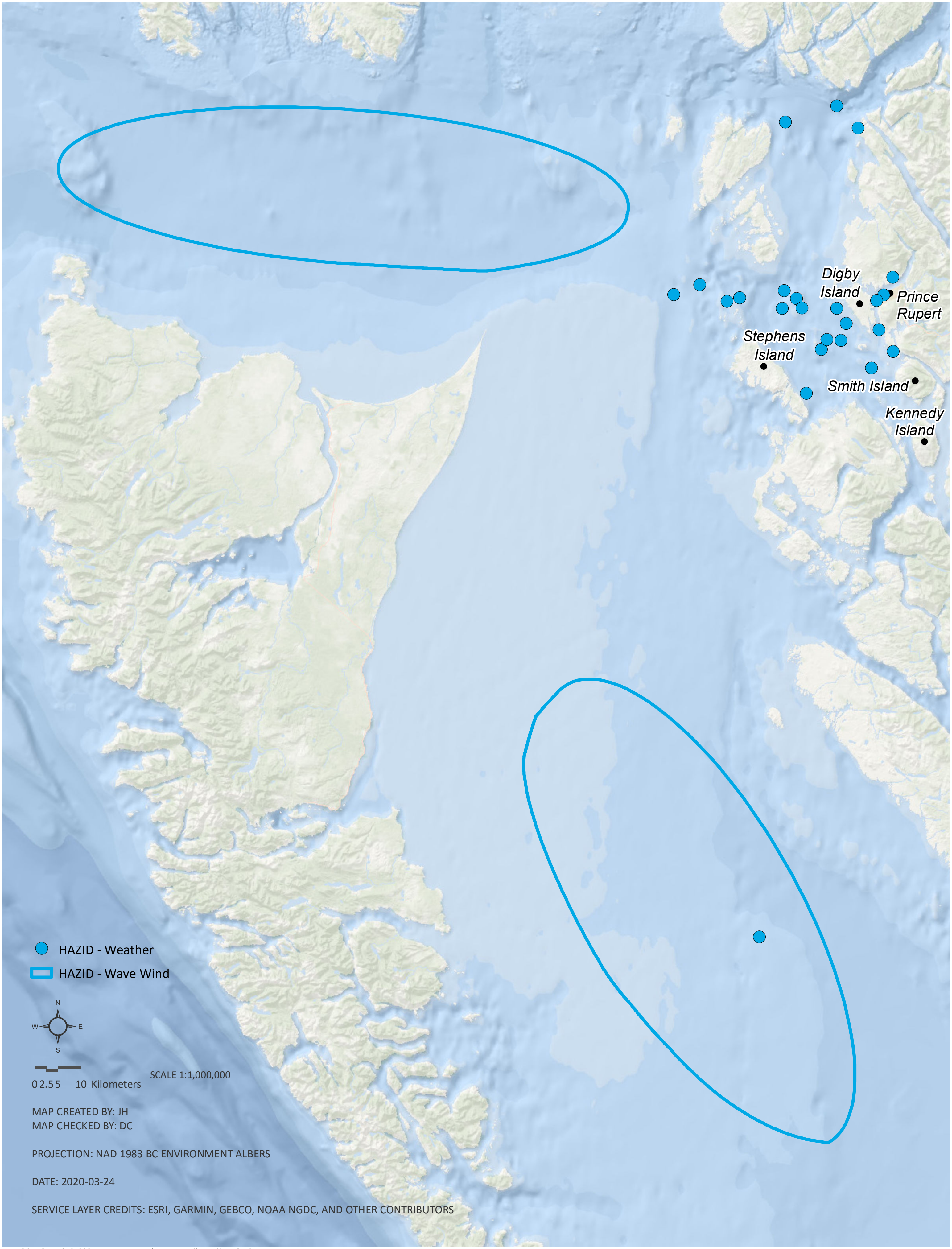

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Appendix C

Marine Navigational Risk Assessment Methodology

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Table of Contents

Figures

Tables

1.0 The SAMSON Model

The Marine Navigation Risk Assessment (MNRA) for the Prince Rupert Port was conducted by the Maritime Research Institute of the Netherlands (MARIN) utilizing their marine traffic modelling software called SAMSON. The SAMSON Model (the Model) utilizes specific inputs in order to calculate the frequency of accidents. This appendix will describe the model inputs and the calculation process that the SAMSON Model undertakes to determine its outputs, which will be described in **Section 2.0**.

SAMSON stands for **S**afety **A**ssessment **M**odels for **S**hipping and **O**ffshore in the **N**orth Sea. With the model, various risk assessment calculations can be performed regarding maritime safety. Although the name suggests SAMSON is only applicable for the North Sea, it is a generic model can be applied to any defined geographic location. The model was developed to determine the probabilities, locations and consequences of various marine accidents, taking into consideration various mitigation measures that could be used to reduce the likelihood of a marine accident (e.g.,: pilotage). The parameters of the casualty models are derived from the worldwide casualty data of 1990-2015. The SAMSON model was originally developed over 40 years ago and since that time it has been extended, validated and improved by MARIN in various studies performed for Rijkswaterstaat, the EU and Transport Canada.

As depicted on **Figure C-1**, using a detailed maritime traffic database, environmental conditions (such as wind and currents), and different mathematical models to incorporate preventative measures and incident statistics, the frequency and probably location of different types of accidents can be determined by SAMSON.

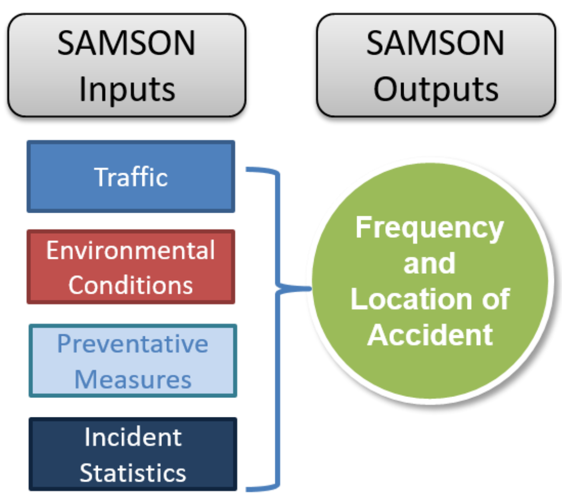

Figure C-1: SAMSON Model Inputs and Outputs

A detailed system diagram of the SAMSON model is presented in **Figure C-2** highlighting the numerous parameters, systems, and impacts that can be considered with SAMSON. The objective of the Prince Rupert MNRA was to determine what the risks are with respect to the increase in vessel traffic and changes in vessel types and sizes (i.e., a future traffic scenario). For the purpose of this study, the likelihood of marine accidents leading to oil (or other) spills was not determined, although this is a frequent use for the SAMSON Model.

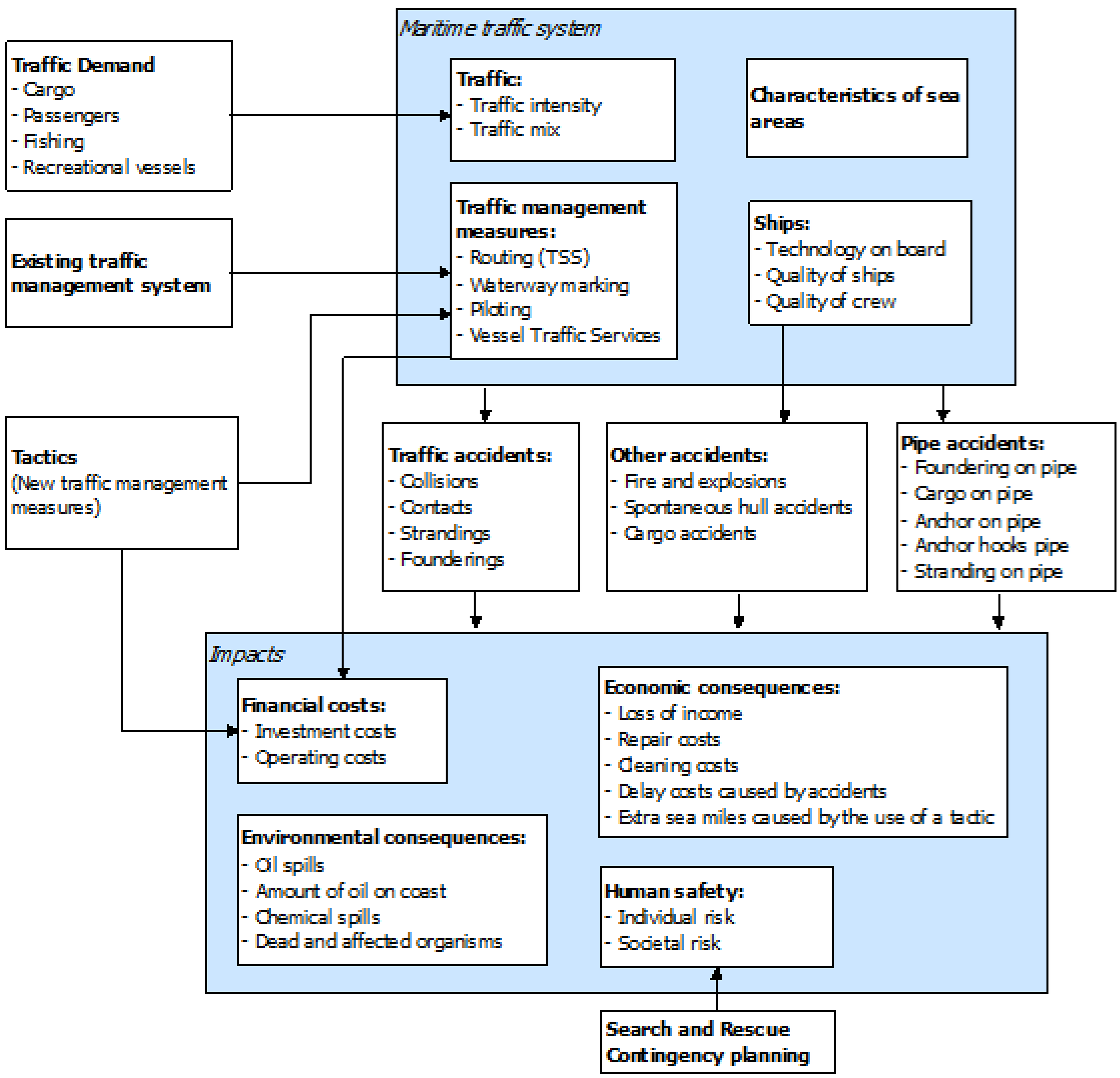

Figure C-2: The SAMSON Model System Diagram

1.1 SAMSON Model Inputs

For the SAMSON Model to be able to calculate the frequency of an accident, it needs a number of data inputs as presented in **Figure C-2**. These inputs can be grouped into five categories:

- Maritime Traffic;
- Environmental Data;
- Preventive Barriers;
- Accident Statistics; and,
- Ship Classes.

Each of these inputs consists of several elements, of which a more detailed description is provided in the sections below.

1.1.1 Maritime Traffic

To determine the frequency of an accident occurring, the number of potentially dangerous situations is determined first. For example, a potentially dangerous situation can occur when a collision between vessels is possible because of their proximity. The potentially dangerous situation occurs when one ship enters within a certain domain around the other ship. To help determine the frequency of potentially dangerous situations occurring, maritime traffic is integrated into the Model using Automated Identification System (AIS) data. The data forms the basis on which the the frequency of an accident is being calculated.

AIS data provides information on vessel intensity and movements in a specific area over a period of one year (for this study). AIS data can be utilized for multiple years and even specific seasons depending on the objective of the study. For the Prince Rupert Port anaylsis, AIS data for the 2018 calendar year (**Figure C-3**) was provided by Alaska Marine Exchange to the Port.

As per the Navigation Safety Regulations (SOR/2005-134) fishing vessels are not required to carry AIS. A reasonable attempt was made to model fishing vessels without AIS based on historical fish catch data (BCMCA, 2008) and on a traffic study completed by the PRPA for Porpoise Harbour (PRPA, 2014).

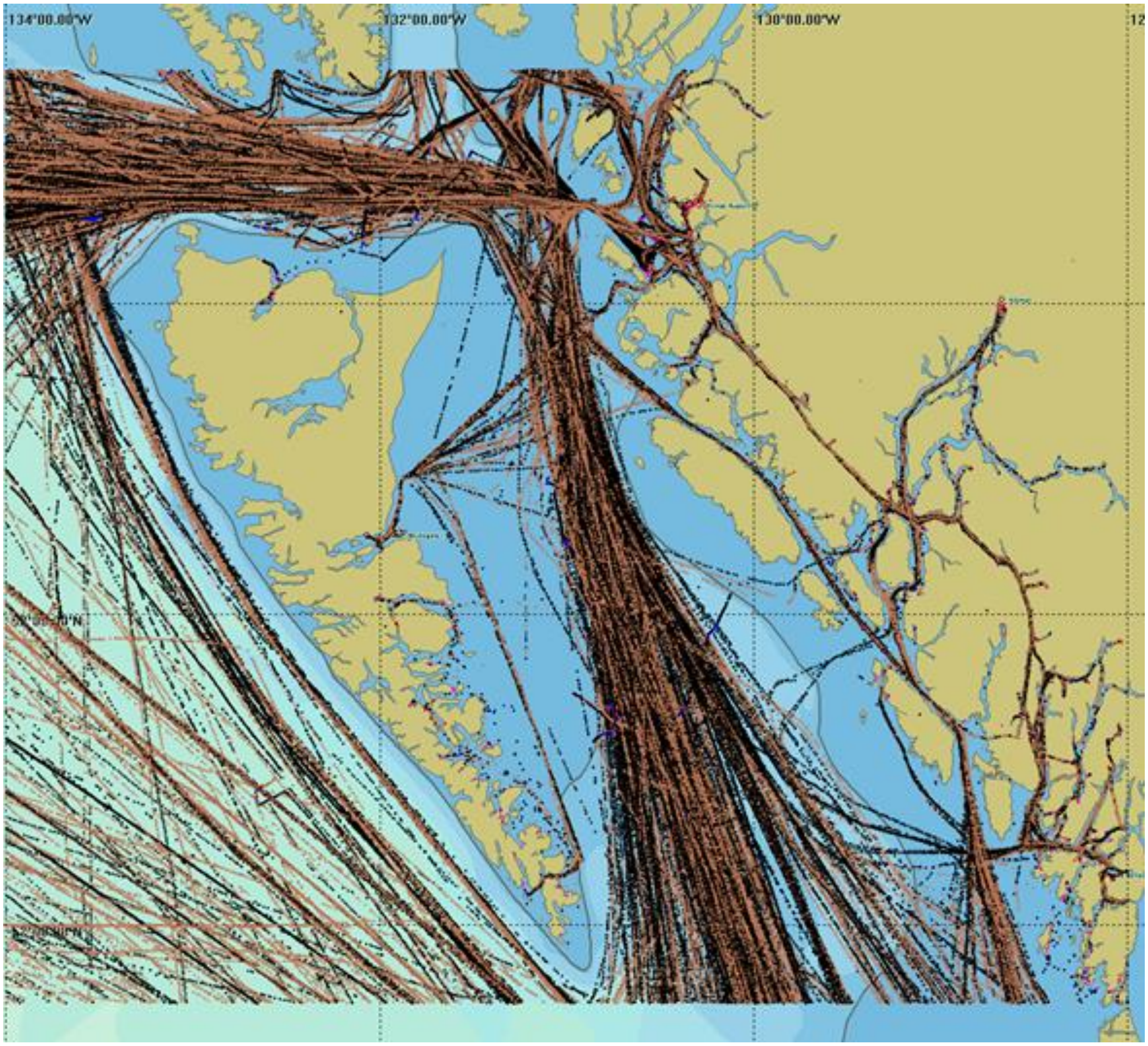

Figure C-3: AIS Signals for 2018, Plotted at 10 Minute Intervals within the Study Area

To model the movement of traffic in a study area, utilizing AIS data, the Model categorizes marine traffic into two categories, Route Bound Traffic and Non-Route Bound Traffic, as described below.

- Route Bound Traffic: generally shipping traffic that travels from point A to point B.
    - Commercial
- Non-Route Bound Traffic: Traffic that travels from point A and comes back to point A
    - Fishing
    - Recreational

The Model's traffic database consists of a network of nodes and links that describe the Route Bound Traffic and a density that describes the Non-Route Bound traffic. There were 36 ship types distinguished in the Route Bound Traffic and six ship types for Non-Route Bound, discussed in **Section 1.1.5**.

1.1.1.1 Route Bound Traffic – Current Scenario

The Route Bound traffic database was constructed using 2018 AIS data supplied by Alaska Marine Exchange and combined with information from a ship characteristics database. The Maritime Mobile Service Identify (MMSI) numbers, which are the unique identifiers in the AIS data, are connected to a Lloyd's Marine Intelligence Unit (LMIU) number, the unique identifier in the ship characteristics database. This database only contains seagoing ships >100 GT. The Route Bound Traffic database in SAMSON consists of 36 ship types. In this Study Area, it was decided to not include fishing vessels, work vessels (e.g., tugs, pilot vessels), and supply vessels in the Route Bound traffic, as these do not act as Route Bound traffic in the Study Area and were instead included in the Non-Route Bound database.

Most of the route-bound ships sail on a large network of links, comparable to a road network on land. This is a result of the location of various ports and Traffic Separation Schemes (TSS) in a specific area. It is assumed that ships sail along the shortest possible navigational route to reach their destination. Moreover, ships have to comply with the rules and regulations that are in place in a specific area. The shipping intensity on the different links is determined based on AIS data. The traffic database contains waypoints and links connecting these waypoints. On each link, the traffic (in number of movements per year) is known for each of the 36 route-bound ship types and eight ship size classes.

