# Analysis of Marine Vessel Traffic in Burrard Inlet

Summary Report written by Bridget Doyle and Spencer Taft
based on the work of Coastal Resource Mapping Ltd.

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**Introduction**
Tsleil-Waututh Nation (TWN) retained Coastal Resource Mapping Ltd. (Coastal Resource Mapping; CRM) to conduct a marine vessel traffic study for Burrard Inlet. The study was undertaken as part of TWN's ongoing Cumulative Effects Monitoring Initiative (CEMI), which is working to understand colonial impacts in Burrard Inlet since European contact, and consequent effects on TWN's rights and ways of being. The TWN CEMI is informed by many lines of evidence, including Western and TWN science, Indigenous Knowledge, and observances and lived experience of Tsleil-Waututh Elders and community members.

Tsleil-Waututh's economy and ways of being continues to be centered on the lands and waters of Burrard Inlet and the Lower Mainland of British Columbia. During pre- and early post-contact times, Burrard Inlet supported a prosperous economy founded on Tsleil-Waututh's free access to and traditional governance and stewardship over abundant marine resources. Burrard Inlet and surrounding waterways were Tsleil-Waututh's trade routes and highways. Today, marine vessel traffic remains an inherent aspect of life and commerce in Burrard Inlet, with the Port of Vancouver now driving commercial vessel traffic as Canada's busiest port.

According to the Vancouver Fraser Port Authority (VFPA), Canada's trade through the port has been increasing steadily for a decade and is forecasted to keep growing at about 3.5% annually[1]. This marine vessel traffic and port activity affect TWN rights, ways of being, and community members lives on a daily basis. However, limited information quantifying marine traffic in Burrard Inlet is readily available. Metrics such as total vessel counts, vessel types, and operating hours are imperative to evaluate long-term marine vessel traffic trends in Burrard Inlet and to determine consequent impacts to TWN's rights and ways of life. TWN commissioned this study to quantify and analyze marine vessel traffic in Burrard Inlet.

This memorandum provides a summary of the study approach and key findings as described in the attached CRM report and associated proprietary tools, and offers additional recommendations and management considerations for TWN.

**Study Approach**
The study used Automatic Identification System (AIS)[2] data to quantify AIS-equipped vessels in Burrard Inlet from January 1, 2021, to December 31, 2021. Ocean Networks Canada (ONC) shared the AIS data with permission from the Canadian Coast Guard (CCG).

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[1] Vancouver Fraser Port Authority, "Port of Vancouver," Vancouver Fraser Port Authority, 2022. [Online]. Available: https://www.portvancouver.com/about-us/. [Accessed 06/03/2023].

[2] The AIS is a vessel tracking system that uses transceivers on vessels to provide vessel location and status details to aid in collision avoidance. However, AIS data can also be obtained to study vessel behaviour and compile statistics. AIS data is transmitted by large commercial vessels as well as some smaller vessels. The International Maritime Organization (IMO) mandates the use of AIS in vessels larger than 300 gross tonnes that travel internationally. AIS equipment is not required for most pleasure craft vessels. AIS data includes, among other things, information on vessel position, speed, heading, ship identification, vessel type, dimensions, and draft.

Coastal Resource Mapping prepared and processed the AIS data. This involved a number of iterative steps to clean, analyze and interpolate the data to make sense of it in a user-friendly format while maintaining quality assurance.

Three fundamental pieces of information contained in AIS data were used: vessel identity (MMSI), vessel position, and a timestamp. Data were sliced to report 1) residence times for vessels at rest (i.e., at anchor or moored), 2) residence times for vessels in transit (i.e., moving along a course), and 3) vessel counts.

Notable barriers or limitations to the study approach existed, including:

1. Transport Canada does not require AIS equipment on all vessels and many are exempt from carrying AIS equipment. This includes vessels under 150 tonnes, such as most pleasure craft vessels and some commercial vessels (e.g.: some fishing boats, False Creek water taxis, guided tours, whale watching, etc.).
2. Non-AIS vessel types – especially pleasure craft - are a significant component of vessel traffic in Burrard Inlet. Some vessels are voluntarily equipped with AIS. Non-AIS Vessels were not captured by this study. This represents a data gap and limits how the report can inform total vessel traffic in the inlet, as previous studies in the area estimate non-AIS vessel types represent upwards of 60% of overall vessel traffic[3].
3. The global COVID-19 pandemic undoubtedly impacted economic activity, international commerce and travel throughout 2020 and at least into 2021. While the duration of these impacts is unclear, we expect they affected vessel traffic during the study period compared to pre-COVID or more recent levels.

For clarity, references to vessels or marine vessel traffic in this report only refers to AIS-equipped vessels, unless otherwise stated.

The data collection, analysis and findings conducted by CRM are provided in the full report (attached). Additionally, CRM produced an interactive dashboard that spatializes and visualizes the data, and allows users to display information by vessel type, residence time (in-transit or at-rest), date range and sub-basin. Figures below are derived from the proprietary dashboard.

**Summary of Key Findings**

This study successfully quantified AIS-equipped vessel traffic in Burrard Inlet for the 2021 calendar year and provided metrics such as total vessel counts, vessel types, and operating hours. To our knowledge, this is the first publicly available information quantifying these metrics in detail in Burrard Inlet or elsewhere in the Port of Vancouver.

Key findings are presented below for the entire inlet and individual sub-basins.

[3] Beatty, S. and Bocking, B. 2021. Tsleil-Waututh Wave Monitoring. Marine Labs Data Systems Inc.

***Burrard Inlet***

A total of 2.7k vessels visited Burrard Inlet in 2021, spending 3.2M hours in its waters (Figure 1). That means that on average across the year, for every hour of every day, there are almost 700 vessel-activity hours (in-transit and at-rest) in the inlet. When visualized, the Inner Harbour is solid with traffic. Traffic is heavy in the Outer and Central Harbours and False Creek. Points of constriction in the inlet, such as the narrows and confined basins, create areas of congestion.

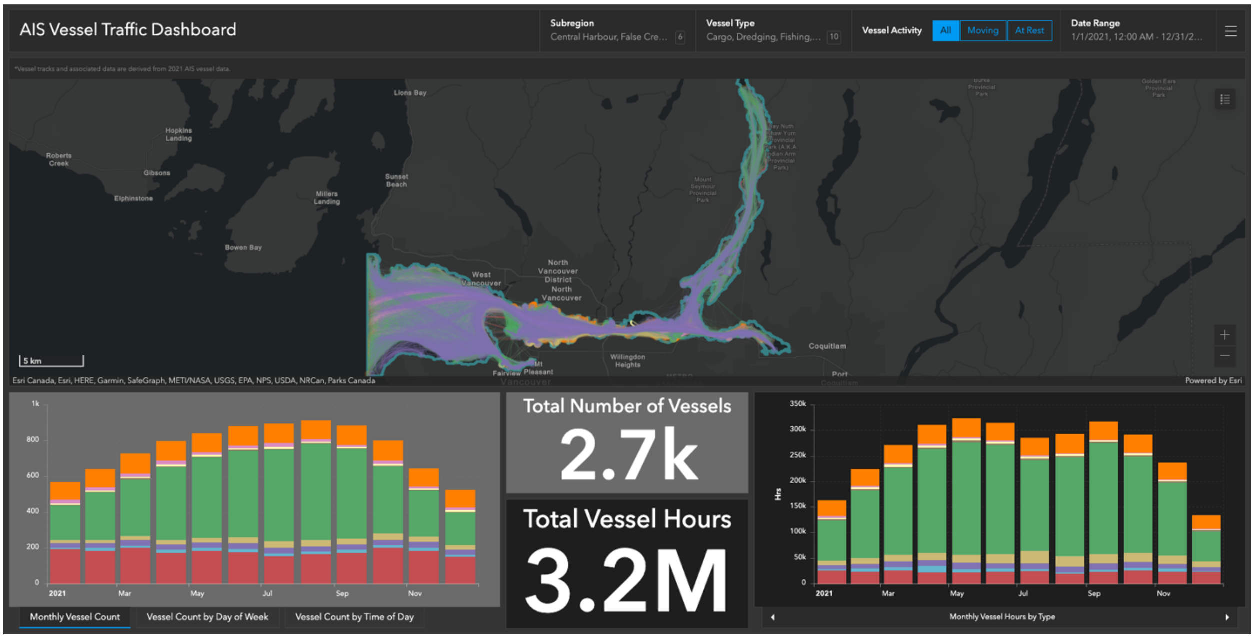


*Figure 1. Overall Burrard Inlet marine vessel traffic for 2021 by vessel type and activity.*

Vessel counts were dominated by Pleasure Craft, Cargo vessels and Tugs. Government/Patrol, Fishing, Passenger, Tankers, and Port Operations vessels had a lower, but consistent presence in the inlet (except for oceangoing vessels in False Creek or upper reaches of Indian Arm).

Overall, vessel counts increased by 40% in the summer months compared to winter months, and vessel residence times increased by 30% during the summer of 2021. This increase was largely attributed to Pleasure Craft.

A total of 1.3k Cargo vessels (averaged 180 vessels per month) transited Burrard Inlet in 2021. The large majority of Cargo traffic was destined for anchorages and terminals concentrated in the Inner and Outer Harbour, but heavy Cargo vessel traffic was observed through to the Central Harbour and Port Moody Arm.

A total of 191 Tugs operated in Burrard Inlet. Tugs are very active throughout Burrard Inlet and frequently transit between basins, with consistent year-round activity (Figure 2). A relatively small number of Port Operations vessels also generated consistently heavy traffic throughout the year. A small number of Dredging vessels were active in the Inner Harbour, Central Harbour, and Port Moody Arm.

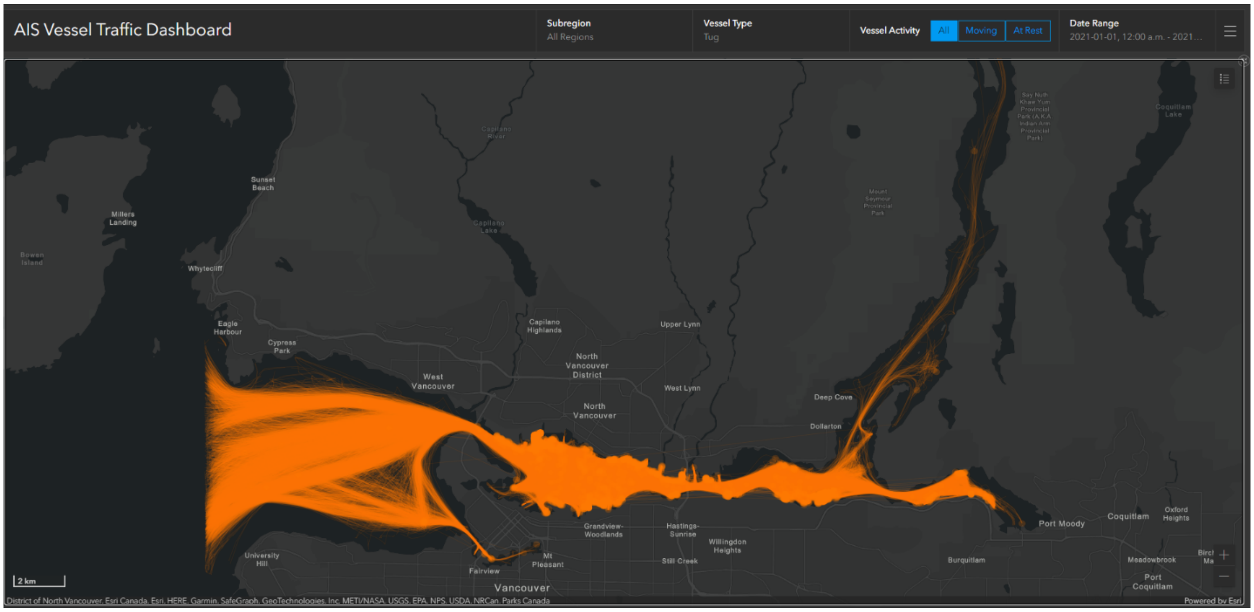


*Figure 2. AIS tracking data from tugboats operating in Burrard Inlet in 2021.*

Fishing vessels generated heavy traffic between the Straight of Georgia and terminals located in Inner Harbour and False Creek, as well as localized traffic in Port Moody Arm and Indian Arm.

Government/Patrol vessels covered every navigable area in Burrard Inlet, including along shorelines, beaches, and marine access points. Residence times for Government/Patrol vessels were highest in the Inner Harbour and False Creek, and the least amount of time was spent in the Central Harbour and Indian Arm.

An average of 17 tankers (total of 119) spent an average of 2.2k hours per month in Burrard Inlet in 2021. Tankers were largely destined for anchorages and terminals in the Central Harbour and Port Moody Arm, where most fossil fuel facilities are situated.

***Outer Harbour***

The Outer Harbour was dominated by Cargo and Pleasure Craft vessel traffic. The seasonal signal shifted from Cargo dominating vessel counts in the fall and winter, to Pleasure Craft in the spring and summer. There was also a significant and consistent amount of transiting Tug traffic in the Outer Harbour, presumably accompanying ships or cargo calling the Port of Vancouver (Figure 3).