Based on the traffic flows that can be seen in **Figure C-4**, a network was defined. The AIS data for the Route Bound traffic within the Study Area was automatically assigned to the network illustrated in **Figure C-5. Figure C-6** provides a closer view of the traffic network near the Port. The black numbers on these figures represent the number of ships per year one direction.

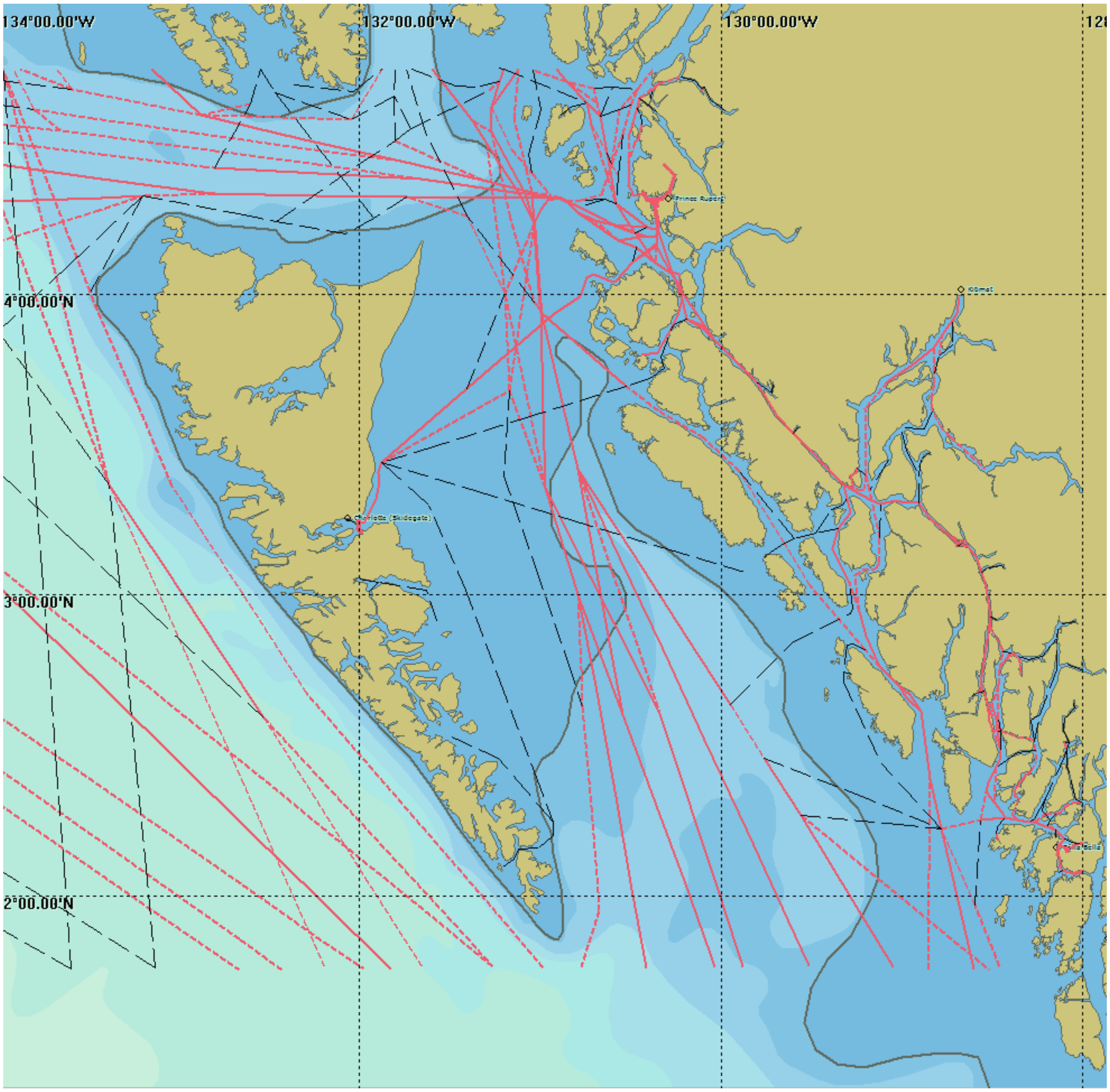

Figure C-4: Traffic Network Based off AIS Signals for 2018

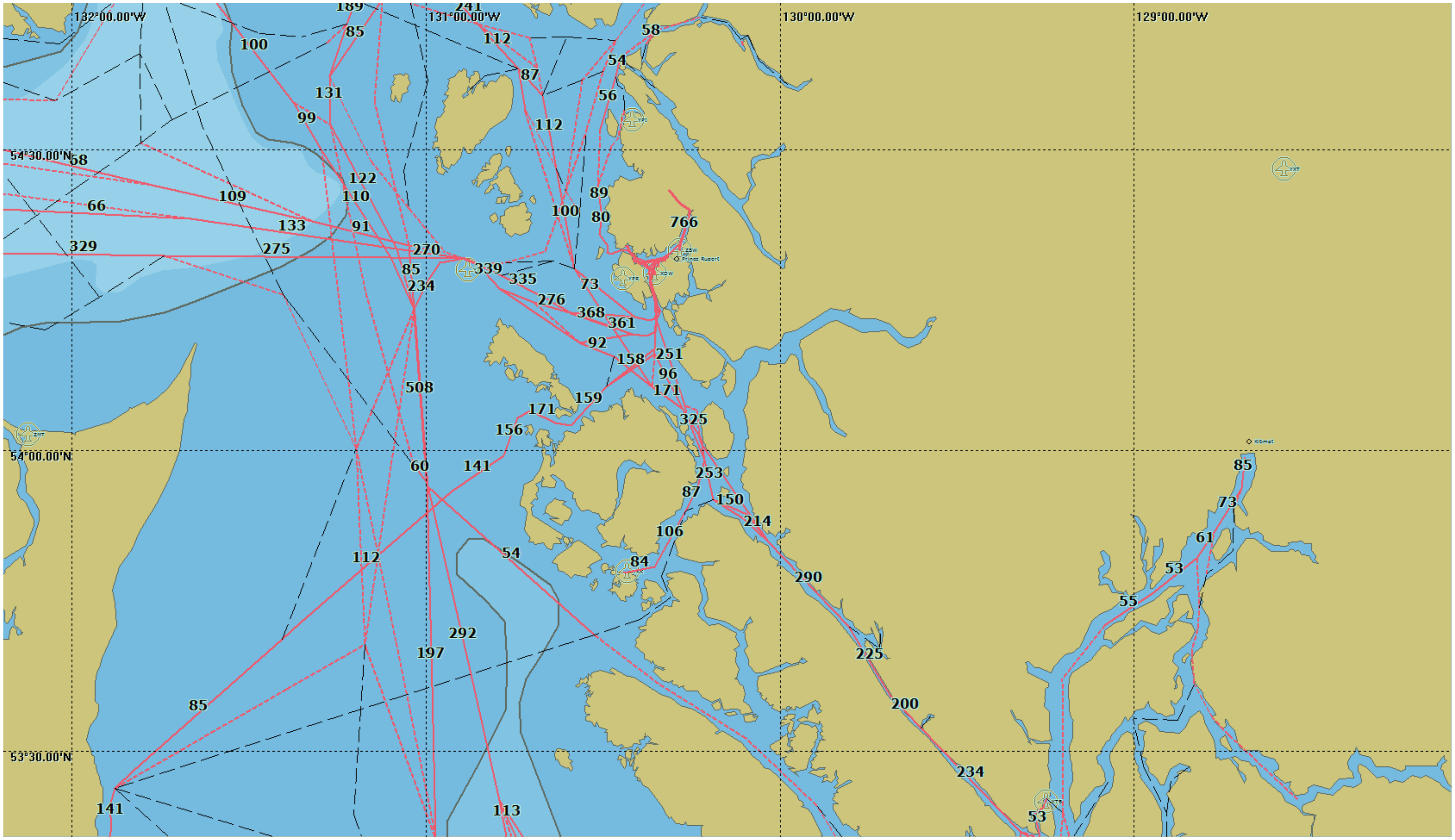

Figure C-5: Route Bound Traffic Database Created Based on 2018 AIS Data with Traffic Intensity

Note: numbers represent number of vessels on route in one direction.

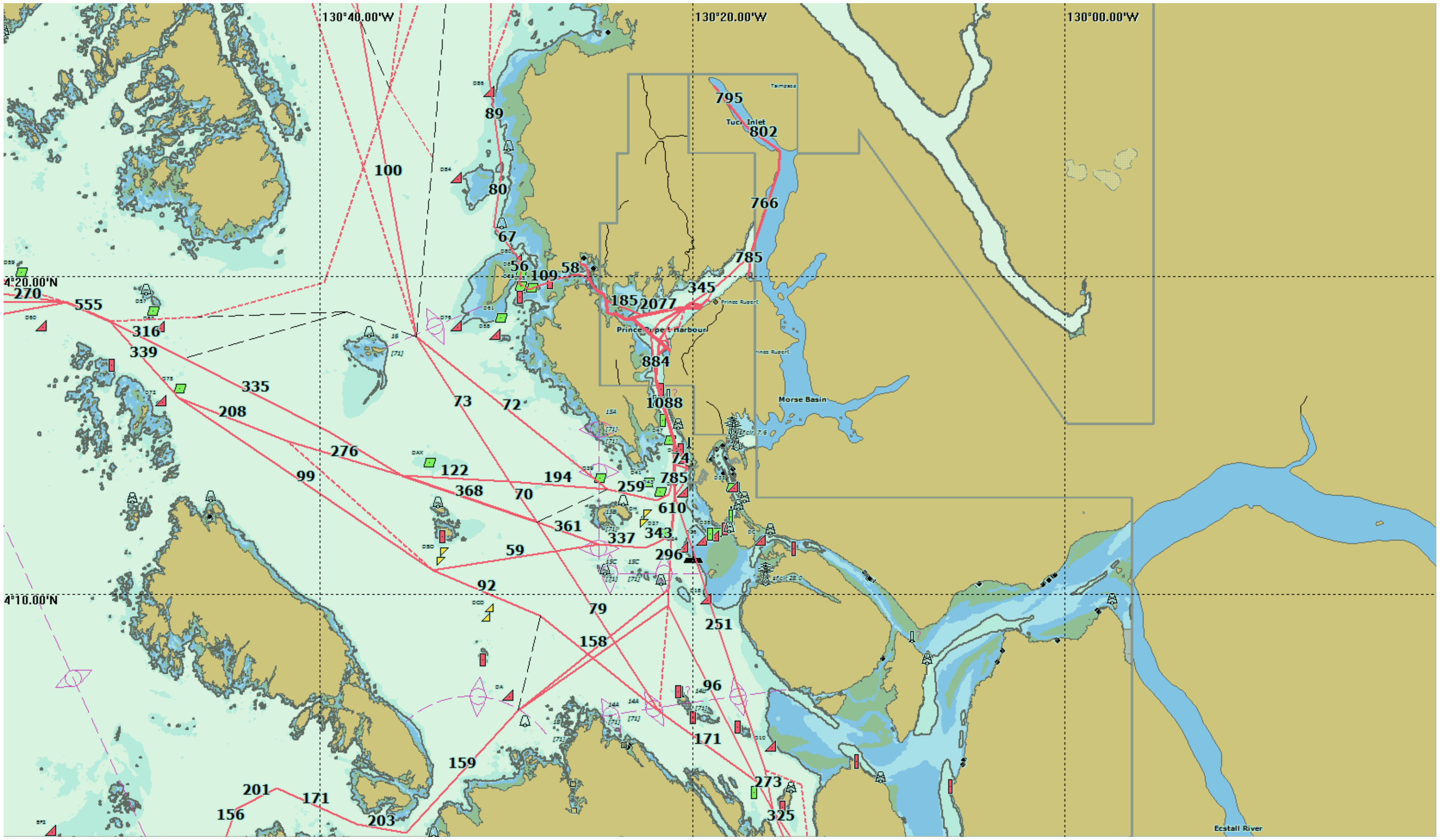

Figure C-6: Overview of the traffic network near the Port

Note: numbers represent number of vessels on route in one direction.

1.1.1.2 Route Bound Traffic - 2030 Scenario

As previously noted, the SAMSON Model also offers flexibility within its parameters, as such it can be used to model potential scenarios. This can help determine impacts of future traffic on navigation safety by including ghost ships into the traffic databases. Based on data received from the port authorities additional traffic was added, for select existing and potential new terminals. **Figure C-7** shows the final traffic database for 2030 near the Port. The additional traffic and terminals included is outlined below.

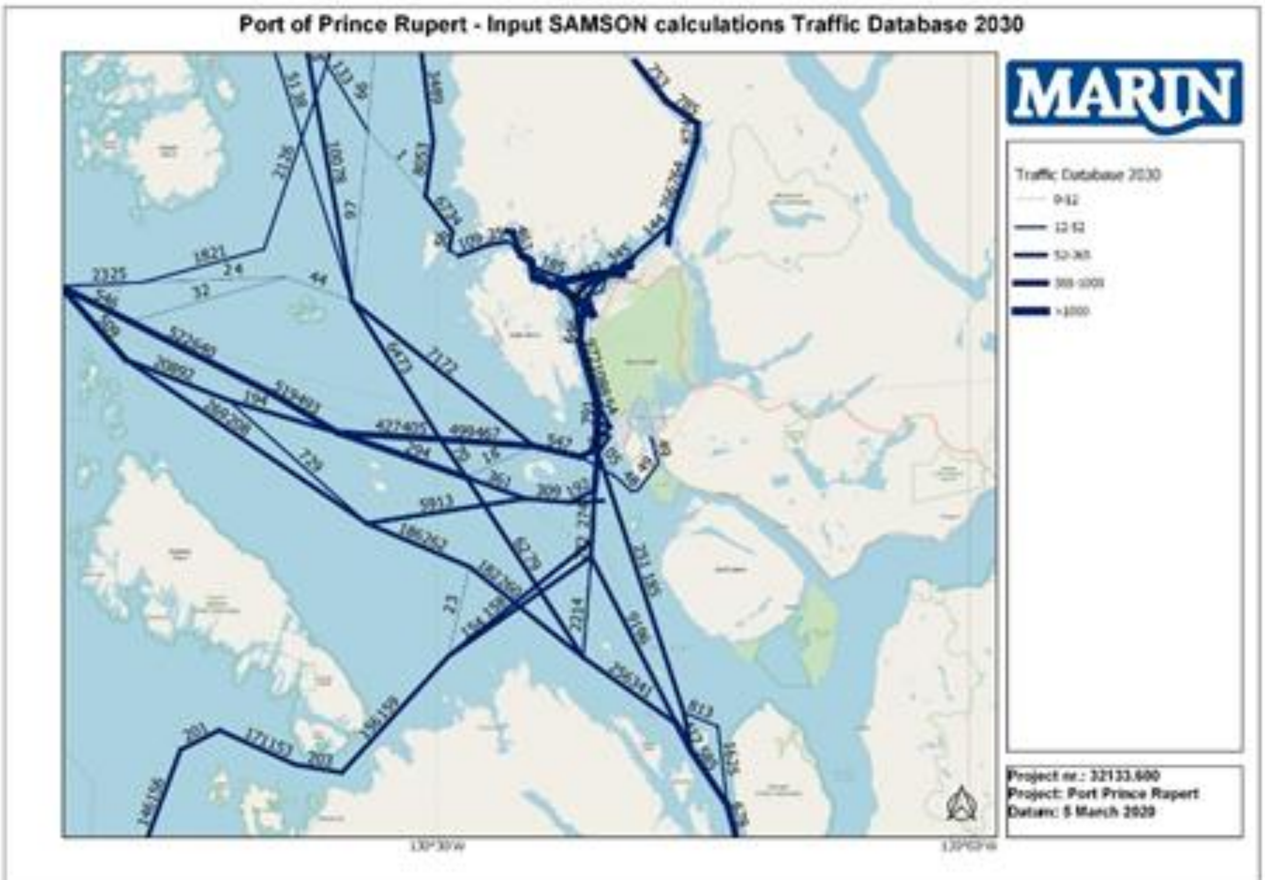

Figure C-7: Traffic Network for 2030 Scenario

Note: numbers represent number of vessels on route in one direction.

Pembina Traffic:

- Anticipated 10 vessels a year commencing 2020[1].
- Assumed to progress to 48 vessels per year.
- Predicted vessel type is 170m LPG flat top carriers.

Alta Gas Traffic:

- Port proposes 27 vessels a year.
- Vessel type is Aframax (250m / 120,000 DWT).

VOPAK Traffic

- Port suggests
- 27 vessels a year LPG. Panamax size tankers (230m / 80,000 DWT)
- 55 vessels a year Clean petroleum products (up to 230m)
- 146 vessels a year for methanol (up to 230m)

Future Container Terminal:

- Assumption: Same size of berth as the current DP World terminal.
- Assumption: 2 400m container ships per year towards the end of the forecasting.

Kitimat Traffic:

- LNG traffic from LNG Canada. 170 vessels a year in Phase 1 (2023 start), but up to 350 vessels per year by 2030. (+290 m LOA 140,000m3 - 170,000m^3 capacity). **Figure C-8** illustrates the proposed route for the LNG Canada project traffic.

[1] The model input the traffic commencing in 2021 since the traffic in 2020 was only expected to start later in the year.