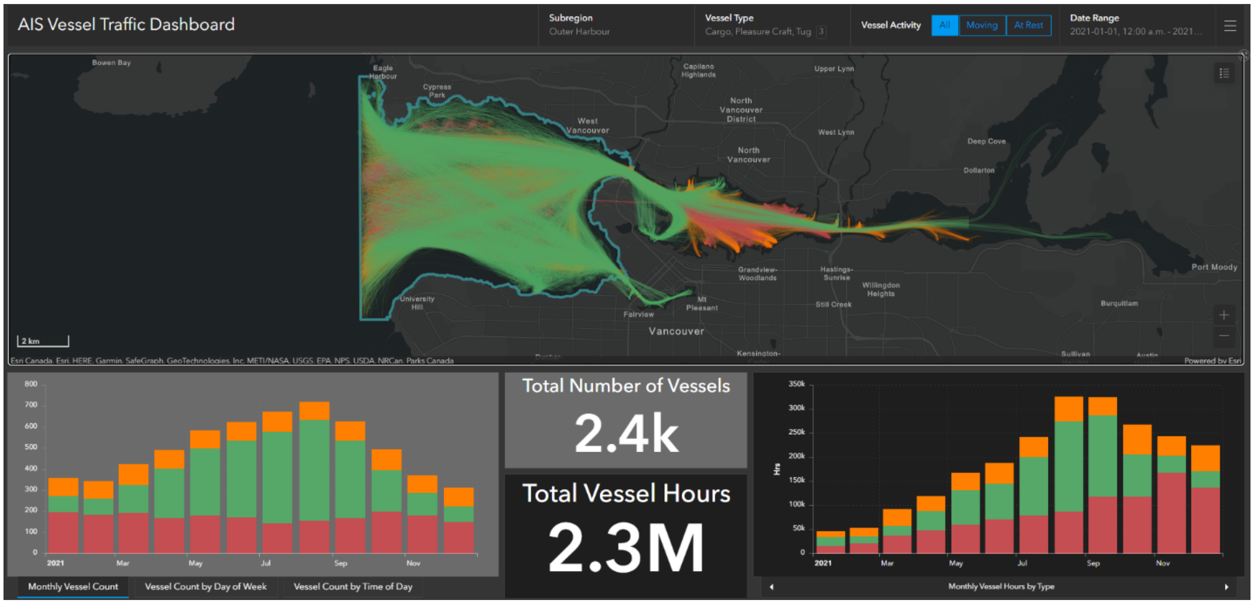

*Figure 3: Tugboats (orange), Pleasure Craft (green), and Cargo Vessels (red) transiting through the Outer Harbour in 2021.*

***Inner Harbour***

The Inner Harbour is highly congested, as every vessel that transits First Narrows from the Outer Harbour either terminates or sails through the basin. The Inner Harbour saw 2.2k vessels in 2021, with a total residence time of 1.8M hours. Vessels are moored at marinas, Port of Vancouver terminals, or at anchorages throughout the basin for the vast majority of vessel residence time. At-rest residence time was 1.7M hours compared to 48.7k hours in-transit.

Apart from the seasonal surge of Pleasure Craft, Cargo represented the highest proportion of vessels. Tugs and Passenger (e.g.: Seabus) vessels were the most active with the highest in-transit times in the Inner Harbour (Figure 4).

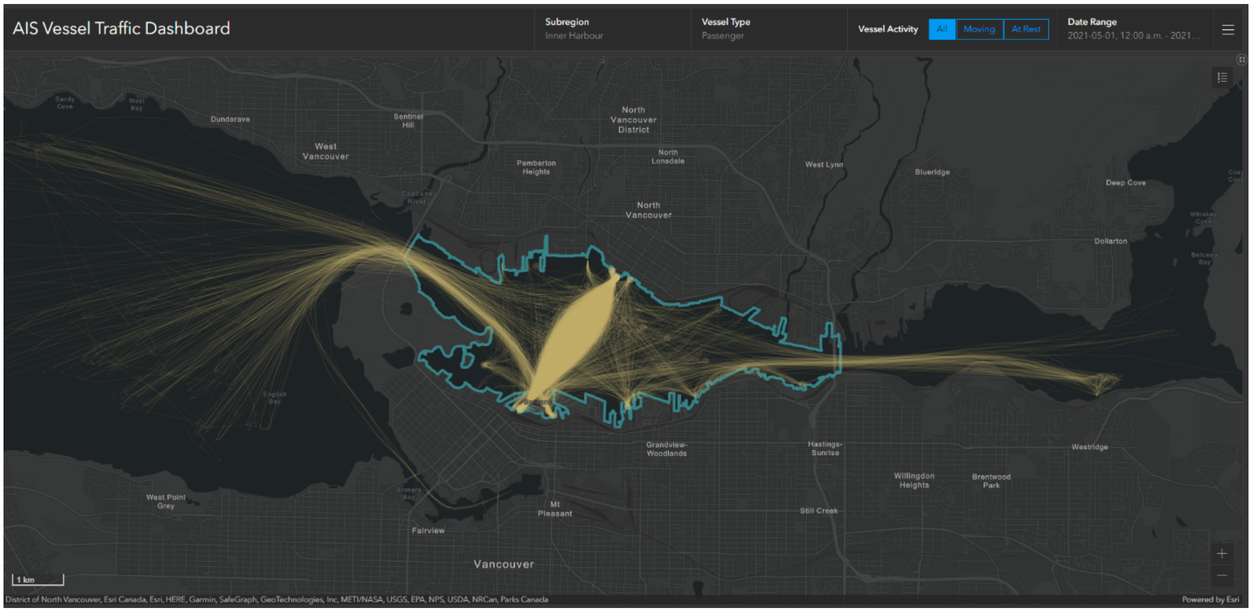


*Figure 4. Passenger vessels transiting through the Inner Harbour during May 2021 (dates restricted to a single month to aid visualization).*

***Central Harbour***

Vessel counts tend to trail off in the Central Harbour in comparison to the Outer and Inner Harbour. In 2021, over 680 vessels transited the Central Harbour with a total residence time of approximately 114k hours; 100.7k hours of which were at-rest. Tugs, Pleasure Craft and Tankers are prominent vessel types to TWN in the Central Harbour (Figure 5).

A relatively small number of Tugs dominated residence time throughout the year; Tugs accounted for nearly 20% of vessel counts and over 70% of residence time. At-rest Tugs congregate at anchorages and terminals near the south shore, with fewer numbers anchored off the north shore between the TWN community and Whey-ah-Wichen/Cates Park (WAW).

Pleasure Craft were more transient than Tugs; they accounted for 45% of vessel counts and 12% of residence time. The seasonal pattern mirrored that of the inlet as a whole. There was an average increase of 42% in vessel counts in Central Harbour during the summer months (May-August) compared to the remaining 8 months of the year, driven by Pleasure Craft traffic.

A disproportionately significant amount of marine vessel traffic in the Central Harbour was centered around the Westridge Marine Terminal in 2021. The traffic at the Westridge Marine Terminal was composed of Pleasure Craft, Passenger, Tugs, Port Operations vessels, and to a lesser extent Tankers and Government/Patrol vessels.

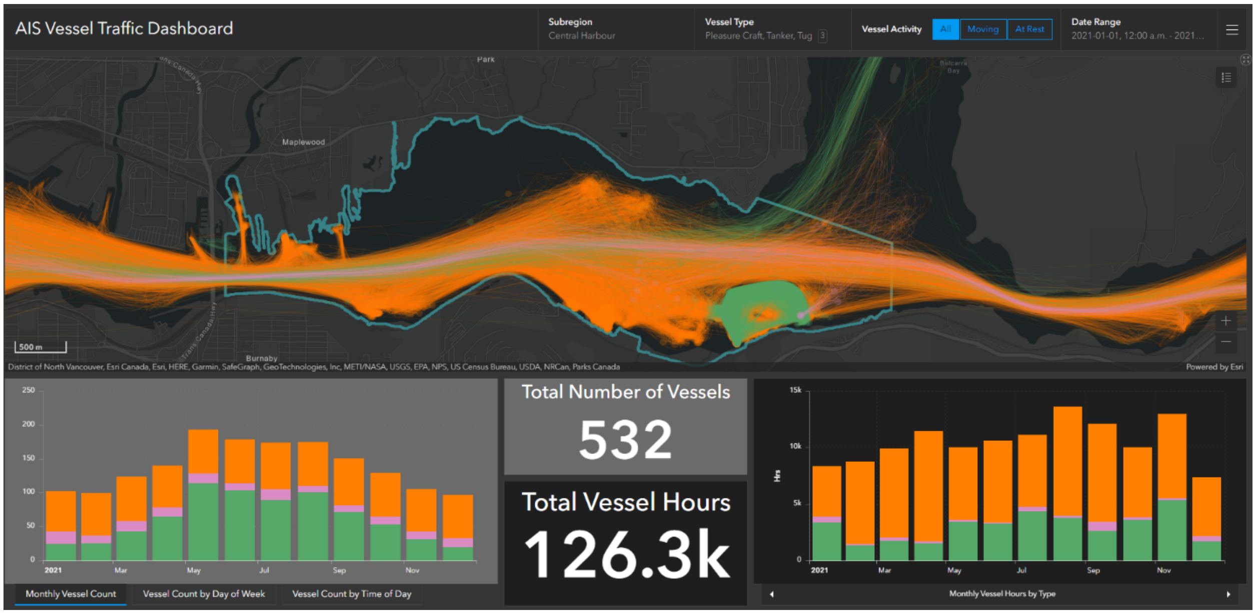


*Figure 5: Tugboat (orange), Pleasure Craft (green) and Tanker (pink) transits through the Central Harbour in 2021.*

### *Port Moody Arm*

Vessel counts in the Port Moody Arm were characterized by consistently high counts of Pleasure Craft and Tug vessels followed by smaller but steady counts of Tanker, Cargo, Government/Patrol, and Passenger vessels. Tugs were the most active, with by far the greatest in-transit resident times. An average of 10 tankers and 12 Cargo vessels operated in Port Moody Arm per month. Fishing vessels contributed to local traffic in Port Moody Arm, with the most time spent in January, September, and October.

### *Indian Arm*

More vessels transited the Indian Arm compared to Port Moody Arm in 2021; however, of all the subregions, vessels spent the least amount of time in the Indian Arm. Pleasure Craft are the dominant vessel type year-round. There was a high concentration of Pleasure Craft anchored in Bedwell Bay, even in comparison to moorages in Deep Cove. There was a notable pattern of vessel activity at the head of Bedwell Bay - which, upon further investigation, TWN staff confirmed was scientific research and the vessel was categorized as Special for this study.

Tugs were consistently present, and a single Cargo vessel operated year-round. A total of 62 Tankers were anchored at the southern end of Indian Arm over the course of the year. Fishing vessels were present in the spring through fall.

### *False Creek*

False Creek is congested with marine vessel traffic; however, due to the constraints of the basin, most oceangoing vessels (ex. Tankers and Cargo) are excluded from entering. Vessel traffic in False Creek was significantly dominated by Pleasure Craft followed by Passenger vessels. Fishing vessels had a particularly strong and active presence (in-transit residence time) in June, and Government/Patrol vessels traffic spiked in August.

**Recommendations and Management Considerations**
Recommendations related to the management and analysis of large AIS datasets for analyzing marine vessel traffic were provided in the attached CRM report.

The following recommendations are related to management considerations for TWN:

- ➢ It is recommended TWN works with the appropriate parties to develop a more accurate understanding of non-AIS vessels (e.g., non-AIS recreational boats, pleasure crafts, and commercial vessels), and their contribution to total vessel traffic in Burrard Inlet.
- ➢ AIS and non-AIS pleasure craft and associated infrastructure (ex. docks, marinas, anchorages, etc.) should be considered in all marine vessel traffic assessments for proposed project developments.
- ➢ Marine vessel traffic assessments should include overall marine traffic in Burrard Inlet and its cumulative effects, rather than vessel traffic related to individual projects.
  - ○ Marine vessel traffic assessments should also account for the geographic and operational constraints of each basin, on-water safety (ex. summer peak of pleasure craft vessel activity; vessel wakes), navigational hazards (ex. Maplewood Mudflats; Second Narrows), and associated infrastructure (ex. docks, marinas, anchorages, etc.) when considering the capacity of each basin to accommodate additional vessel traffic.
  - ○ Overall traffic, on-water safety, navigational hazards, and infrastructure need to be considered in the context of prominent vessel types used by TWN members to access and exercise their rights (ex. canoe).
- ➢ All marine vessels used for project-related construction and operations in Burrard inlet should be equipped with AIS, either in compliance with Transport Canada requirements or a voluntary measure.
- ➢ Marine vessel traffic in Burrard Inlet has seasonal signals, as does the local ecosystem and TWN's way of life. The cumulative effects of marine vessel traffic in Burrard Inlet needs to be considered alongside life histories of cultural and ecological keystone species, TWN harvesting times, and TWN cultural activities and ceremonial practices.
  - ○ Management measures could be developed to help mitigate specific seasonal impacts (ex. use of seasonal windows for certain activities) or to protect TWN values in specific locations (ex. restrictions around specific harvesting, cultural or ceremonial sites).
  - ○ Specific policies should be created and enforced to avoid and mitigate impacts of marine vessel traffic and associated infrastructure on limited and sensitive nearshore habitats in Burrard Inlet, such as eelgrass and kelp beds.
- ➢ Each vessel type has unique attributes which could potentially cause direct and acute impacts to TWN's traditional economy, as well as contribute to cumulative effects. Management measures could be developed for specific high-traffic vessel types to address priority and known impacts (ex. Tug vessel wakes).

- ➢ Work with the appropriate parties to plan for the marine vessel traffic associated with the projected growth of the VFPA’s trade and Metro Vancouver’s population to mitigate detrimental impacts on TWN’s rights, title, and traditional economy. A planning process may allow for certain management measures such as adjusted speed limits, exclusion zones, no-wake zones, etc.

TWN has also completed a wave monitoring study and sediment transport model for the Central Harbour. Future work entails interpreting the results of each of these studies together, to articulate the cumulative effects of marine vessel traffic in Burrard Inlet.