Figure C-8: Proposed Traffic Route for LNG Canada Traffic

1.1.1.3 Non-Route Bound Traffic

The Non-Route Bound traffic database was constructed from three datasets:

- The first dataset was created by assigning any Route Bound traffic that could not be assigned to a network to a density.
    - This includes ships that are for example waiting and sailing around.
- The second dataset was created by assigning the typical vessels found in the Non-Route Bound database.
    - Such as vessels that have a mission at sea like fishing vessels, supply vessels, escort tugs and other vessels that do not follow a defined network.
- The third dataset was created by assigning the unknown AIS signals to the Non-Route Bound database.
    - Unknown AIS signals are AIS signals from vessels where there is no information on the type, size or mission of the vessel. It is assumed that unknown ships are all small vessels.

Using the AIS signals of these three datasets, the Non-Route Bound database is created and assigns a vessel density to each grid (2x2nm) of the Study Area that is then subsequently used to calculate the probability of an accident. The Non-Route Bound traffic database for fishing vessels is shown on **Figure C-9** and the Non-Route Bound traffic database for work vessels is presented in **Figure C-10.**

A Non-Route Bound future scenario (2030) could not be modeled due to a lack of available information that could be provided on the potential growth of these vessel movements.

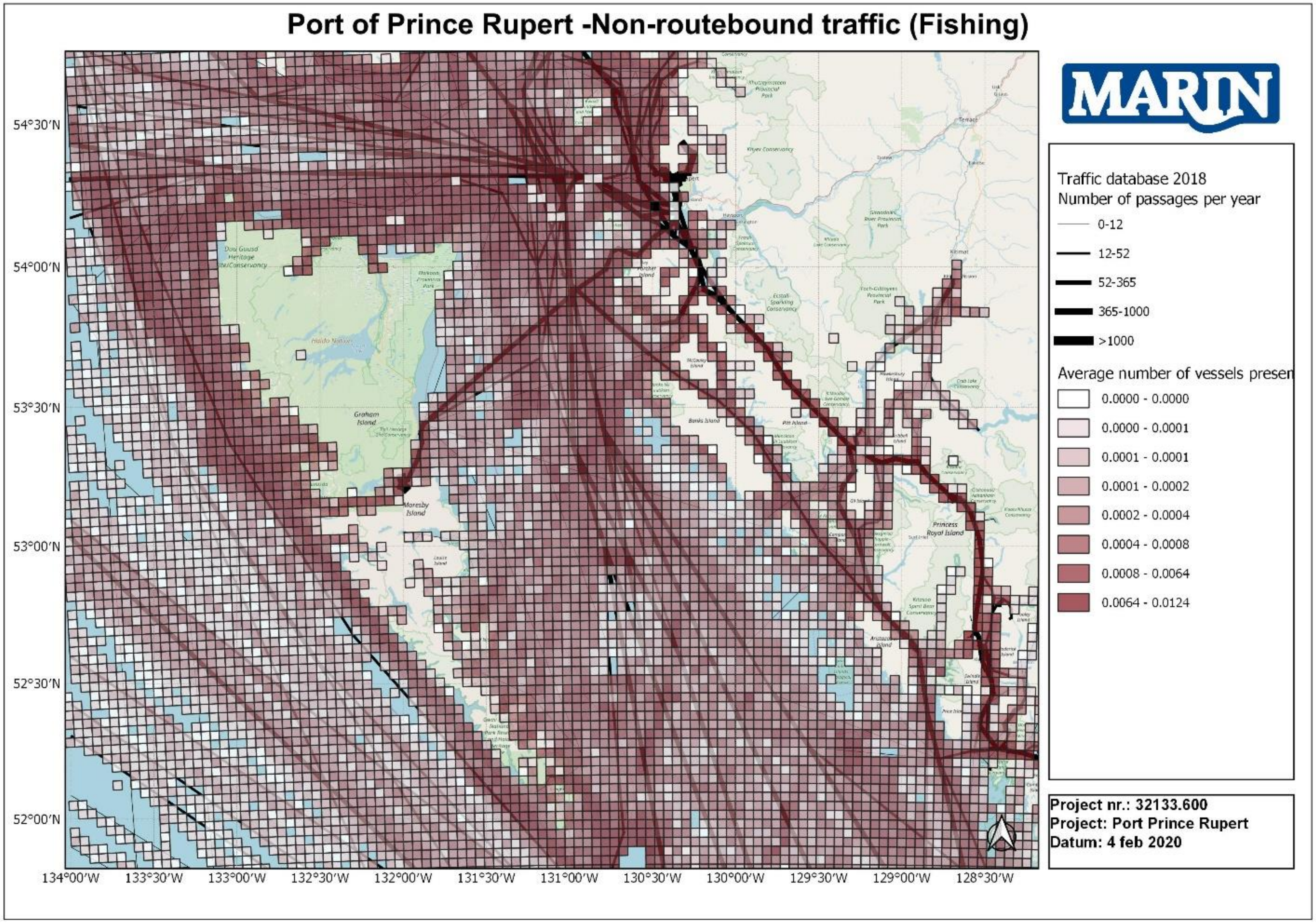

Figure C-9: Non-Route Bound Fishing Traffic Database

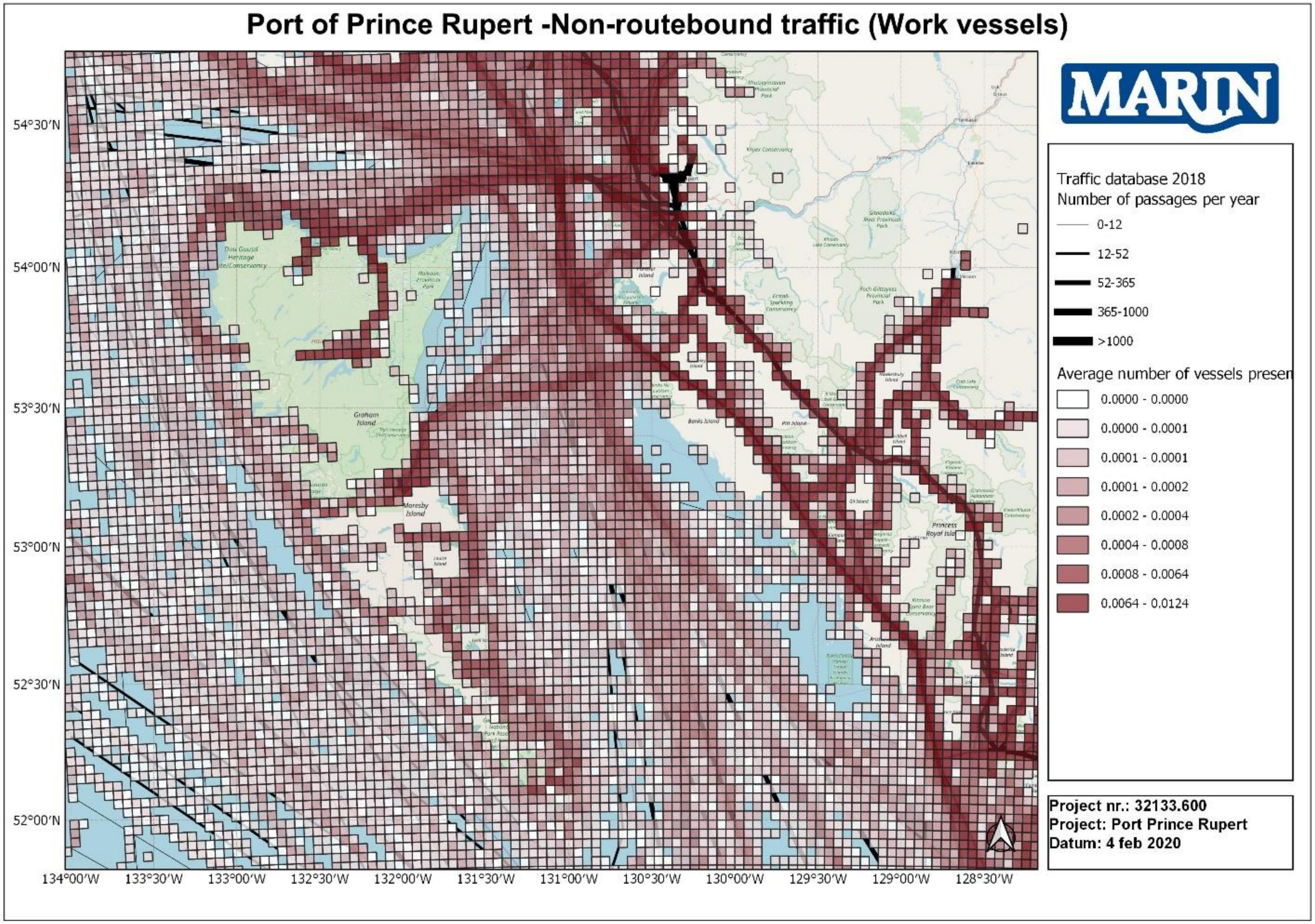

Figure C-10: Non-Route Bound Work Vessel Traffic Database

1.1.2 Input Data

The SAMON model requires local data to be input into the model to accurately predict the likelihood of incidents. The environmental conditions, such as wind and current, are an important input for some of the models of SAMSON. For example, in the case of an engine failure the ship starts drifting. The drifting speed and the trajectory depend on the prevailing current and wind. Therefore these factors play an important role in the calculation of the grounding frequencies. Wind force has an impact on the probability that a ship founders or has an engine failure. These probabilities are larger in storm conditions. Bathymetry data is also important in order to determine the depth and the likelihood of ships running aground depending on the draught of each ship.

1.1.2.1 Stranding Lines

The SAMSON Model calculates the expected frequency of a wreck or stranding accident. To do this, the Model will assign what is called "stranding lines" using nautical charts and/or bathymetry data. These lines represent the location in the Study Area where a ship has the potential of a wreck or stranding due to the physical characteristics of the area (i.e., depth of water) and vessel characteristics (i.e., vessel draught). It is possible to define different stranding lines for ships with a draught of 5 m, 10 m and 20 m. It was determined that, within the Study Area, these lines are close to each other; therefore, only one stranding line is used in the calculations (**Figure C-11**).

The number of wrecked/stranded accidents is calculated for each stranding line. In the output, the accidents are assigned to the grid cell in which the centre of the stranding line is located.

Figure C-11: Location of Stranding Lines

1.1.2.2 Currents and Wind

Tetra Tech provided detailed wind and current data from which the suitable data could be generated as input for SAMSON. Data from 21 geographical positions was requested to feed into the SAMSON model. Tetra Tech provided the current data for each point containing an hourly registration of the current size and direction from January to December 2015. The required tidal current is modelled as a sinusoidal current with a spring and a neap top derived from these datasets. Tetra Tech's 3-D hydrodynamic model was used to hindcast 3D ocean currents throughout the study area for the selected year. In addition, current roses were developed for each data point and provided detailed information for the modelling of the traffic.

Tetra Tech provided the wind data for each point containing an hourly registration of the wind force and direction from January to December 2015. The average wind compass in the points was used as the input for the SAMSON Model. A wind rose was developed for each datapoint to provide detailed information for the model.

See **Appendix A** for more information on environmental data models.

1.1.3 Preventive Barriers

The SAMSON Model also incorporates different barriers (preventative measures) within its model. Preventive barriers include the navigational aids and measures that assist in reducing the frequency of an accident. Some of these barriers are integrated as a part of the model and run for every simulation (such as anchorage areas and navigational aids) while others can be adjusted and removed (such as pilotage and tugs). This allows for the impact of preventative measures to be evaluated.

Since the results of the SAMSON Model identify specific locations within an area that have a higher probability for an accident to occur, this can allows for the adjustment of response plans for these areas. The SAMSON model can run multiple simulations to incorporate adjustments to or to add additional preventative measures to highlight which measures could reduce the frequency of an accident from occurring. For example prior to moving a pilot station or adding a Traffic Separation Scheme, the SAMSON Model could be run to determine the effect these measures have on traffic and the risk of a marine accident so that a port can determine which measures to implement or alter.

Table C-1 provides an overview of the preventative barriers which are built into SAMSON, adjustable, and excluded. Several preventative barriers are also included indirectly in the SAMSON Model and not as separate parameters or factors; those include barriers such as: ice regime and ice breakers, approach and mooring procedures, and electronic navigation (ENAV). Descriptions of each preventative barrier and how they apply to the Prince Rupert Study Area is outlined below. The information on these measures is provided by Electronic Nautical Charts (ENC), which are obtained from the Canadian Hydrographic Service.

Table C-1: Preventative Barriers for SAMSON Model

Built into the Model	Adjustable Elements	Not in the Model
Admission Policy	Pilotage	Dynamic Positioning System
AIS & Electronic Chart Display and Information System (ECDIS)	Traffic Separation Schemes	Fire Fighting Tug
Aids to Navigation	Vessel Traffic Management System (VTMS)	Safe Haven of Refuge
Anchoring Areas	Tugs (Tethered and Escort)	Emergency Anchorage
Marine Safety Info.		Emergency Tow Vessel
Waterways Management		
Safety Distances		

Built into the Model

These barriers are built into the SAMSON Model by only using accident statistics that have these barriers included.

Adjustable Elements

The four barriers are defined below.

Pilotage Areas

The location of mandatory pilotage areas was obtained from the ENC charts, Annual Notice to Mariners (CCG, 2019), Port Information Books, Sailing Directions and local port authorities. The zones in each area that require pilots, including where the pilots embark and disembark are used in the SAMSON Model calculations. The effect pilots have on reducing the risk of an accident occurring is presented in **Table C-2.**

Traffic Separation Schemes (TSS)

The location of TSS was obtained from the ENC Charts. In areas where TSS are in place they act to reduce the number of encounters which reduces the number of accidents as traffic is separated laterally from each other. The SAMSON Model assigns a 0 percent reduction to TSS as it is assumed that the number of encounters has already been reduced given that TSS is already in effect. There were no TSS applied within this Study Area

Vessel Traffic Management System (VTMS) Areas

The location of VTMS areas was obtained from the ENC Charts, Annual Notice to Mariners (CCG, 2019) and Sailing Directions. In areas where there is VTMS, vessel movements are being monitored and navigational safety information is provided. VTMS is used in the SAMSON Model calculations and the percentage effect it has on reducing the risk on an accident is presented in **Table C-2**. The entire Study Area is contained within a by VTMS zone.

Tugs

In some areas it could be mandatory to have escort and tethered tugs. The locations where escort and tethered tugs are required was obtained during the HAZID workshop. In addition to the locational requirement, the number and positioning of the tugs is obtained as well as the size and types of vessels that require tugs. Modelling of tugs in the SAMSON Model calculations is dependent on area characteristics. The percentage effect that both escort and tethered tugs have on reducing the risk of an accident is presented in **Table C-2**.

Table C-2: Reduction Percentages for Adjustable Elements

Element	Accident Type					
	Allision/Contact (Drift/Ramming)		Collision	Stranding		Other*
	Drift	Ramming	Ramming	Drift	Ramming	
Pilotage	0%	62%	62%	0%	62%	0%
TSS	Reduces the number of encounters so therefore reduces the number of accidents					
VTMS	0%	0%	30%	0%	0%	0%
Tugs-Escort	90%	0%	0%	90%	0%	0%
Tugs-Tethered	99%	50%	0%	99%	50%	0%

*Other accidents include Fire/Explosion, Foundering, and Hull Failure.

Not in the Model

Four preventative barriers were are not included in the SAMSON model runs completed for this study. These were previously identified in **Table C-1** and are as follows:

- Dynamic Positioning System – Can be included in the SAMSON Model as a preventative barrier if vessels use the system during loading/unloading. At the time of the study there was no known use of Dynamic Positioning Systems by vessels within the Study Area;
- Fire Fighting Tugs – Can be included in the SAMSON Model to look at the reduction in damage to a vessel from fire with a fire fighting tug present;
- Safe Haven of Refuge – Can be included in the SAMSON Model but not included in the study, as there are currently no designated places of refuge in the study area; and
- Emergency Anchorage – Designated emergency anchorage locations can be included in the SAMSON Model if these have been designated and an emergency anchorage procedure has been developed. However, the emergency anchorages in the study area are not recommended for use

There was no change in the preventative barriers for the future modelling in the Study Area.

1.1.4 Accident Statistics

The final step in calculating the frequency of accidents, is multiplying the calculated potentially dangerous situations, with the accident rate corresponding to the type of potentially dangerous situation (i.e., historically how often will a collision occur in a similar scenario). An accident rate defines the frequency of a potential dangerous situation leading to an actual accident. The accident rates are based on the worldwide data from the International IHS Fairplay Collision database, collected between 1990 and 2015. The international statistics obtained from the IHS Fairplay Database are filtered to include maritime countries in the North Sea with similar regimes to Canada. The countries selected were Germany, France, Netherlands, Norway, and United Kingdom.

1.1.4.1 Calculating Accident Frequency

The frequency of accidents is calculated on the basis of exposures for the different type of accidents as presented in **Table C-3**. Exposures can be described as "*possible dangerous situations that could lead to an accident*".

Table C-3: Relationship between Accident Type and Exposure

Accident Type	Exposure
Collision	Encounters
Allision	Stranding Opportunity
Wreck/Stranding	Stranding Opportunity (powered) and Danger miles (unpowered)
Foundering	Foundering rate per Nautical Miles (ship miles)
Fire/Explosion	Fire/Explosions rate per Nautical Miles (ship miles)
Hull/Machinery Failure	Hull/Machinery Failure rate per Nautical Miles (ship miles)

The exposure for a collision between two ships is an encounter. Ships can only collide when they are within a certain range of each other. An encounter occurs when a ship enters the domain of another ship. This domain is defined as a circle with a radius of 0.125 nm around a ship. Only a small part of all encounters will actually result in a collision. The casualty rate, the relation between the number of exposures and the number of accidents, depends on the type and size of the ship.