# Analysis of Marine Vessel Traffic in Burrard Inlet

Work performed by Coastal Resource Mapping Ltd, September 2022

Contact: Mark Dahl, mark@crmltd.ca

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# 1 Introduction

## 1.1 Background

The traditional territory of the Tsleil-Waututh Nation (TWN) includes the waters of the Burrard Inlet. Today, these waters host many additional marine uses, including the Port of Vancouver. The Port of Vancouver is Canada's largest port and the destination for thousands of oceangoing vessels annually. According to the Port Authority,

> *Canada's trade through the port has been increasing steadily for a decade and is forecasted to keep growing at about 3.5% annually. [1]*

Additionally, the Metro Vancouver region is expected to grow in population by 1 million people by 2050 [2]. Growth comes with benefits, but it also comes with change.

Among the changes are the impacts to traditional uses of the marine areas by the Tsleil-Waututh people. Tsleil-Waututh have continuously used and occupied these waters for millennia - long before Vancouver was on the map. Some of these activities were, and continue to be, economic in nature, including hunting, fishing, and shoreline gathering. Other activities are cultural or spiritual. Tsleil-Waututh used these waters for trade long before the Port Authority was established.

TWN obtained Coastal Resource Mapping (CRM) to quantitatively describe marine vessel traffic in Burrard Inlet. This is an essential step before additional work can be done to better understand and demonstrate impacts of marine vessel traffic and related cumulative effects on Tsleil-Waututh's inherent and constitutionally-protected rights, title and interests. The study period was January 1, 2021 to December 31, 2021.

## 1.2 Objectives

The objectives of this project are to:

- Generate quantitative measures of vessel interactions within defined subregions of the TWN marine area.
- Develop tools for data interrogation that put the TWN in control of the information.

- Generate a final report that succinctly presents methods and results clearly in such a fashion that work can be replicated in the future. The final report should also include any recommendations to inform the TWN's ongoing and future work.

# 2 Data

## 2.1 Data description and sources

At the core of this work is marine vessel Automatic Identification System (AIS) data acquired in the study area. Additional data include a static AIS data table with vessel attribution referenced by a Maritime Mobile Service Identity (MMSI) key as well as a spatial file with AOI polygons and attribution with respect to IMU indicators.

### 2.1.1 AIS data

The automatic identification system (AIS) is an automatic tracking system that uses radio signals and transceivers to identify and locate marine vessels. AIS data can be collected by a variety of methods, although most AIS data are collected by land-based receivers. AIS data collected by the Canadian Coast Guard (CCG) and was provided by Ocean Networks Canada (ONC) with permission from the CCG. Three fundamental pieces of information contained in AIS data were used: vessel identity (MMSI), vessel position, and a timestamp. A great wealth of analytical information is made available by processing the AIS data as a spatiotemporal dataset and are the primary data used for vessel analysis in this work. ONC provided an additional static AIS metadata attribution related to vessel type and dimensions which was used for vessel type classification.

### 2.1.2 Coastline data

To define the marine area within the study AOI, we used the *HydOcean* polygon feature class from the District of North Vancouver Open Data portal [3].

### 2.1.3 Study area of interest data

The study area of interest (AOI) was described by a polygon shapefile provided by TWN. The AOI included six subregions covering Burrard Inlet, including the Port Moody and Indian Arms, which were used for slicing data spatially. Boundaries were unmodified except for a portion of the boundary between False Creek and the Outer Harbour, which was adjusted to cross False Creek along a shorter path perpendicular to the shoreline. The *HydOcean* polygon was intersected with AOI to separate the marine from non-marine areas within the study AOI (Figure 1).

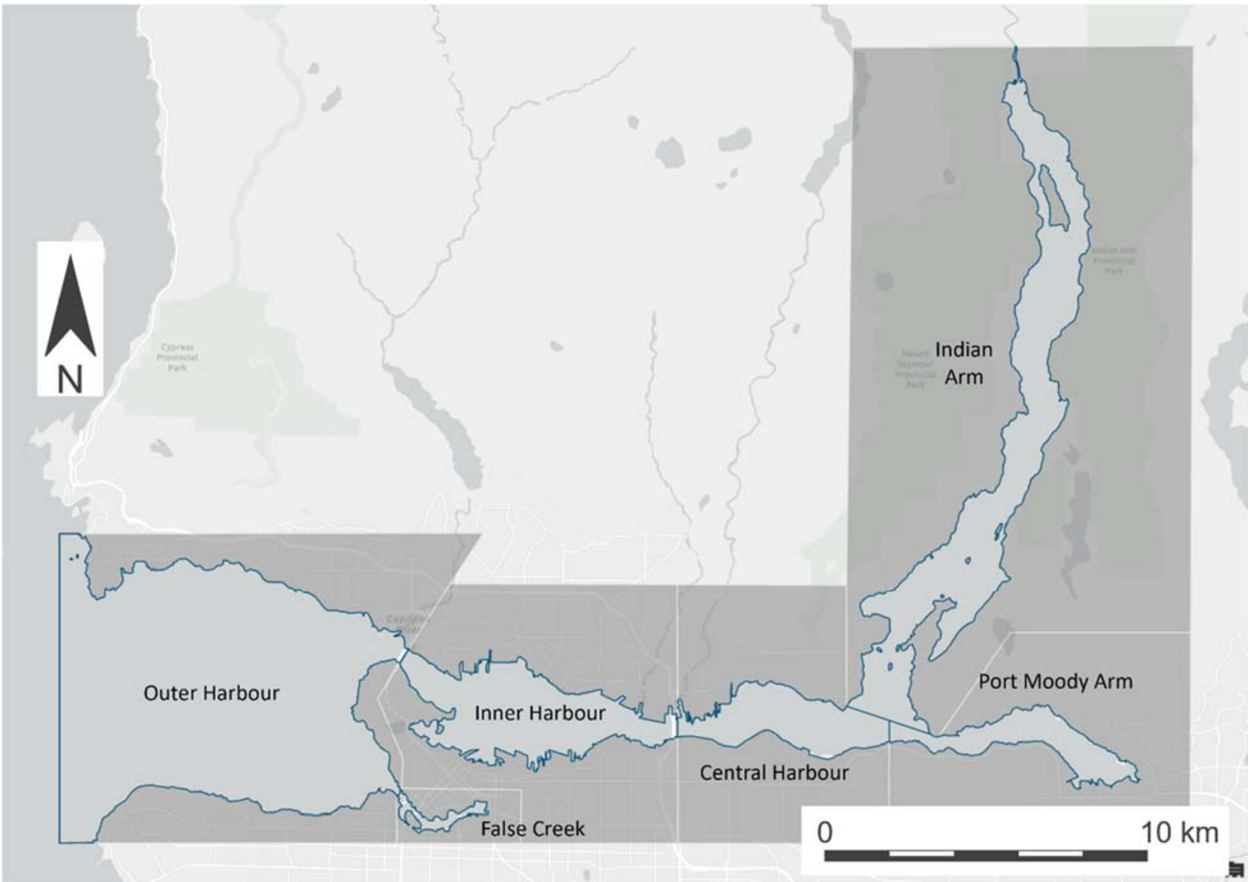


*Figure 1: TWN AOI.*

## 2.2 Data standards

Data submissions, as either inputs into the or outputs from the analysis, must adhere to the specifications documented in this section for final delivery. During data capture, investigation, development and quality control stages, project data may be in several formats for internal use.

### 2.2.1 Input data standards

*AIS data*. Preprocessed AIS data were provided by ONC as flat files (CSV format). The preprocessed file included attribution is described in Table 1.

*Table 1: Attribution requirements for AIS data.*

| *Field* | *Description* | *Data type* | *Standard* |
|---|---|---|---|
| *MMSI* | A Maritime Mobile Service Identity (MMSI) is a series of nine digits that are sent in digital form over a radio frequency channel to uniquely identify ship stations, ship earth stations, coast stations, coast earth stations, and group calls. An MMSI is registered to a single vessel and is used as a key. | INT | Required |
| *IMO* | Vessels registered with the International Maritime Organization (IMO) receive an IMO reference number that, like the MMSI, is used as a unique identifier for the vessel. Unlike the MMSI, IMO values are not available for all vessels. | INT | Not required |
| *Name* | Registered vessel name. | STRING | Not required |
| *Flag* | | STRING | Not required |
| *Type* | Vessel type. | STRING | Required |
| *Length* | Vessel length (m). | FLOAT | Required |
| *Beam* | Vessel width (beam) (m). | FLOAT | Not required |
| *Draught* | Vessel maximum draught (m). | FLOAT | Not required |
| *UTC Time* | A timestamp referenced to UTC time associated with each location coordinate pair. | DATETIME | Required |
| *Local Time* | A timestamp referenced to local time (PST/PDT) associated with each location coordinate pair. | DATETIME | Required |

| | | | |
|---|---|---|---|
| *Longitude* | Longitude of vessel. Vessel location is reported in geographical (WGS 84) coordinates pairs. | FLOAT | Required |
| *Latitude* | Latitude of vessel. Vessel location is reported in geographical (WGS 84) coordinates pairs. | FLOAT | Required |
| *SOG* | Speed over ground. Is the actual speed of travel. | FLOAT | Not required |
| *COG* | Course over ground is the actual direction of travel. | FLOAT | Not required |
| *Heading* | Heading, or forward orientation, of vessel. | INT | Not required |
| *Status* | Vessel activity status. | STRING | Not required |
| *Destination* | Next port-of-call for vessel. | STRING | Not required |

*AOI*. The study AOI was provided by the TWN as a polygon in shapefile format. An AOI must be of shapefile or feature class format and attributed with labels and attribution necessary for data slicing.

### 2.2.2 Output data standards

*Spatial data*. Spatial data generated from the vessel transit analysis was packaged as a geodatabase. Spatial data provided includes 1) AIS data, processed at a one-minute frequency, 2) kernel density rasters generated from processed AIS data, and 3) polygons used in data processing and slicing. No map formatting was provided with the spatial data.

*Non-spatial data*. Non-spatial data generated from the vessel transit analysis provided includes tables and charts. Tabular data were delivered as CSV flat files and charts as PNG image files.

*Dashboard*. In addition to the spatial and non-spatial data deliverables, an interactive, Cloud-based Dashboard configured to facilitate interrogation of the vessel traffic analysis was provided to TWN. To ensure functionality and performance, AIS data were converted to line features at a one-hour frequency.

# 3 Methods and analysis

## 3.1 Software

All data processing, analysis, and modeling was executed with the Python 3 [4] programming language, while all spatial analysis and mapping was conducted using ESRI ArcGIS Pro 2.9 [5].

## 3.2 AIS data processing

AIS data preparation and processing conducted before any analysis included importing data into ArcGIS Pro, cleaning data, identifying data discontinuities, interpolating time-series data across continuous data, and performing quality audits.

### 3.2.1 Calculation of distance

Using a vessel's MMSI as an index, the AIS data can be laid out as a spatiotemporal array of points—a path—for each vessel. Distance cannot be calculated directly from a latitude and longitude coordinate pair, as geographic coordinates are separated by an angle rather than an arc distance. The distance between AIS points was fundamental to this work, required for data processing and vessel activity classification, so it is worth presenting in some detail. We used Vincenty's Method [6] to calculate all distances between consecutive points. Like the Haversine Formula in form, Vincenty's Method is a better approximation, representing the Earth as an oblate sphere rather than a sphere. See Appendix A for more on Vincenty's Method.

### 3.2.2 Cleaning AIS data

AIS data errors are not uncommon. These errors may be a bad position, an incorrectly referenced timestamp, or an incorrect MMSI. An effective way to identify a bad AIS data point is to look for anomalously high velocities. The average velocity between two consecutive points was calculated as $d / \Delta t$, where $d$ is the distance between two consecutive points of the same vessel and $\Delta t$ is the elapsed time between those points. To clean the data, we iteratively identified and discarded positions that resulted in vessel average velocities over 30 m/s (58.3 Knots). Although some vessels may be capable of this velocity, none of the velocities greater than this threshold observed in the dataset were legitimate.

Errors also manifest as unrealistic positions, such as many of the positions observed on land. To deal with erroneous land points, we select those land points within 100 m of the shoreline and snapped them to the nearest shoreline vertex. In some cases, these land points are legitimate; however, legitimate land points tend to quickly move away from the shoreline (e.g., a pleasure craft towed on a trailer). All land points greater than or equal to 100 m from the shoreline were removed. This approach presented the best compromise between preserving marine positions and eliminating non-marine positions.

Duplicate records may be observed in AIS data. While preparing the AIS data for processing, we removed duplicate records. A duplicate record was identified as a record with matching timestamp and vessel MMSI. In the case of a duplicate record, the first occurrence of the record, sorted by MMSI and timestamp, was preserved.

These preprocessing steps ensured that we began our analysis steps with a relatively clean and error-free dataset.

### 3.2.3 Interpolating time-series data

The next step was to create a regular-frequency dataset for time series analysis. A regular time-step makes differences in vessel motion vectors time-independent and allows for direct comparison of vessel motion. One can imagine that a vessel evaluated over different time intervals might return the same average velocity while performing very different activities within those intervals. For example, a vessel moving around a single location evaluated hourly might appear to be at-rest. Additionally, using a regular time-step simplified the evaluation of residence times to an exercise of counting rows in tables.

AIS data timestamps are recorded to the millisecond (ms) and are only coincident with seconds and minutes by chance. Data, as received from ONC, was resampled and typically represented each vessel with a consistent frequency. However, the frequency used varied by vessel. To generate a smooth interpolation between source points, we first resampled the data to a one-second frequency and then eliminated all but those points falling on the minute, leaving us with a one-minute frequency.

### 3.2.4 Data discontinuities

The data must be ordered before interpolation is performed. It is obvious that each vessel must be processed separately; however, within the records of each vessel, the data may represent several distinct voyages, separating by periods outside of the AOI. Additionally, if an AIS transponder is inactive for any significant duration, it is not appropriate to presume that the vessel's position can be interpolated across those time gaps with an acceptable level of confidence.

To identify discontinuities, we flagged discontinuities within AIS data for each vessel to create a voyage index according to these criteria:

1) Consecutive positions greater than 1 hour apart and

2) Consecutive positions at a distance greater than 900 m from each other.