The two main causes for the accident types, allisions and wrecks/stranding, are navigational error and technical failure, which causes the ship to be uncontrollable. The exposure measure for an allision or wreck/stranding caused by a navigational error is called the stranding opportunity. An allision or wreck/stranding caused by a navigational error can only occur when the ship is located close enough to the stranding line or fixed object. Only then, can a navigational error be critical. The stranding opportunity is based on the location, sailing direction, speed and length of the ship and the location of the stranding line or fixed object. The stranding lines and fixed objects within a study area are obtained from nautical charts within the study area and include depth contour lines where a vessel would ground as well as fixed navigational hazards (e.g., submerged rocks, shoals and other hazards). An allision and wreck/stranding caused by a technical failure will only take place when the failure occurs near the stranding line or fixed object and when the ship drifts in the direction of the stranding line or object. In addition, the repair time and the probability of successful anchoring are important factors. The exposure for this type of accident is called "danger mile[2]".

The frequencies of foundering, fire/explosion and hull/machinery failure are determined using the international statistics. Using the international statistics for these failures within the North Sea as well as historical AIS data a frequency rate for foundering, fire/explosion and hull/machinery failure was determined on a per nautical mile sailed basis. These rates are used within the SAMSON Model to determine the frequency of a vessel foundering, having a fire/explosion aboard and having a hull/machinery failure.

1.1.5 Ship Classes

In order to adequately represent the various ships within a study area, the SAMSON Model distinguishes 42 different ship classes, divided between two main groups of ships: Route-Bound ships and Non-Route Bound ships (see **Table C-4** and **Table C-5**). Each of the 42 ship classes are further divided into eight size classes ranging from 100 tonnes to 100,000 tonnes. While also considering the multiple ship types obtained from the Lloyd's registry, this results in over 3,000 different ships being modelled in the SAMSON Model. This large number of classes is required for subsequent calculations, such as for the calculation of the kinetic energy when a ship strikes another vessel or runs aground. The outcome of the accident will depend on a number of factors including the ship's characteristics and the kinetic energy.

Table C-4: Ship Types (Classes) for Route-bound Traffic

No.	Ship Type	No.	Ship Type
1	Oil / Bulk / Combination Tanker	19	LNG
2	Oil/ Bulk/ Ore Combination Tanker DH	20	LPG Refrigerated
3	Chemical Tanker IMO 1	21	LPG Semi Pressured
4	Chemical Tanker IMO 1 DH	22	LPG Pressured
5	Chemical Tanker IMO 2	23	LPG Remaining
6	Chemical Tanker IMO 2 DH	24	Bulkers
7	Chemical Tanker IMO 3	25	Unitized Container
8	Chemical Tanker IMO 3 DH	26	Unitized RoRo
9	Chemical Tanker	27	Unitized Vehicle
10	Chemical Tanker DH	28	General Dry Cargo
11	Chemical Tanker Water/Wine/Replenishment	29	General Dry Cargo with Containers

[2] Definition of "Danger Mile" - The total distance of the main traffic routes on which a contact with an object occurs due to navigation error or engine failure.

No.	Ship Type	No.	Ship Type
12	Chemical Tanker Water/Wine/Replenishment DH	30	General Dry Cargo Reefer
13	Oil Tanker, Crude Oil	31	Passenger
14	Oil Tanker, Crude Oil DH	32	Passenger RoRo
15	Oil Product Tanker	33	Ferries
16	Oil Product Tanker DH	34	High Speed Ferries
17	Oil Remaining	35	Miscellaneous
18	Oil Remaining DH	36	Tugs

Notes: IMO – International Maritime Organization number
LNG – Liquefied Natural Gas carrier
LPG – Liquefied Petroleum Gas carrier

Table C-5: Ship Types (Classes) for Non-Route Bound Traffic

No.	Ship Type	No.	Ship Type
1	Work Vessels	4	Chemical Tanker
2	All route-bound ships outside route network, excluding oil and chemical tankers	5	Oil Tanker
3	Fishing from/to	6	Recreation

2.0 SAMSON Model Outputs

The modelling and calculation processes of the SAMSON Model generate several outputs, which are presented in table format and/or visually in maps.

2.1 Marine Traffic Output

The output of the marine traffic model is best presented on maps, showing the main transport routes of oil in a specific area and providing information on the volumes of oil carried by ships in a specific area. An example of the AIS signals for the Port Prince Rupert Area for 2018, with a time interval of ten minutes, is shown in **Figure C-12**.

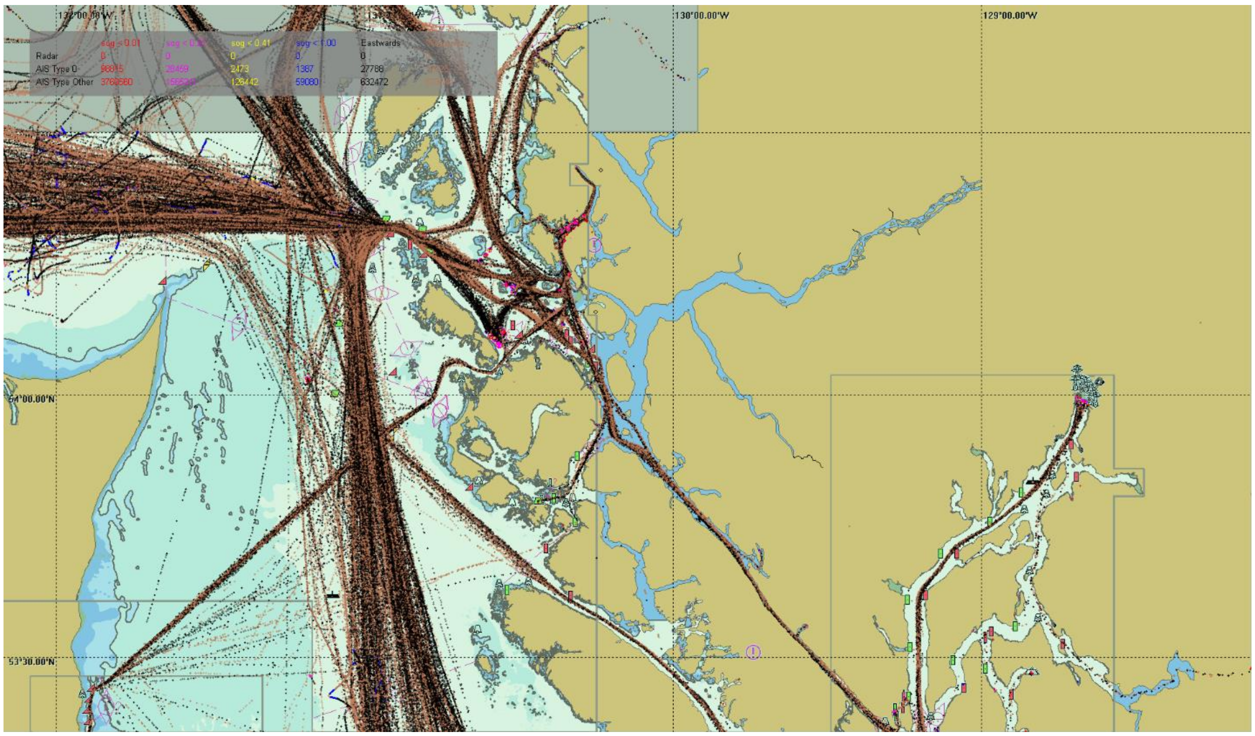

Figure C-12: Port Price Rupert Area AIS Signals Route-bound Traffic for 2018

2.2 Frequency of Accidents

The calculations of the accident frequency results are the main output of the SAMSON Model. The outputs of the frequency calculations are used to determine the frequency of an accident in a specific grid cell or location. The results can be visualized for grid cells on a map of a specific area.

For each grid cell the following information is provided as an output of the SAMSON Model:

- Latitude (or grid number in northern direction);
- Longitude (or grid number in eastern direction;
- Ship Type;

- Ship Size Class j; and
- Accident Type a.

Detailed results of the SAMSON Model can be seen in **Appendix D**.

3.0 Bibliography

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Appendix D

Marine Navigational Risk Assessment Detailed Results

DILLON CONSULTING

Additional MNRA Grounding Results

Table D-1: Groundings by commercial ship type – 2018 – Sub area

Main Ship type	2018 - Sub area										
	Ramming frequency				Drifting frequency				Total		
	draft <5 m	draft 5-10m	draft >10m	Total	draft <5 m	draft 5-10m	draft >10m	Total	Freq per year	Once every ... year	%
GDC - Bulker	0.0002	0.0356	0.0015	0.0372	0.0001	0.0034	0.0001	0.0036	0.0409	24	4.1%
Container	0.0000	0.0147	0.0290	0.0437	0.0000	0.0005	0.0007	0.0012	0.0449	22	4.5%
Tanker - chemical	0.0000	0.0003	0.0000	0.0003	0.0000	0.0001	0.0000	0.0001	0.0004	2720	0.0%
Tanker - oil	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	14664	0.0%
LNG-LPG	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0.0%
Pass -Ferry-Roro	0.1040	0.0215	0.0000	0.1255	0.0202	0.0028	0.0000	0.0230	0.1486	7	15.0%
SubTotal	**0.1042**	**0.0721**	**0.0305**	**0.2068**	**0.0204**	**0.0067**	**0.0009**	**0.0280**	**0.2348**	**4**	23.7%
Fishing	0.0677	0.0000	0.0000	0.0677	0.0067	0.0000	0.0000	0.0067	0.0745	13	7.5%
Uncategorized	0.6051	0.0000	0.0000	0.6051	0.0746	0.0000	0.0000	0.0746	0.6797	1	68.7%
SubTotal	**0.6728**	**0.0000**	**0.0000**	**0.6728**	**0.0813**	**0.0000**	**0.0000**	**0.0813**	**0.7542**	**1.3**	76.3%
Total	**0.7770**	**0.0721**	**0.0305**	**0.8796**	**0.1017**	**0.0067**	**0.0009**	**0.1093**	**0.9889**	**1.0**	100.0%

Table D-2: Groundings by commercial ship type – 2030 – 170 LNG vessels from Kitimat area – Sub area

Main Ship type	2030 - 170LNG - Sub area										
	Ramming frequency				Drifting frequency				Total		
	draft <5 m	draft 5-10m	draft >10m	Total	draft <5 m	draft 5-10m	draft >10m	Total	Freq per year	Once every ... year	%
GDC - Bulker	0.0002	0.0364	0.0016	0.0381	0.0001	0.0034	0.0001	0.0036	0.0417	24	4.1%
Container	0.0000	0.0151	0.0300	0.0451	0.0000	0.0005	0.0007	0.0012	0.0463	22	4.6%
Tanker - chemical	0.0000	0.0071	0.0000	0.0071	0.0000	0.0020	0.0000	0.0020	0.0090	111	0.9%
Tanker - oil	0.0000	0.0025	0.0000	0.0025	0.0000	0.0008	0.0000	0.0008	0.0033	307	0.3%
LNG-LPG	0.0000	0.0052	0.0000	0.0052	0.0000	0.0013	0.0000	0.0013	0.0065	154	0.6%
Pass -Ferry-Roro	0.1033	0.0217	0.0000	0.1250	0.0194	0.0028	0.0000	0.0223	0.1473	7	14.6%
SubTotal	**0.1034**	**0.0880**	**0.0315**	**0.2230**	**0.0196**	**0.0107**	**0.0009**	**0.0312**	**0.2542**	**3.9**	**25.2%**
Fishing	0.0677	0.0000	0.0000	0.0677	0.0067	0.0000	0.0000	0.0067	0.0745	13	7.4%
Uncategorized	0.6051	0.0000	0.0000	0.6051	0.0746	0.0000	0.0000	0.0746	0.6797	1	67.4%
SubTotal	**0.6728**	**0.0000**	**0.0000**	**0.6728**	**0.0813**	**0.0000**	**0.0000**	**0.0813**	**0.7542**	**1.3**	**74.8%**
Total	**0.7763**	**0.0880**	**0.0315**	**0.8958**	**0.1009**	**0.0107**	**0.0009**	**0.1125**	**1.0083**	**1.0**	**100.0%**

Table D-3: Groundings by commercial ship type – 2030 – 350 LNG from Kitimat – Sub area

Main Ship type	2030 - 350LNG – Sub area										
	Ramming frequency				Drifting frequency				Total		
	draft <5 m	draft 5-10m	draft >10m	Total	draft <5 m	draft 5-10m	draft >10m	Total	Freq per year	Once every ... year	%
GDC - Bulker	0.0002	0.0364	0.0016	0.0381	0.0001	0.0034	0.0001	0.0036	0.0417	24	4.1%
Container	0.0000	0.0151	0.0300	0.0451	0.0000	0.0005	0.0007	0.0012	0.0463	22	4.6%
Tanker - chemical	0.0000	0.0071	0.0000	0.0071	0.0000	0.0020	0.0000	0.0020	0.0090	111	0.9%
Tanker - oil	0.0000	0.0025	0.0000	0.0025	0.0000	0.0008	0.0000	0.0008	0.0033	307	0.3%
LNG-LPG	0.0000	0.0052	0.0000	0.0052	0.0000	0.0014	0.0000	0.0014	0.0066	151	0.7%
Pass -Ferry-Roro	0.1033	0.0217	0.0000	0.1250	0.0194	0.0028	0.0000	0.0223	0.1473	7	14.6%
SubTotal	**0.1034**	**0.0880**	**0.0315**	**0.2230**	**0.0196**	**0.0108**	**0.0009**	**0.0313**	**0.2543**	**3.9**	**25.2%**
Fishing	0.0677	0.0000	0.0000	0.0677	0.0067	0.0000	0.0000	0.0067	0.0745	13	7.4%
Miscellaneous	0.6051	0.0000	0.0000	0.6051	0.0746	0.0000	0.0000	0.0746	0.6797	1	67.4%
SubTotal	**0.6728**	**0.0000**	**0.0000**	**0.6728**	**0.0813**	**0.0000**	**0.0000**	**0.0813**	**0.7542**	**1.3**	**74.8%**
Total	**0.7763**	**0.0880**	**0.0315**	**0.8958**	**0.1009**	**0.0108**	**0.0009**	**0.1127**	**1.0085**	**1.0**	**100.0%**

Table D-4: Groundings by commercial ship type – 2018 – Study area

Main Ship type	2018 - Study area										
	Ramming frequency				Drifting frequency				Total		
	draft <5 m	draft 5-10m	draft >10m	Total	draft <5 m	draft 5-10m	draft >10m	Total	Freq per year	Once every ... year	%
GDC - Bulker	0.0018	0.0591	0.0016	0.0625	0.0024	0.0100	0.0002	0.0126	0.0751	13	2.3%
Container	0.0016	0.0155	0.0309	0.0480	0.0021	0.0009	0.0012	0.0042	0.0522	19	1.6%
Tanker - chemical	0.0000	0.0018	0.0000	0.0018	0.0000	0.0005	0.0000	0.0005	0.0023	432	0.1%
Tanker - oil	0.0000	0.0001	0.0000	0.0001	0.0000	0.0000	0.0000	0.0000	0.0001	12562	0.0%
LNG-LPG	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0	0.0%
Pass -Ferry-Roro	0.1195	0.0949	0.0002	0.2145	0.0376	0.0182	0.0006	0.0564	0.2710	4	8.4%
Fishing	0.2954	0.0000	0.0000	0.2954	0.0277	0.0000	0.0000	0.0277	0.3231	3	10.0%
Miscellaneous	2.2260	0.0000	0.0000	2.2260	0.2653	0.0000	0.0000	0.2653	2.4913	0.4	77.5%
SubTotal	**2.5214**	**0.0000**	**0.0000**	**2.5214**	**0.2929**	**0.0000**	**0.0000**	**0.2929**	**2.8143**	**0**	87.5%
Total	**2.6443**	**0.1713**	**0.0326**	**2.8482**	**0.3351**	**0.0296**	**0.0020**	**0.3667**	**3.2149**	**0**	100.0%

Table D-5: Groundings by commercial ship type – 2030 – 170 LNG from Kitimat – Study area

Main Ship type	2030 - 170LNG - Study area										
	Ramming frequency				Drifting frequency				Total		
	draft <5 m	draft 5-10m	draft >10m	Total	draft <5 m	draft 5-10m	draft >10m	Total	Freq per year	Once every ... year	%
GDC - Bulker	0.0020	0.0602	0.0017	0.0639	0.0024	0.0100	0.0002	0.0126	0.0765	13	2.2%
Container	0.0017	0.0160	0.0319	0.0496	0.0021	0.0009	0.0013	0.0042	0.0538	19	1.6%
Tanker - chemical	0.0000	0.0088	0.0000	0.0088	0.0000	0.0040	0.0000	0.0040	0.0129	78	0.4%
Tanker - oil	0.0000	0.0026	0.0000	0.0026	0.0000	0.0015	0.0000	0.0015	0.0041	244	0.1%
LNG-LPG	0.0000	0.1471	0.0000	0.1471	0.0000	0.0226	0.0000	0.0226	0.1698	6	5.0%
Pass -Ferry-Roro	0.1186	0.0967	0.0002	0.2155	0.0370	0.0185	0.0006	0.0561	0.2716	4	8.0%
Fishing	0.2954	0.0000	0.0000	0.2954	0.0277	0.0000	0.0000	0.0277	0.3231	3	9.5%
Miscellaneous	2.2260	0.0000	0.0000	2.2260	0.2653	0.0000	0.0000	0.2653	2.4913	0	73.2%
SubTotal	**2.5214**	**0.0000**	**0.0000**	**2.5214**	**0.2929**	**0.0000**	**0.0000**	**0.2929**	**2.8143**	**0**	**82.7%**
Total	**2.6437**	**0.3314**	**0.0338**	**3.0089**	**0.3345**	**0.0575**	**0.0021**	**0.3941**	**3.4030**	**0**	**100.0%**