Processing data by vessel and voyage, we preserved voyage continuity over relatively small time-gaps as well as relatively large time-gaps with small changes in vessel position (i.e., positions at rest) while avoiding interpolation over low-confidence data gaps. To more accurately represent vessels not transmitting as AIS signal while at rest, interpolated positions evaluated as *at rest* were preserved. A position was evaluated as at rest where velocity, as calculated from the source data during the data cleaning step, was less than 0.25 m/s (0.486 knots). Note that this is only a first approximation of vessel behaviour and not used as the final vessel activity label.

### 3.2.5 Quality control

Processed AIS data was visually inspected to ensure quality. Among the errors observed in the output were vessel paths between points of entry into the Outer Harbour from the Straight of Georgia within one hour or 900 m of the point of exit. This condition resulted in interpolation between the points as though the vessel was at rest. To address this error, interpolated vessel paths along the western margin of the Outer Harbour were manually eliminated from the result. Due to the rugosity of the shoreline of Burrard Inlet and Indian Arm, some interpolated points fell on land. These points were snapped to the nearest edge of the shoreline.

## 3.3 Vessel traffic analysis

The purpose of vessel traffic analysis is to generate labels that allow the data to be sliced. Two of the most important data dimensions required for data slicing are characteristic of AIS data: time and vessel MMSI. In addition to time and vessel MMSI, the data dimensions required to create the output data slices are 1) vessel subregion, 2) vessel activity status, and 3) vessel type.

### 3.3.1 Vessel subregion residence

To facilitate data slicing in terms of subregions within the AOI, the preprocessed AIS data are spatially joined to the AOI feature class. Vessel subregion is inherited from the spatial join and carried throughout the analysis.

### 3.3.2 Vessel activity status

Vessel activity status is reported for some vessels, but not for all. Furthermore, many vessels reporting vessel activity status are incomplete or incorrect, making use of provided labels unreliable. For example, it is common to observe a vessel report the status “moored” at a terminal and then, after leaving the terminal, continue to report the status “moored” along a course away from the terminal and out of the AOI. Fortunately, a vessel’s activity status can be inferred by its motion.

Depending on the vessel type, vessel activity can be classified as any one of a variety of statuses: moored, at anchor, sailing, sailing under engine power, under engine power, towing, pushing, and so on. However, many of these vessel activities cannot accurately be predicted without accurate reporting of engine output. Using only vessel motion metrics, vessels can be broadly classified as being at rest (i.e., at anchor or moored) or in transit (i.e., moving along a course).

Through some iteration, we generated accurate points-of-rest for a vessel in three steps.

1) Calculate the two-way average velocity at each point. A two-way average is a better approximation of instantaneous velocity at each point than a velocity calculated in a single direction (looking forward or looking backward).
2) Evaluate each point as *at-rest* or *not at-rest*. As before, a vessel is said to be *at rest* at a velocity less than 0.25 m/s (0.486 knots). We arrived at this value through iterative sensitivity testing. Note that other methods, including Machine Learning techniques were considered for this step, but uncertainty in the training data eliminated these options.
3) Apply three successive maximum filters of size k=5 to consolidate point-of-rest broken by one or more *not at-rest* point. The three maximum filters are directly followed by three successive minimum filters of size k=5, which limits the duration of the point-of-rest to the original start and end points.

After performing these three steps, most points-of-rest are aggregated into blocks of 13 minutes or greater. Points-of-rest can be shorter in duration if the original end points span a shorter period or if a lack of data continuity precludes filtering. Note that five continuous data points are required for a filter of size k=5, nine continuous data points are required for two filters of size k=5, and thirteen continuous data points are required for three filters of size k=5.

As a final step performed before data slicing, all but the initial AIS point of a continuous point-of-rest were eliminated with the single point being assigned the summation of the time deltas for the duration of the point-of-rest. The time delta for points-of-rest, therefore, were variable at this point. This step was necessary to perform data slicing, as memory requirements to load all points-of-rest at a one-minute frequency were prohibitively great. Collapsing the one-minute frequency sequence of a point-of-rest to a single point had the additional benefit of cleaning up the visual display of the output. Tens, hundreds, or thousands of points scattered around a location to communicate a single point-of-rest just creates visual clutter.

### 3.3.3 Vessel types

Vessel type was included among attribution provided with data received from ONC. Vessel type reflects the category a vessel is registered as, according to its function. However, vessel type classes, as received, were more specific than required for this analysis. To simplify vessel type, we eliminated variations on general vessel type class. For example, all vessel types with "Cargo" in the name were remapped to a single vessel type called "Cargo". The resulting vessel type classes were still too numerous, so several classes were grouped together. Additionally, some labels provided in the source data were found to be incorrect. Consequently, final vessel type labels were determined after cross-referencing more detailed vessel type attribution available on Marine Traffic's web-based database.  Table 2 briefly describes each vessel type class used in this study.

*Table 2: Vessel type descriptions.*

| Vessel Type | Description |
|---|---|
| **CARGO** | Any vessel used to carry cargo, goods, and materials from one port (or vessel) to another. Cargo vessels include dry bulk carriers, vehicle carriers, container ships, wood chips carriers, reefer ships, supply ships, and so on. Note that tankers are excluded from the Cargo category. |
| **DREDGING** | Any vessel used to excavate the material from the submarine environment, making the waters of ports, rivers, lakes, and nearshore locations safe to navigate. While Dredgers are not numerous, they can disproportionately impact the marine environment due to their function. |
| **FISHING** | Any vessel used for catching fish or other sea life, transporting the catch of another vessel, or supporting fishing activities. |
| **GOVERNMENT/PATROL** | Any vessel used for patrol, law enforcement, military operations, pollution control, search and rescue, public safety, ice breaking, or public service activities. |
| **PASSENGER** | Any vessel used to carry one of more passengers, where a passenger is one who has paid for a voyage. Cruise ships are excluded from the Passenger category. |

| | |
|---|---|
| **PLEASURE CRAFT** | Any vessel used for pleasure or recreation and not used 1) to carry paying passengers or 2) for commercial or governmental services. |
| **PORT OPERATIONS** | Any vessel operated under command of a port authority and used to regulate the movement of vessels in and out of a port or aid in the operation of the port. Most Port Operations vessels are a form of Tug but are treated separately due to their specific functions and limited operational range. |
| **SPECIAL** | Any vessel with a specified function that fell outside the other vessel type categories (e.g., Cable Laying, Buoy Laying, Diving, Survey, Research, and so on). |
| **TANKER** | Any vessel used to carry fluids in bulk. Tankers fall within the broader Cargo category but is given its own category here due to specific differences in design and safety concerns associated with transporting fluids. |
| **TUG** | Any vessel used to move non-self-propelled structures (e.g., barges, platforms, and log booms), support the manoeuvring of large vessels, or perform a variety of industrial operations requiring powerful and manoeuvrable watercraft. |

## 3.4 Slicing data

Data were sliced to report 1) residence times for vessels at rest, 2) residence times for vessels in transit, and 3) vessel counts. For this report, data were sliced by subregion, by month, and by vessel type. For the Dashboard, additional slices were provided to better facilitate interrogation of the results. Irrespective of the data slice, the data within the slice were summarized consistently.