Table D-6: Groundings by commercial ship type – 2030 – 350 LNG from Kitimat – Study area

Main Ship type	2030 - 350LNG - Study area										
	Ramming frequency				Drifting frequency				Total		
	draft <5 m	draft 5-10m	draft >10m	Total	draft <5 m	draft 5-10m	draft >10m	Total	Freq per year	Once every ... year	%
GDC - Bulker	0.0020	0.0602	0.0017	0.0639	0.0024	0.0100	0.0002	0.0126	0.0765	13	2.1%
Container	0.0017	0.0160	0.0319	0.0496	0.0021	0.0009	0.0013	0.0042	0.0538	19	1.5%
Tanker - chemical	0.0000	0.0088	0.0000	0.0088	0.0000	0.0040	0.0000	0.0040	0.0129	78	0.4%
Tanker - oil	0.0000	0.0026	0.0000	0.0026	0.0000	0.0015	0.0000	0.0015	0.0041	244	0.1%
LNG-LPG	0.0000	0.2972	0.0000	0.2972	0.0000	0.0445	0.0000	0.0445	0.3417	3	9.6%
Pass -Ferry-Roro	0.1186	0.0967	0.0002	0.2155	0.0370	0.0185	0.0006	0.0561	0.2716	4	7.6%
Fishing	0.2954	0.0000	0.0000	0.2954	0.0277	0.0000	0.0000	0.0277	0.3231	3	9.0%
Miscellaneous	2.2260	0.0000	0.0000	2.2260	0.2653	0.0000	0.0000	0.2653	2.4913	0.4	69.7%
SubTotal	**2.5214**	**0.0000**	**0.0000**	**2.5214**	**0.2929**	**0.0000**	**0.0000**	**0.2929**	**2.8143**	**0**	**78.7%**
Total	**2.6437**	**0.4815**	**0.0338**	**3.1590**	**0.3345**	**0.0793**	**0.0021**	**0.4159**	**3.5749**	**0**	**100.0%**

Additional MNRA Collision Results

Table D-7: Collision results – 2030 – 350 LNG from Kitimat

	With VTS and pilot						
	Study area				Sub area		
	2019	2030	% grow		2019	2030	% grow
Average number of route bound vessels present	4.01	5.78	44.09%		0.64	0.73	13.73%
Average number of non route bound vessels present	15.71	15.71	0.00%		2.74	2.74	0.00%
Total average number of vessels present	19.72	21.49	8.97%		3.38	3.47	2.60%
Total number of sailed nm in the area by route bound vessels	567651	823843	45.13%		83357	94371	13.21%
Total number of sailed nm in the area by non route bound vesse	1349236	1349236	0.00%		234261	234261	0.00%
Total number of sailed nm in the area	1916887	2173079	13.37%		317618	328632	3.47%

	With VTS and pilot						
	Expecten collision frequency per year						
	Study area				Sub area		
Collsion frequency per year	2019	2030	% grow		2019	2030	% grow
collision_route bound vessels	0.0086	0.0141	64.69%		0.0063	0.0071	13.07%
collision_route bound and non route bound vessels	0.0088	0.0116	31.61%		0.0067	0.0076	13.22%
collision_non route bound and route bound vessels	0.0115	0.0134	16.94%		0.0079	0.0084	6.32%
collision_non route bound vessels	0.0600	0.0600	0.00%		0.0250	0.0250	0.00%
Total	0.0888	0.0991	11.56%		0.0460	0.0482	4.82%

	Once every ... year						
	Study area				Sub area		
Collision one every ... year	2019	2030			2019	2030	
collision_route bound vessels	117	71			158	140	
collision_route bound and non route bound vessels	113	86			148	131	
collision_non route bound and route bound vessels	87	75			127	119	
collision_non route bound vessels	17	17			40	40	
Total	11	10			22	21	

Table D- 8: Collision results – 2030 – 170 LNG from Kitimat

	With VTS and pilot						
	Study area				Sub area		
	2019	2030	% grow		2019	2030	% grow
Average number of route bound vessels present	4.01	5.20	29.59%		0.64	0.73	13.73%
Average number of non route bound vessels preser	15.71	15.71	0.00%		2.74	2.74	0.00%
Total average number of vessels present	19.72	20.91	6.02%		3.38	3.47	2.60%
Total number of sailed nm in the area by route bour	567651	733103	29.15%		83357	94371	13.21%
Total number of sailed nm in the area by non route	1349236	1349236	0.00%		234261	234261	0.00%
Total number of sailed nm in the area	1916887	2082339	8.63%		317618	328632	3.47%

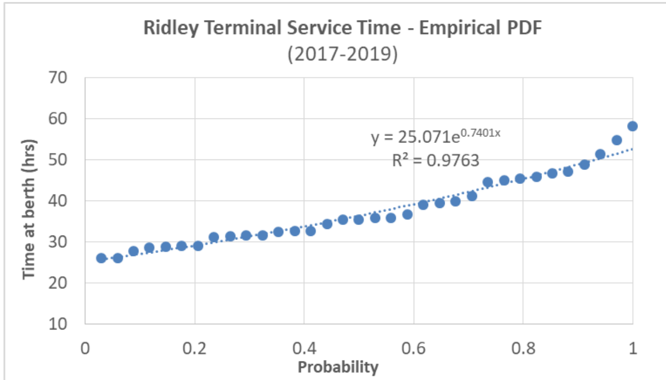
	With VTS and pilot						
	Expecten collision frequency per year						
	Study area				Sub area		
Collsion frequency per year	2019	2030	% grow		2019	2030	% grow
collision_route bound vessels	0.0086	0.0123	43.74%		0.0063	0.0071	13.07%
collision_route bound and non route bound vessels	0.0088	0.0109	23.70%		0.0067	0.0076	13.22%
collision_non route bound and route bound vessels	0.0115	0.0128	11.76%		0.0079	0.0084	6.32%
collision_non route bound vessels	0.0600	0.0600	0.00%		0.0250	0.0250	0.00%
Total	0.0888	0.0960	8.09%		0.0460	0.0482	4.82%

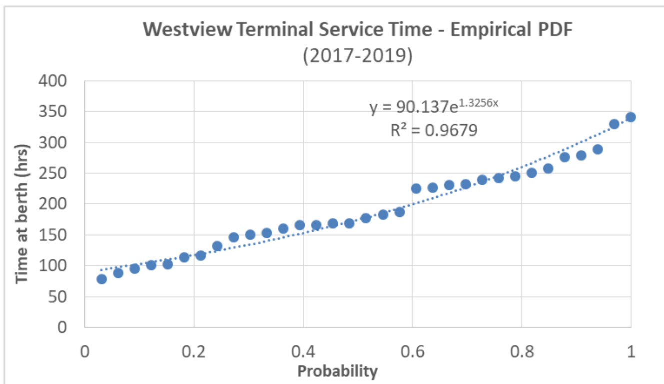
	Once every ... year						
	Study area				Sub area		
Collision one every ... year	2019	2030			2019	2030	
collision_route bound vessels	117	81			158	140	
collision_route bound and non route bound vessels	113	91			148	131	
collision_non route bound and route bound vessels	87	78			127	119	
collision_non route bound vessels	17	17			40	40	
Total	11	10			22	21	

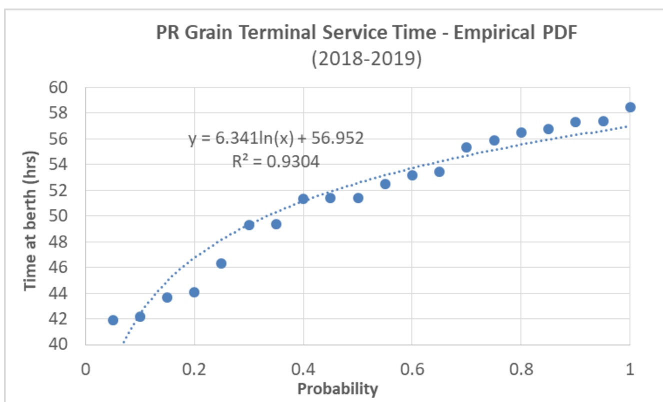
Appendix E

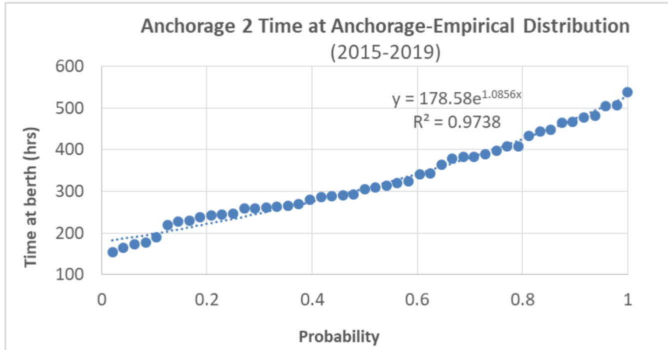
Anchorage Area Analysis Inputs

Discrete Event Simulation Input Modelling





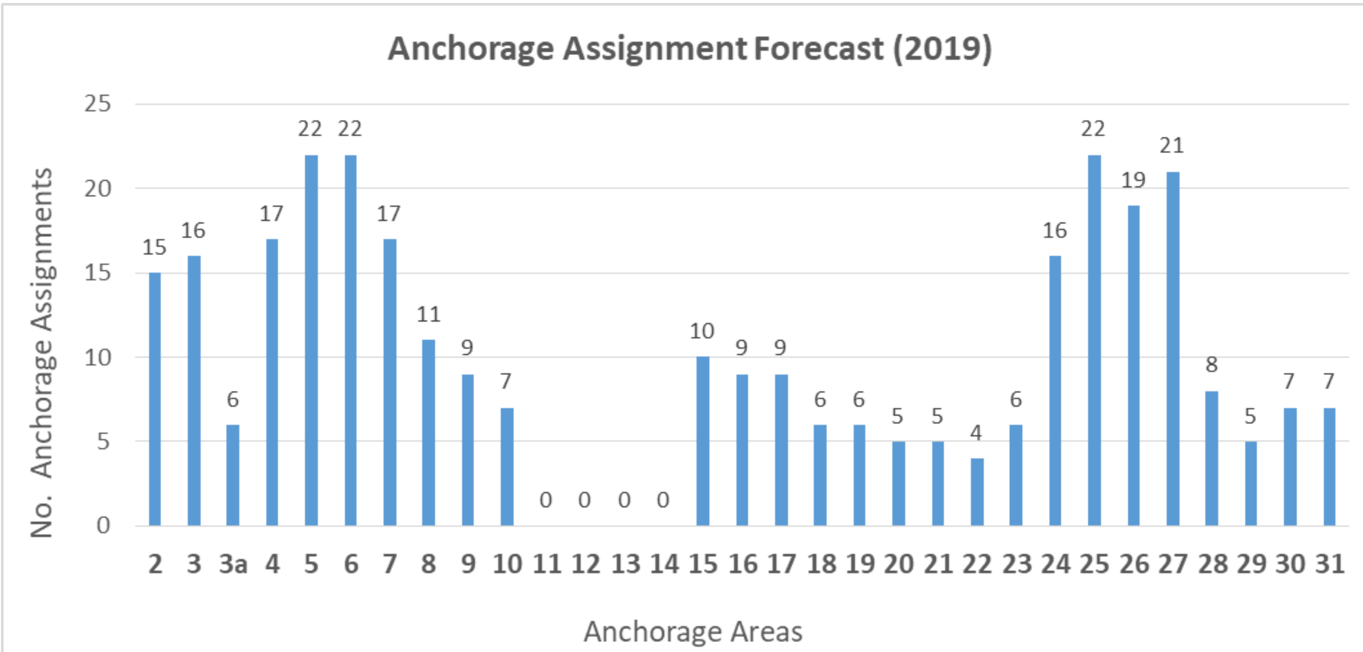


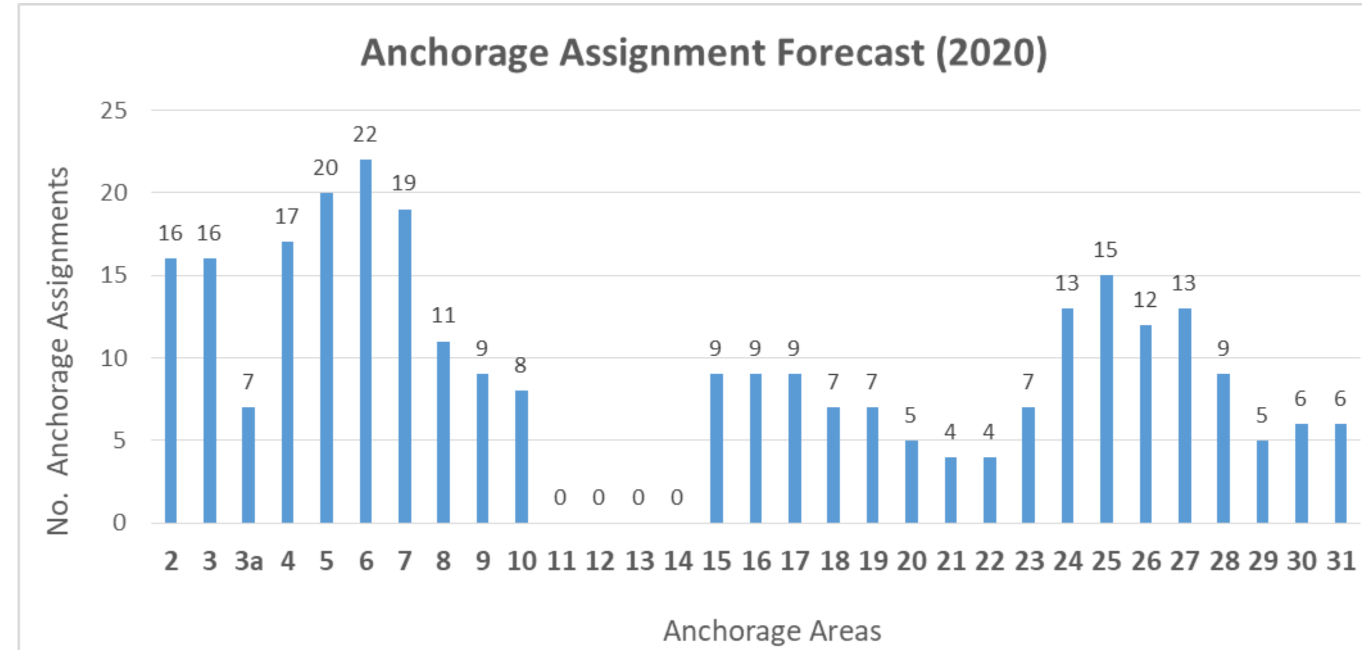

Anchorage 2 Time at Anchorage-Empirical Distribution
(2015-2019)
y = 178.58e^1.0856x
R² = 0.9738
Time at berth (hrs)
Probability
600
500
400
300
200
100
0
0.2
0.4
0.6
0.8
1

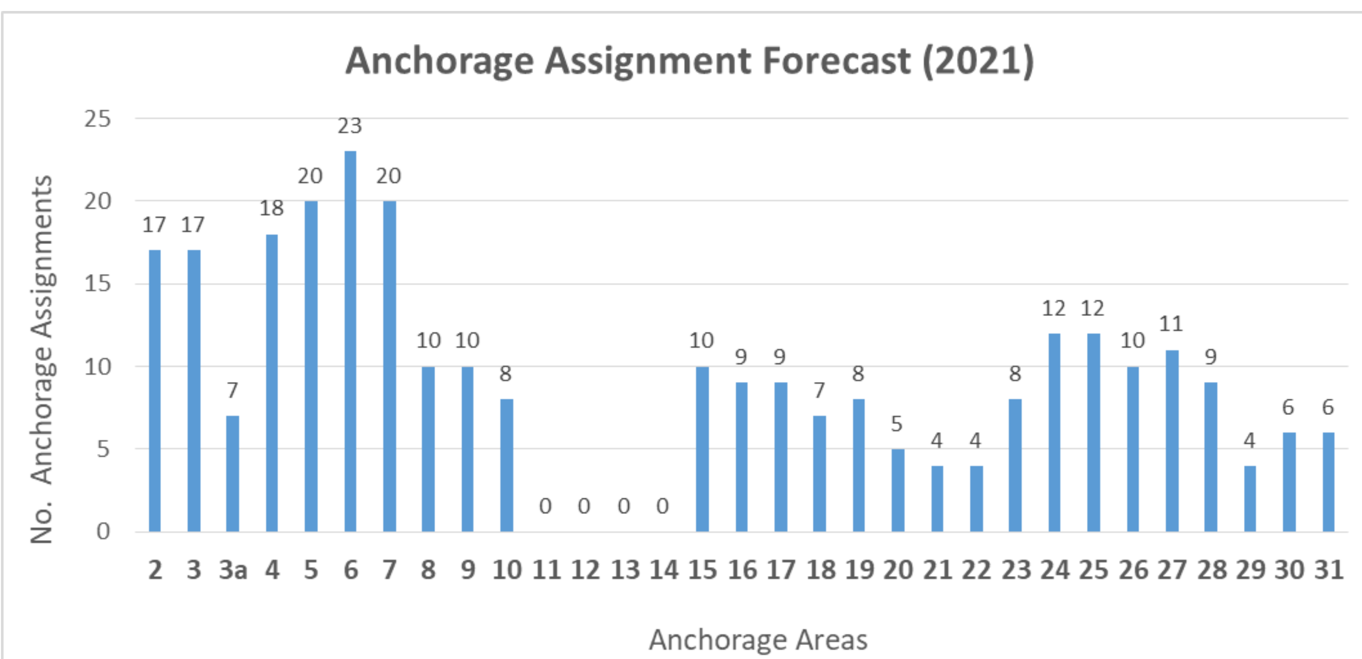
Appendix F

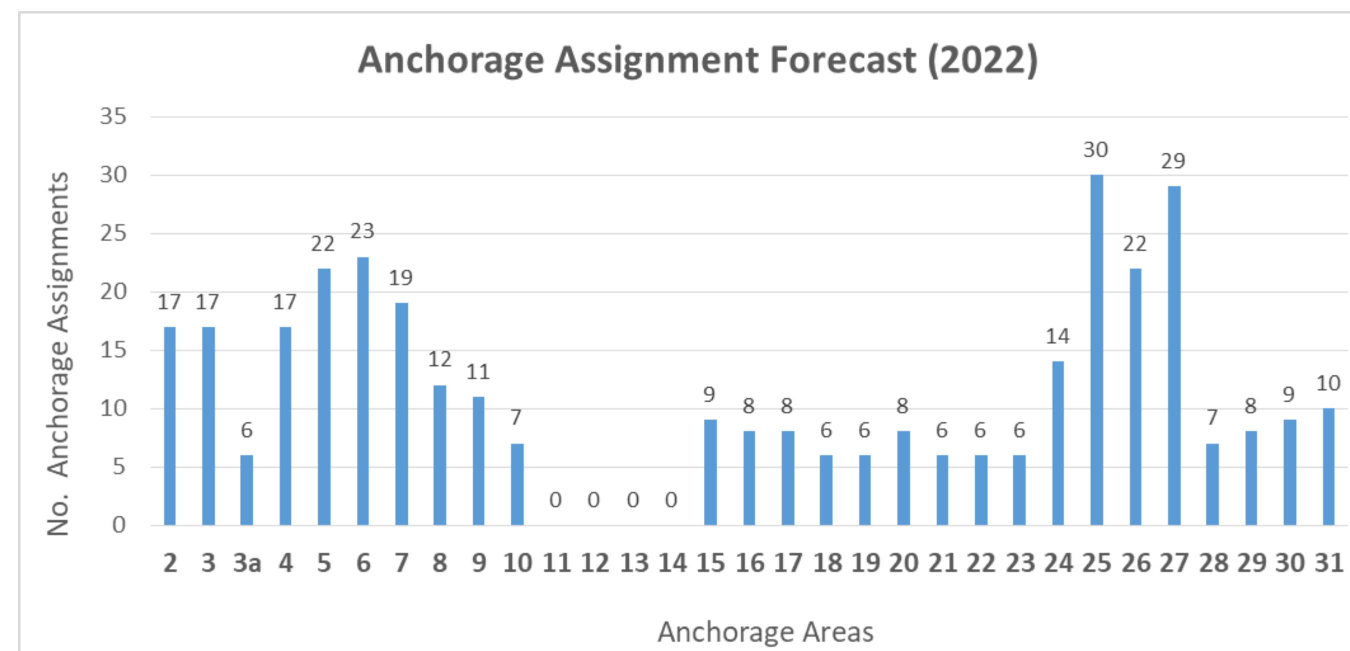
Anchorage Area Detailed Results

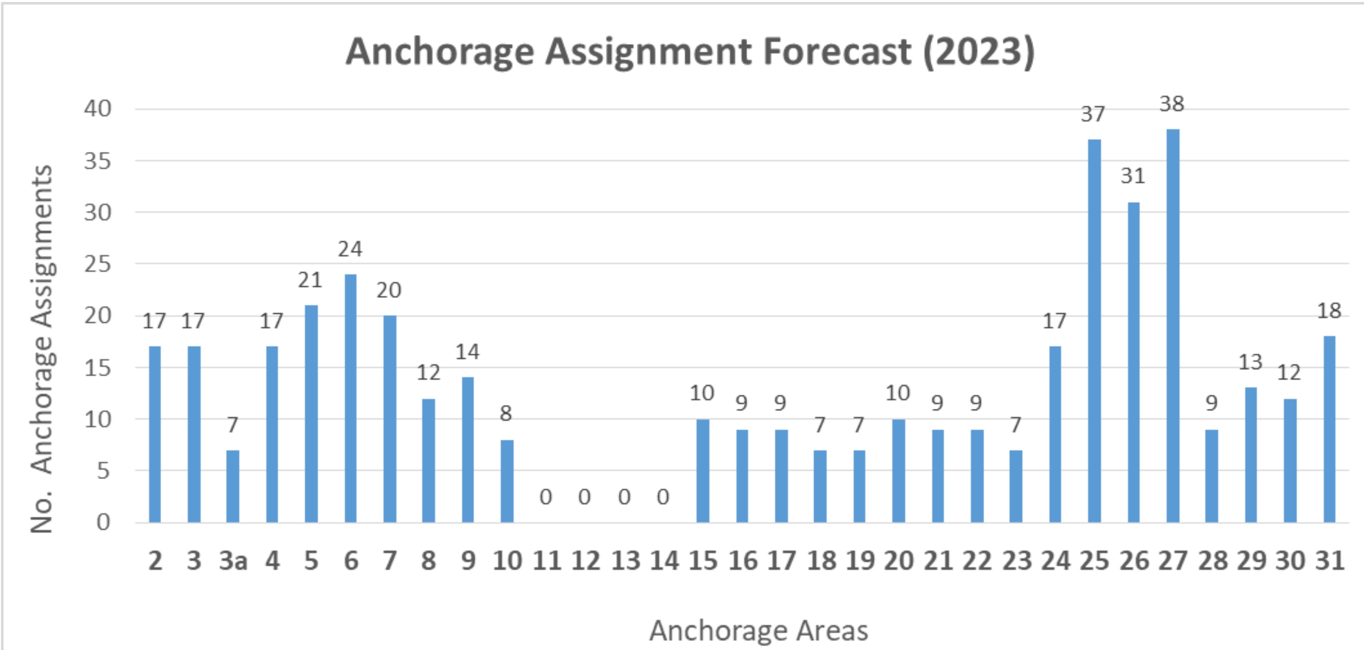
Anchorage Assignment Simulation Results – Annual Average Anchorage Assignments

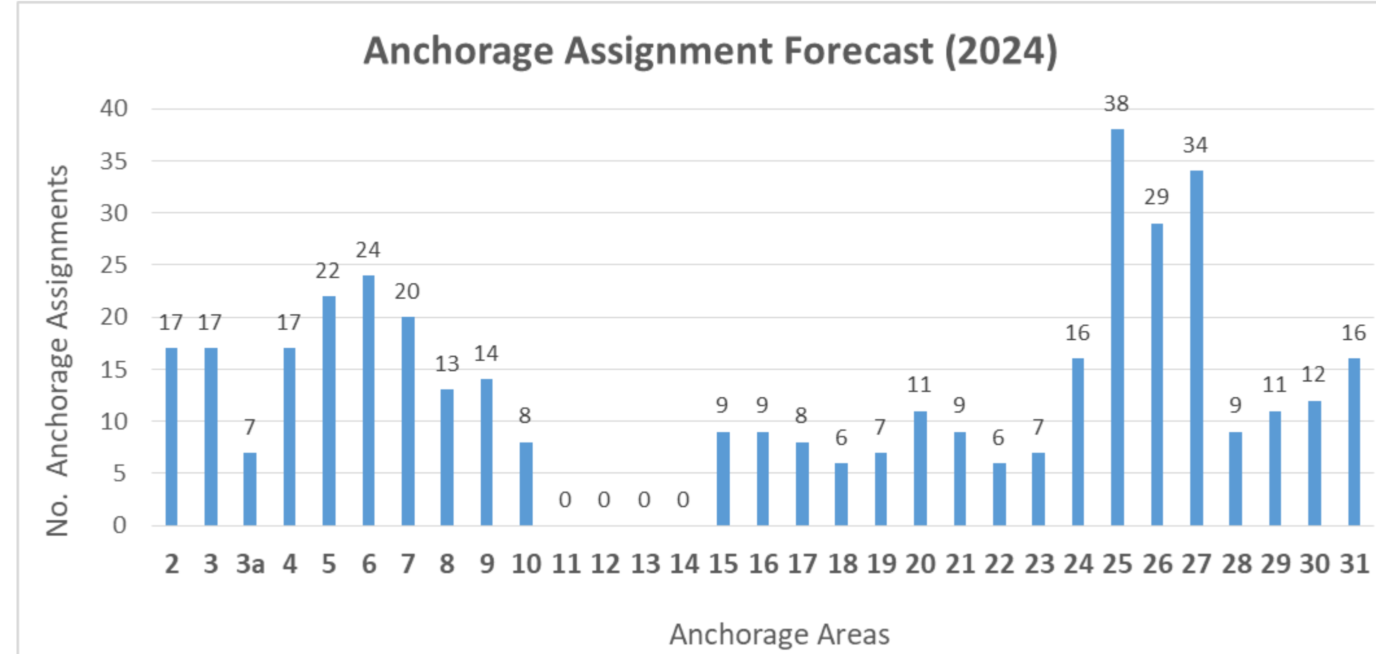


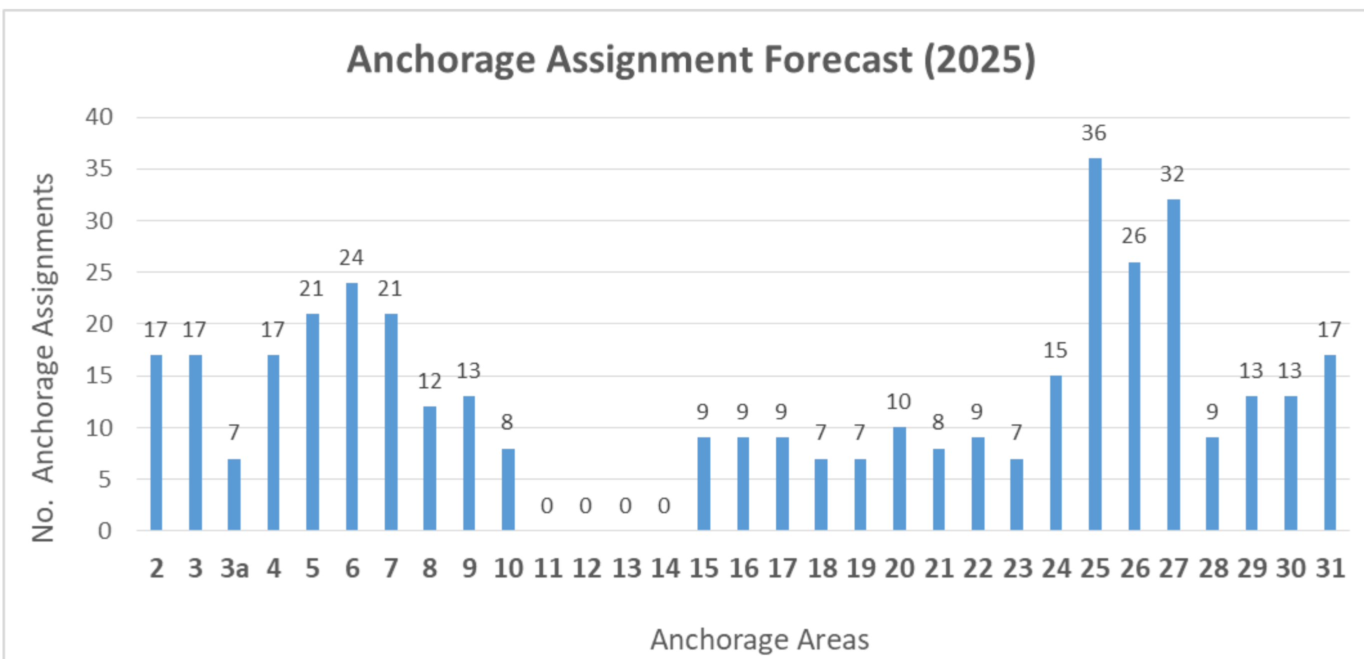


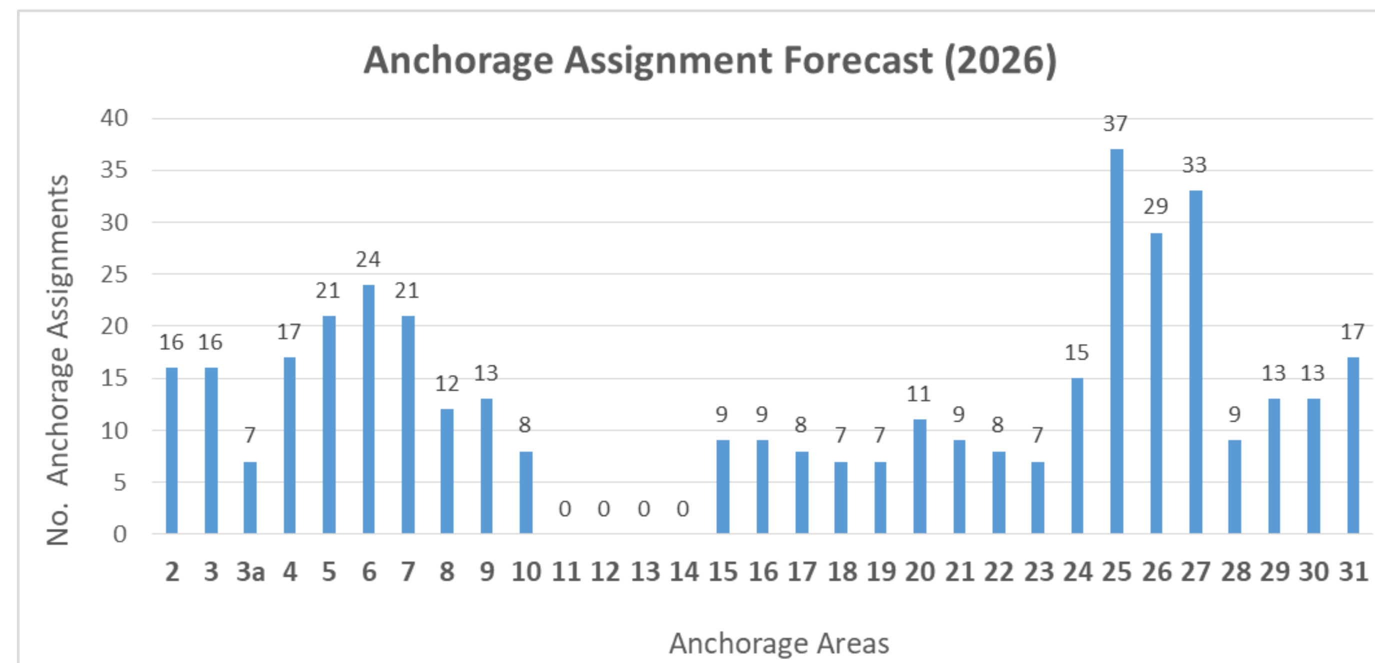


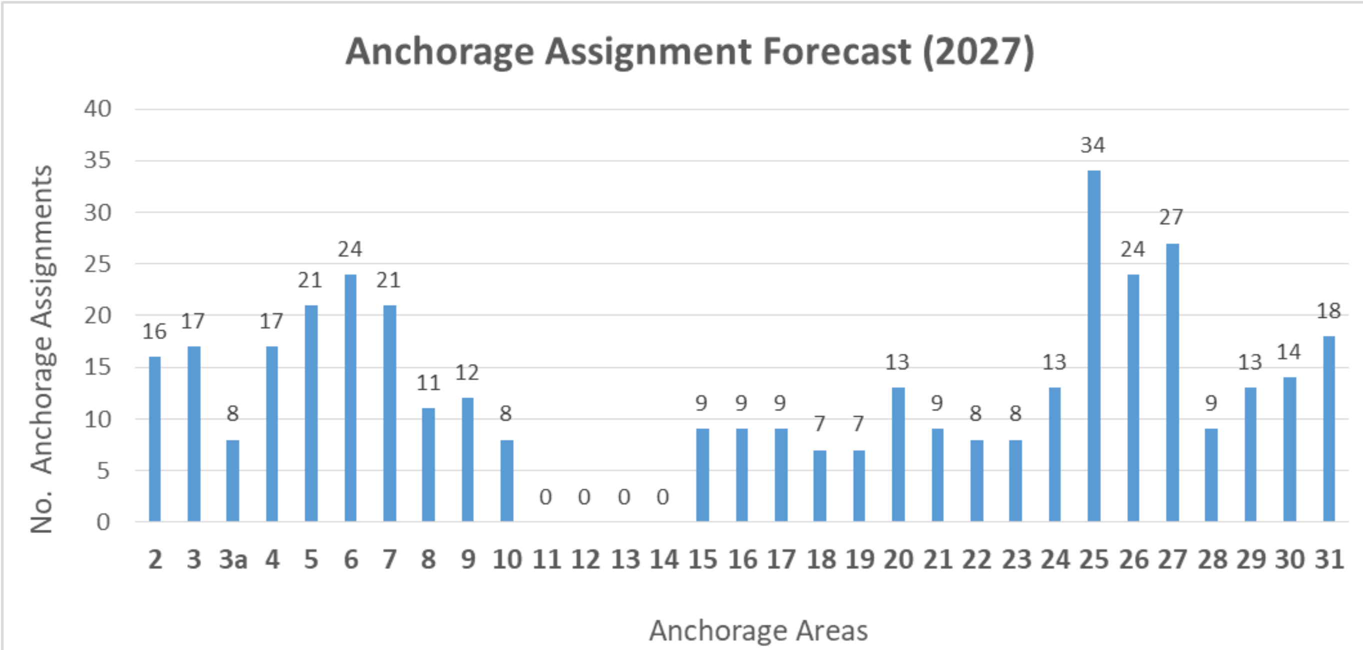


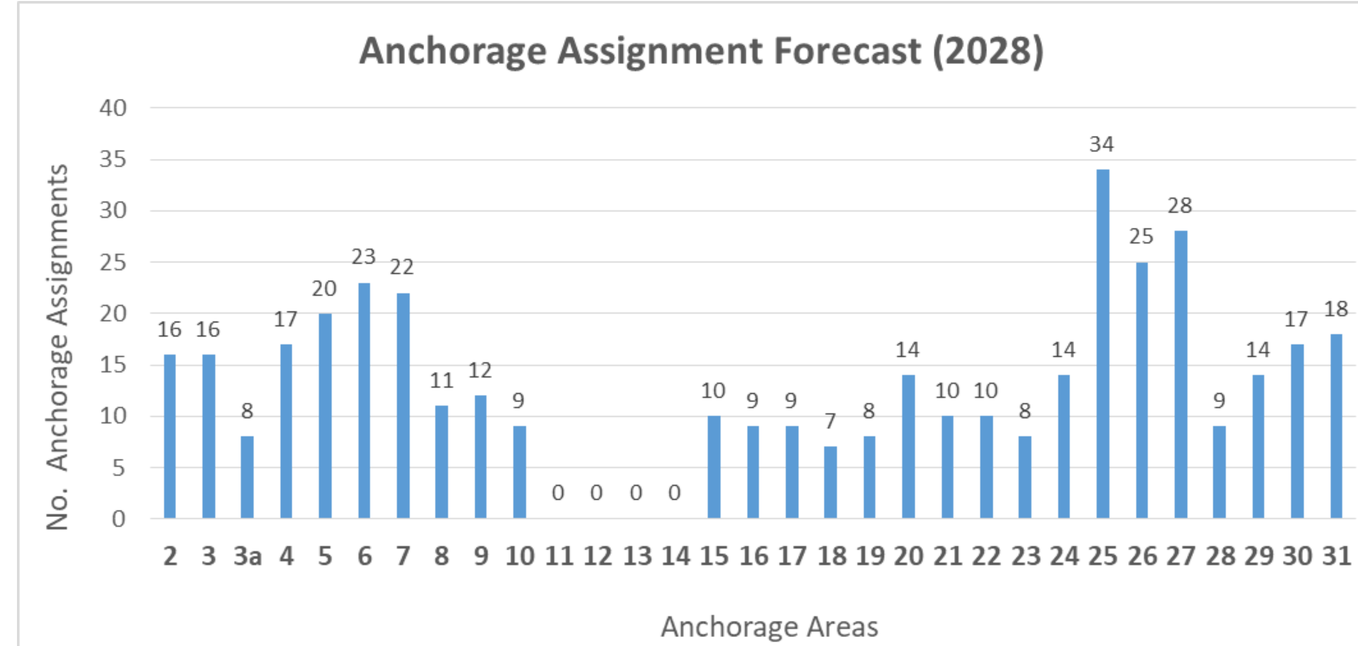

Anchorage Assignment Forecast (2023)
No. Anchorage Assignments
Anchorage Areas
2 3 3a 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
17 17 7 17 21 24 20 12 14 8 0 0 0 0 10 9 9 7 7 10 9 9 7 17 37 31 38 9 13 12 18

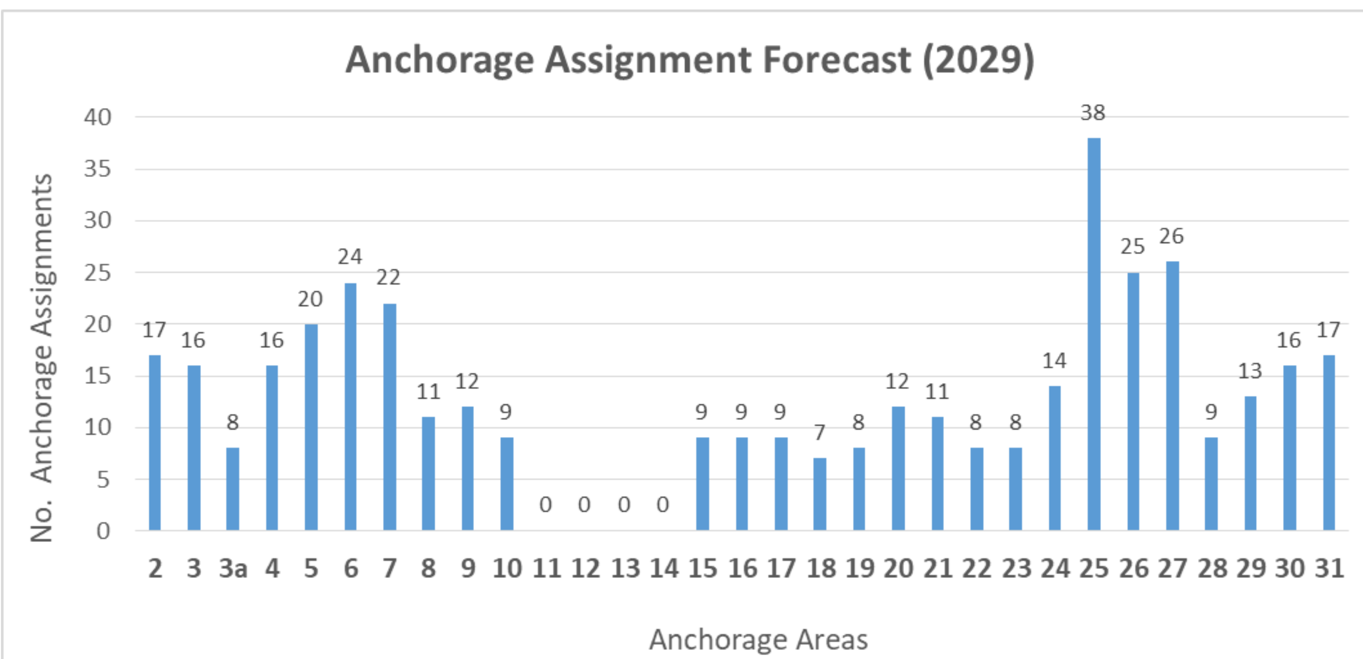

Anchorage Assignment Forecast (2024)
No. Anchorage Assignments
Anchorage Areas
2 3 3a 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
17 17 7 17 22 24 20 13 14 8 0 0 0 0 9 9 8 6 7 11 9 6 7 16 38 29 34 9 11 12 16

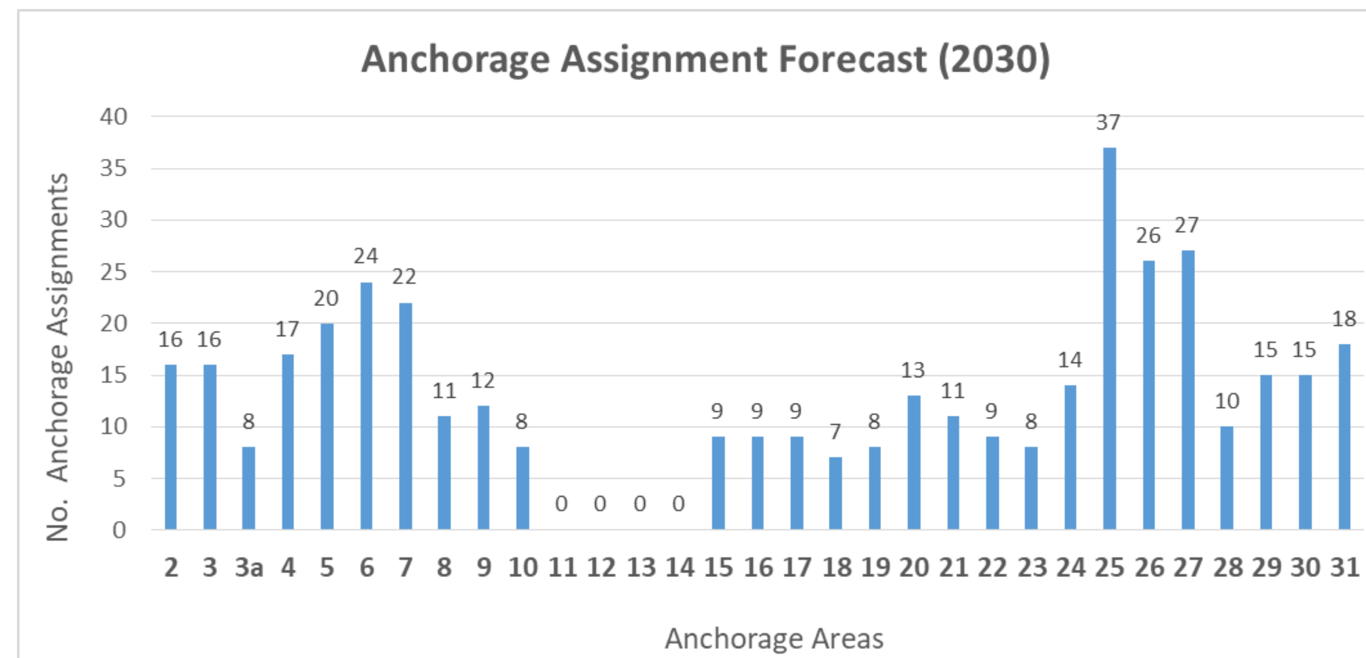

Anchorage Assignment Forecast (2025)
No. Anchorage Assignments
Anchorage Areas
2 3 3a 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
17 17 7 17 21 24 21 12 13 8 0 0 0 0 9 9 9 7 7 10 8 9 7 15 36 26 32 9 13 13 17


Anchorage Assignment Forecast (2026)
No. Anchorage Assignments
Anchorage Areas
2 3 3a 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
16 16 7 17 21 24 21 12 13 8 0 0 0 0 9 9 8 7 7 11 9 8 7 15 37 29 33 9 13 13 17


Anchorage Assignment Forecast (2027)
No. Anchorage Assignments
0 5 10 15 20 25 30 35 40
2 3 3a 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
16 17 8 17 21 24 21 11 12 8 0 0 0 0 9 9 9 7 7 13 9 8 8 13 34 24 27 9 13 14 18
Anchorage Areas


Anchorage Assignment Forecast (2028)
No. Anchorage Assignments
0 5 10 15 20 25 30 35 40
2 3 3a 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
16 16 8 17 20 23 22 11 12 9 0 0 0 0 10 9 9 7 8 14 10 10 8 14 34 25 28 9 14 17 18
Anchorage Areas


Anchorage Assignment Forecast (2029)
No. Anchorage Assignments
0 5 10 15 20 25 30 35 40
2 3 3a 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
17 16 8 16 20 24 22 11 12 9 0 0 0 0 9 9 9 7 8 12 11 8 8 14 38 25 26 9 13 16 17
Anchorage Areas


Anchorage Assignment Forecast (2030)
No. Anchorage Assignments
0 5 10 15 20 25 30 35 40
2 3 3a 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31
16 16 8 17 20 24 22 11 12 8 0 0 0 0 9 9 9 7 8 13 11 9 8 14 37 26 27 10 15 15 18
Anchorage Areas

Simulation Output Summary Tables

	2019					2020					2021					2022					2023					2024				
A#	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**
2	11	14	15	18	22	12	14	16	19	28	12	14	17	22	28	13	14	17	20	26	13	15	17	19	26	12	15	17	20	27
3	11	14	16	19	23	11	14	16	20	26	11	14	17	20	27	11	15	17	20	25	13	15	17	20	26	11	15	17	21	29
3a	0	3	6	9	11	2	5	7	9	11	2	5	7	9	10	0	4	6	9	11	1	5	7	10	11	0	4	7	10	13
4	13	15	17	21	25	13	15	17	20	29	13	15	18	22	30	12	15	17	21	27	13	15	17	20	28	12	16	17	20	25
5	15	18	22	28	38	14	17	20	25	32	14	17	20	25	31	16	18	22	27	37	15	18	21	25	37	15	19	22	28	38
6	12	19	22	25	29	16	19	22	25	31	18	20	23	26	37	16	20	23	27	31	17	21	24	27	31	19	22	24	28	32
7	7	12	17	22	26	13	16	19	23	27	14	17	20	24	32	6	16	19	23	27	12	17	20	24	28	8	17	20	24	30
8	7	9	11	13	24	4	9	11	14	20	5	9	10	13	17	6	10	12	17	25	8	10	12	16	30	7	10	13	18	30
9	4	7	9	11	14	5	8	9	12	14	5	9	10	12	16	5	9	11	16	22	5	10	14	19	28	6	10	14	19	31
10	1	5	7	10	12	2	7	8	10	11	5	7	8	10	13	2	5	7	10	11	3	6	8	10	13	2	6	8	10	18
11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
13	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	6	8	10	13	16	6	8	9	12	14	5	8	10	12	14	3	7	9	12	17	5	8	10	12	24	3	7	9	12	17
16	4	7	9	12	14	4	8	9	11	14	5	8	9	11	14	3	6	8	11	20	3	7	9	12	15	2	7	9	12	18
17	3	7	9	11	14	4	8	9	11	16	5	8	9	11	13	1	6	8	10	12	3	7	9	11	14	1	6	8	11	15
18	0	3	6	9	10	3	5	7	9	11	3	6	7	9	10	0	3	6	9	11	1	5	7	9	11	0	4	6	9	13
19	0	4	6	9	11	4	6	7	10	11	4	7	8	10	11	1	4	6	9	12	1	5	7	9	13	0	4	7	9	16
20	0	2	5	9	14	1	3	5	8	16	2	4	5	7	11	0	2	8	18	41	1	3	10	22	50	0	3	11	22	64
21	0	2	5	8	12	1	3	4	8	13	2	3	4	7	11	0	1	6	13	28	1	2	9	21	43	0	2	9	20	42
22	0	2	4	8	17	1	3	4	7	10	2	3	4	6	9	0	1	6	14	36	1	2	9	19	45	0	1	6	15	32
23	0	4	6	9	10	2	6	7	9	12	3	6	8	10	11	0	4	6	9	11	1	5	7	9	15	0	4	7	9	16
24	7	12	16	22	31	7	11	13	18	24	7	11	12	15	19	5	10	14	21	33	8	11	17	25	36	8	11	16	24	43
25	9	13	22	32	46	6	10	15	22	33	7	9	12	16	24	10	19	30	45	69	11	22	37	54	86	10	22	38	57	104
26	5	11	19	28	37	5	8	12	18	31	4	8	10	13	21	6	12	22	34	52	11	17	31	47	72	9	15	29	45	59
27	9	14	21	30	40	7	9	13	19	36	6	8	11	16	26	11	18	29	43	58	15	23	38	57	122	10	21	34	51	84
28	1	6	8	12	16	5	7	9	11	16	5	8	9	12	13	1	5	7	10	15	2	7	9	13	25	1	7	9	14	20
29	0	2	5	9	17	1	3	5	9	18	2	4	4	7	12	0	2	8	18	40	0	3	13	33	64	0	2	11	24	61
30	0	3	7	13	19	1	4	6	9	13	2	5	6	8	15	0	2	9	20	42	0	4	12	24	45	0	3	12	24	79
31	1	4	7	12	25	1	4	6	10	20	2	4	6	8	13	0	3	10	20	48	1	6	18	32	87	0	4	16	31	65

	2025					2026					2027					2028					2029					2030				
A#	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**	**Min.**	**P10**	**Avg.**	**P90**	**Max.**
2	13	15	17	20	30	12	14	16	25	19	13	15	16	19	26	12	14	16	19	25	12	14	17	20	26	12	14	16	19	24
3	13	15	17	20	25	12	15	16	28	19	12	15	17	19	27	13	15	16	20	23	12	15	16	19	31	13	15	16	19	31
3a	1	6	7	10	13	1	6	7	11	9	1	7	8	10	13	2	7	8	10	12	3	7	8	10	14	5	7	8	10	20
4	13	15	17	20	26	12	15	17	24	19	12	15	17	20	27	12	15	17	20	28	12	15	16	19	24	12	15	17	19	30
5	16	18	21	26	34	14	18	21	35	26	16	18	21	24	34	15	17	20	23	28	14	18	20	24	38	14	18	20	24	30
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11	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
12	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
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14	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15	4	8	9	12	15	5	8	9	15	12	4	8	9	11	13	5	8	10	12	19	4	8	9	12	20	6	8	9	12	16
16	5	8	9	11	15	5	7	9	17	11	3	8	9	11	29	5	8	9	11	15	3	8	9	12	20	6	8	9	12	17
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19	3	5	7	10	12	2	5	7	13	9	3	6	7	10	14	3	6	8	10	16	4	6	8	10	21	4	6	8	10	18
20	1	3	10	21	51	1	3	11	61	23	1	3	13	30	52	2	4	14	30	53	1	3	12	27	69	2	3	13	30	69
21	1	2	8	18	36	1	2	9	45	20	1	3	9	20	41	2	3	10	21	49	1	3	11	25	75	1	3	11	23	58
22	1	2	9	19	53	0	2	8	74	20	1	2	8	16	55	1	2	10	21	58	1	2	8	18	63	1	2	9	20	50
23	1	5	7	10	30	1	6	7	13	9	1	6	8	10	15	3	7	8	10	21	2	6	8	10	17	3	6	8	10	15
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25	10	20	36	55	107	9	21	37	89	58	10	16	34	59	92	7	17	34	57	81	8	17	38	63	119	5	19	37	58	101
26	5	11	26	43	64	9	16	29	76	46	5	11	24	40	72	6	12	25	42	86	6	13	25	42	65	6	12	26	43	80
27	9	19	32	49	78	11	19	33	65	47	7	13	27	46	86	5	14	28	46	85	8	14	26	39	67	9	14	27	43	71
28	3	7	9	13	24	2	7	9	20	12	3	7	9	12	20	6	7	9	13	23	4	7	9	14	22	6	7	10	14	35
29	1	3	13	31	98	0	3	13	69	25	1	3	13	31	80	1	3	14	29	102	1	2	13	29	90	1	3	15	35	82
30	1	4	13	26	59	1	4	13	48	25	1	3	14	34	60	1	4	17	37	77	1	4	16	30	64	1	4	15	30	72
31	1	6	17	34	71	1	5	17	68	32	1	4	18	35	81	2	5	18	42	70	1	3	17	36	75	1	5	18	35	68

Maximum Anchorage Holding Capacity and Wind Speed Safety Threshold

Anchorage Areas	Ultimate Anchor System Static Holding Capacity (kN)	90th Percentile Wind Velocity (knots)	Wind Speed Safety Threshold (knots)
2	333	27.7	23.2
3	333	27.7	23.2
3a	333	27.7	23.2
4	333	27.7	12
5	333	27.7	12
6	354	27.7	24.2
7	354	27.7	24.1
8	371	18.7	62.2
9	433	18.7	71.9
10	468	18.7	73.5
11	371	18.7	68.6
12	371	18.7	68.6
13	371	18.7	62.2
14	371	18.7	47.1
15	371	18.7	62.2
16	371	18.7	62.2
17	371	18.7	62.2
18	414	18.7	70.9
19	414	18.7	70.9
20	414	18.7	64.2
21	414	18.7	70.9
22	414	18.7	64.2
23	414	18.7	48.5
24	433	18.7	71.9
25	433	18.7	71.9
26	433	18.7	65.0
27	433	18.7	65.0
28	433	18.7	71.9
29	433	18.7	71.9
30	433	18.7	71.9
31	433	18.7	71.9

Assumptions:

LOA = 270 m

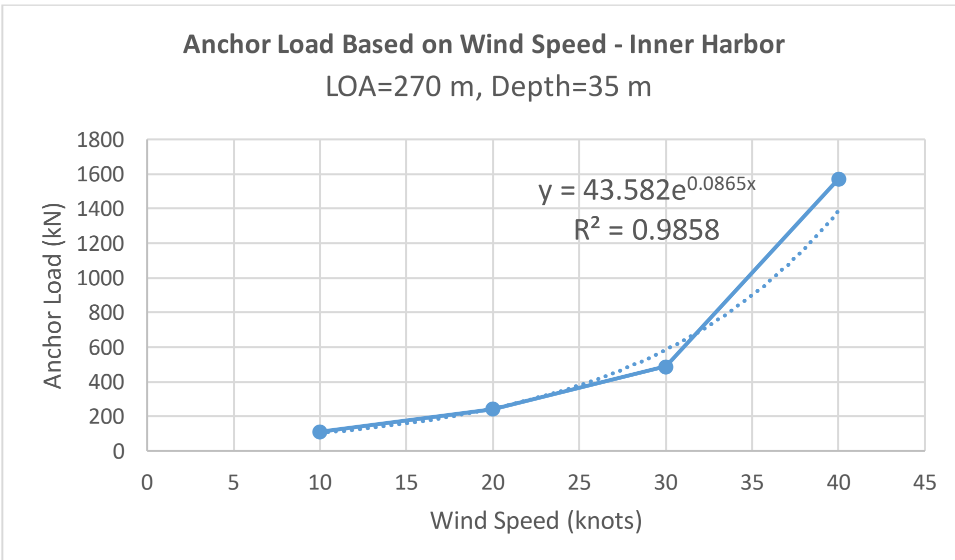
No shelter protection against wind is assumed in the calculations

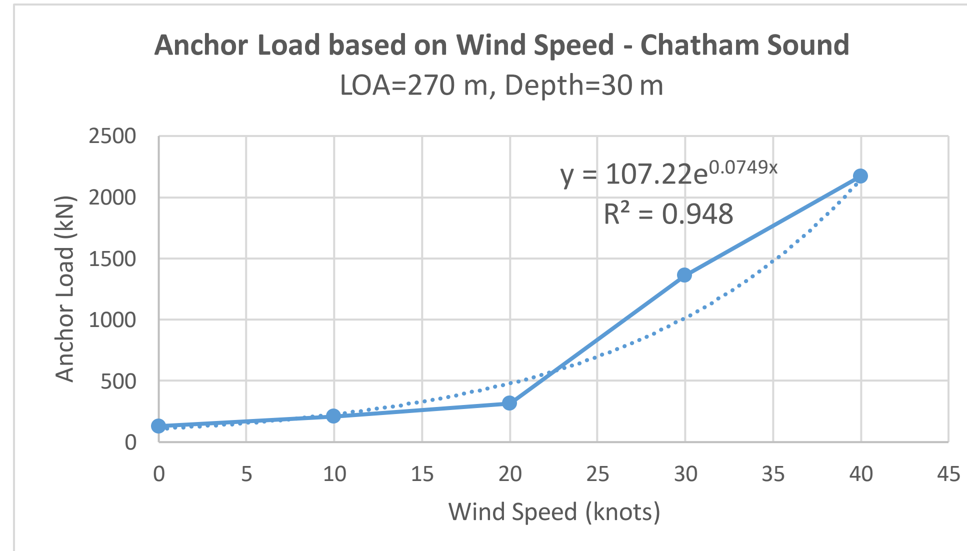
Anchor loads are based on fitted curves to the simulation results provided by Moffatt & Nichol (2012, p 30-32). Fitted Curves are provided.

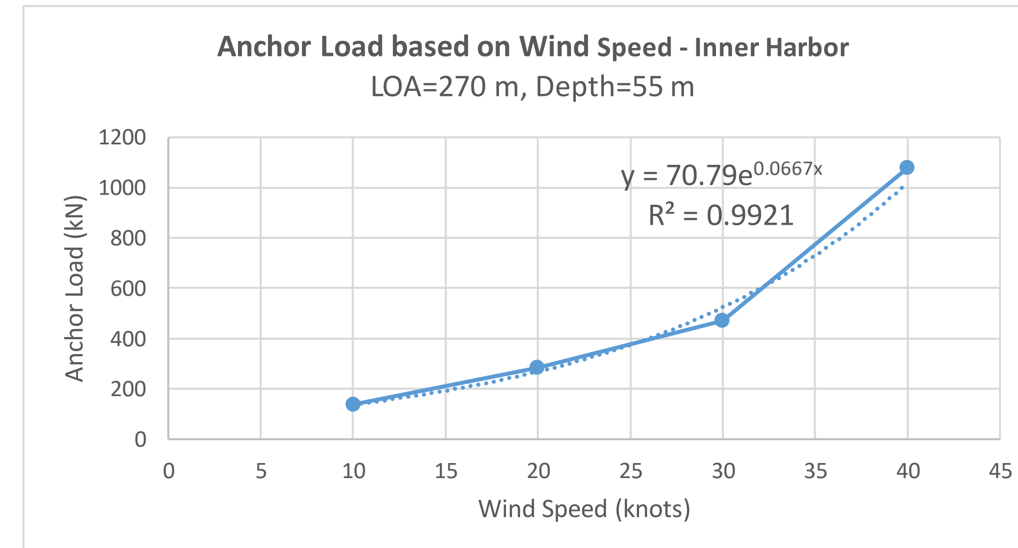
Within the calculations, the depth of each anchorage are assumed to be equal to the closest available figure in the Moffatt & Nichol (2012, p 30-32) tables (Avg. error=10%)

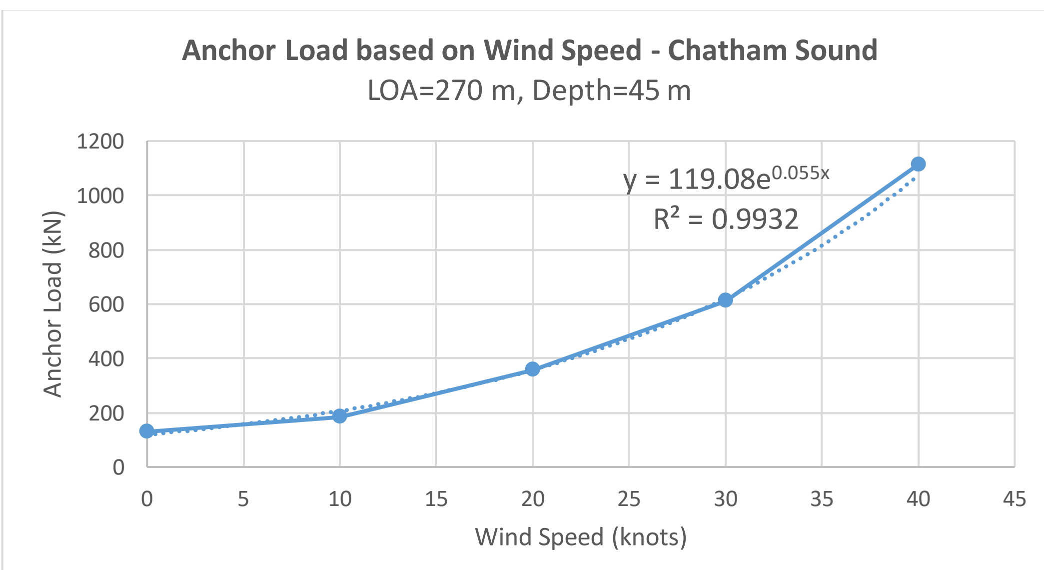
Wind gust is not included in the analysis

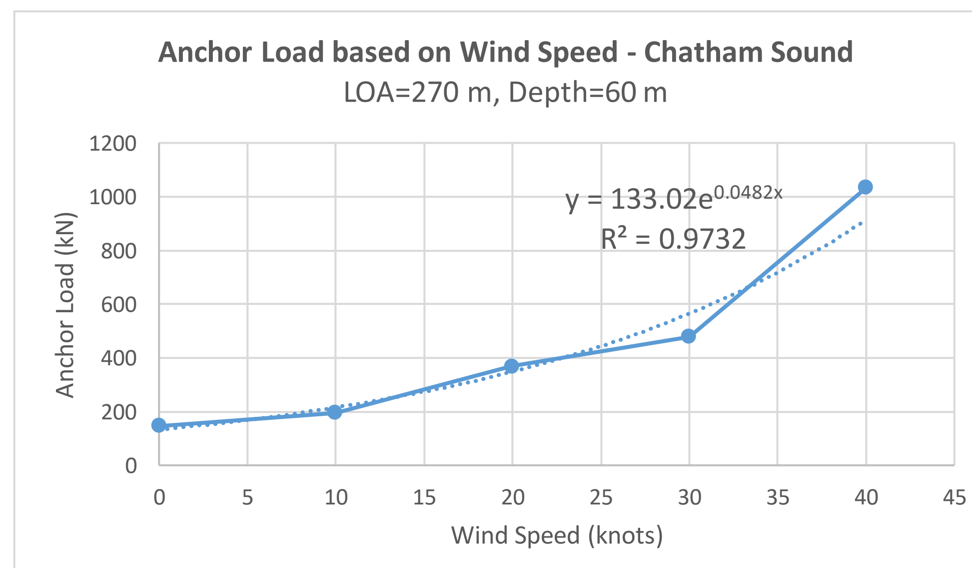
Anchor Loading Estimation – Fitted Curves



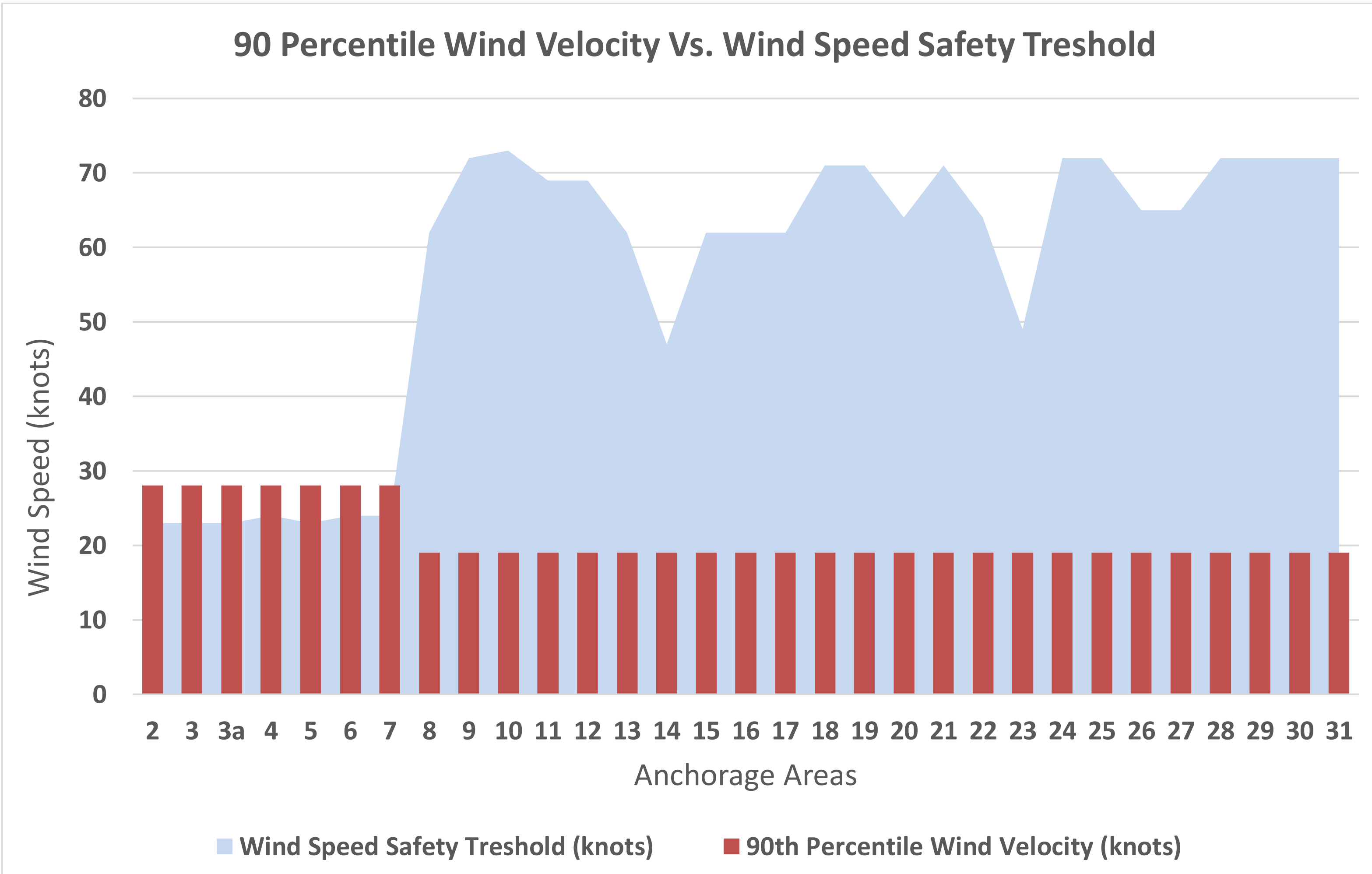








Wind Speed Safety Threshold for 270 LOA vs. Wind Speed



Appendix G

IMO Guidance for Masters on Keeping Safe Anchor Watch

INTERNATIONAL MARITIME ORGANIZATION
4 ALBERT EMBANKMENT
LONDON SE1 7SR

Telephone: 020 7735 7611
Fax: 020 7587 3210

IMO

E

Ref. T2/4.1.5

STCW.7/Circ.14
24 May 2004

GUIDANCE FOR MASTERS ON KEEPING A SAFE ANCHOR WATCH

1 The Sub-Committee on Standards of Training and Watchkeeping, at its thirty-fifth session (26 to 30 January 2004), considered the requirements in section A-VIII of the STCW Code relating to watchkeeping requirements at anchor after seeking the advice of the NAV Sub-Committee as this was an operational matter.

2 The Sub-Committee, noting the advice issued by the NAV Sub-Committee, developed additional guidance for masters on keeping a safe anchor watch, set out at annex.

3 The Maritime Safety Committee, at its seventy-eighth session (12 to 21 May 2004), approved the circulation of this guidance for masters on keeping a safe anchor watch.

4 Member Governments are invited to bring the guidance to the attention of those concerned.

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ANNEX

GUIDANCE FOR MASTERS ON KEEPING A SAFE ANCHOR WATCH

1 The master of every ship at an unsheltered anchorage, at an open roadstead or any other virtually "at sea" conditions in accordance with chapter VIII, section A-VIII/2, part 3-1, paragraph 51 of the STCW Code, is bound to ensure that watchkeeping arrangements are adequate for maintaining a safe watch at all times. A deck officer shall at all times maintain responsibility for a safe anchor watch.

2 In determining the watchkeeping arrangements, and commensurate with maintaining the ship's safety and security and the protection of the marine environment, the master shall take into account all pertinent circumstances and conditions such as:

.1 maintaining a continuous state of vigilance by sight and hearing as well as by all other available means;

.2 ship-to-ship and ship-to-shore communication requirements;

.3 the prevailing weather, sea, ice and current conditions;

.4 the need to continuously monitor the ship's position;

.5 the nature, size and characteristics of anchorage;

.6 traffic conditions;

.7 situations which might affect the security of the ship;

.8 loading and discharging operations;

.9 the designation of stand-by crew members; and

.10 the procedure to alert the master and maintain engine readiness.

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