### 3.4.1 At-rest period

Vessel points-of-rest had been assigned a time delta value according to the duration of the continuous period at rest. The sum of the time delta was reported for each slice and tabulated in the results.

### 3.4.2 In-transit period

During preprocessing, AIS were resampled to a one-minute frequency. However, discontinuities in the data result in some time deltas greater than one minute, which do not necessarily reflect a vessel's residence time in the AOI. Therefore, rather than summing the time delta values, we simply count the transit rows in each slice to determine the number of minutes of transit time.

### 3.4.3 Vessel counts

To determine vessel counts, the count of unique vessel MMSI is reported for each data slice.

# 4 Results

The results from performing analysis AIS data to characterize marine vessel traffic were summarized in two sections. In the first, vessel types observed in the dataset were tabulated. In the second, data were intersected with AOI polygons and sliced by calendar month and vessel type to summarize residence periods and counts.

## 4.1 Vessel types observed

Vessel type labels used for data slicing that were observed in the subregion AOI were tabulated.  Each vessel type label assigned in the source data was cross-referenced, showing the value mapping from the source to output. Additionally, counts of each unique combination of vessel type assignment were provided (Table 3).

*Table 3: Vessel types observed in AOI.*

| VESSEL TYPE (SOURCE LABEL) | VESSEL TYPE (REMAPPED LABEL) | COUNT |
|---|---|---|
| **ANTI-POLLUTION FACIL./EQUIP.** | Government/Patrol | 17 |
| **CARGO SHIP** | Cargo | 1178 |
| **CARGO SHIP** | Fishing | 2 |
| **CARGO SHIP** | Pleasure Craft | 1 |
| **CARGO SHIP** | Tanker | 1 |
| **CARGO SHIP** | Tug | 2 |
| **CARGO SHIP:DG,HS,MP(OS)** | Cargo | 21 |
| **CARGO SHIP:DG,HS,MP(X)** | Cargo | 80 |
| **CARGO SHIP:DG,HS,MP(X)** | Tug | 2 |
| **CARGO SHIP:DG,HS,MP(Y)** | Cargo | 12 |
| **CARGO SHIP:DG,HS,MP(Z)** | Cargo | 8 |
| **DIVING OP.** | Special | 3 |

| | | |
|---|---|---|
| **DREDGING OR UNDERWATER OP.** | Dredging | 2 |
| **DREDGING OR UNDERWATER OP.** | Special | 3 |
| **FISHING** | Fishing | 48 |
| **FISHING** | Pleasure Craft | 1 |
| **HSC** | Passenger | 1 |
| **LAW ENFORCEMENT** | Government/Patrol | 3 |
| **LOCAL SHIP** | Government/Patrol | 1 |
| **LOCAL SHIP** | Tug | 5 |
| **MILITARY OP.** | Government/Patrol | 11 |
| **OTHER** | Cargo | 3 |
| **OTHER** | Fishing | 1 |
| **OTHER** | Passenger | 3 |
| **OTHER** | Pleasure Craft | 2 |
| **OTHER** | Special | 9 |
| **OTHER** | Tanker | 1 |
| **OTHER** | Tug | 5 |
| **PASSENGER SHIP** | Passenger | 52 |
| **PASSENGER SHIP** | Special | 1 |
| **PILOT** | Port Operations | 3 |
| **PLEASURE CRAFT** | Passenger | 1 |
| **PLEASURE CRAFT** | Pleasure Craft | 612 |
| **PLEASURE CRAFT** | Special | 1 |
| **PORT TENDER** | Pleasure Craft | 1 |
| **PORT TENDER** | Port Operations | 3 |
| **SAILING** | Pleasure Craft | 285 |
| **SAILING** | Tug | 1 |
| **SEARCH/RESCUE** | Government/Patrol | 34 |
| **SEARCH/RESCUE** | Special | 3 |
| **SHIP** | Tug | 1 |
| **TANKER** | Cargo | 1 |
| **TANKER** | Tanker | 93 |
| **TANKER** | Tug | 1 |

| | | |
|---|---|---|
| **TANKER:DG,HS,MP(OS)** | Tanker | 2 |
| **TANKER:DG,HS,MP(X)** | Tanker | 2 |
| **TANKER:DG,HS,MP(Y)** | Tanker | 20 |
| **TOWING** | Tug | 47 |
| **TOWING(200/25)** | Tug | 23 |
| **TUG** | Tug | 104 |

## 4.2 Interpreting marine vessel traffic results

Results have been presented as a series of maps, tables, and charts. Each table is a statistical summary of data sliced by month, activity status, and vessel type. For all tables and charts for each subregion and vessel activity, data were sliced by month and by vessel type. As the primary objective of the maps was to illustrate spatially variation in data, data were not sliced by month and vessel type. However, data symbology was used to illustrate data slices in maps, according to the specific information being displayed in each map.

The summary tables and charts are presented following this layout:

1. Characterizing spatial variation of vessel traffic
    a. A map for the full AOI and all vessel types, with points sliced by anchorages and transits.
    b. A map for the full AOI and each vessel type, kernel density.

For each subregion, summary tables and charts are presented following this layout:

1. At-rest period
    a. Table, sliced by month and vessel type.
    b. Chart, sliced by month and vessel type.
2. In-transit period
    a. Table, sliced by month and vessel type.
    b. Chart, sliced by month and vessel type.
3. Vessel counts
    a. Table, sliced by month and vessel type.
    b. Chart, sliced by month and vessel type.

With the layout of the figures characterized, we can address the information within each figure.

*Tables*. Tables summarize numerical data sliced along categorical and temporal dimensions. Each row of a table contains data summarized from one calendar month. Each column of a table contains data associated with one vessel type class. Monthly row and vessel type column values are summed, providing totals for each. As many vessels are present in multiple months, the annual count of unique vessels is less than the sum of monthly counts of unique vessels.

*Charts*. The same numerical values summarized in tables have been illustrated with stacked bar charts. Like the row of a table, each bar of a chart represents data summarized from one calendar month and, like the column of a table, each colour-coded portion of the stacked bar represents data associated with one vessel type class. Rather than using numerical values, the bar height represents the magnitude of the corresponding value in the table.

*Maps*. Maps are included to show spatial relationships in the data that would otherwise not be evident in table or chart form. Data are illustrated spatially in maps using several symbology methods.

*Vessel residence periods*. To visualize vessel residency, or overall use, of the marine area, two types of maps have been provided.

- *Point map*. Vessel positions are plotted directly as points at a 1-minute frequency, shown for all vessels across the full duration of the dataset (i.e., from the beginning of January 2021 to the end of December 2021). The density of points, inferred visually, is a qualitative means of evaluating spatial variation of marine vessel traffic. Transit points are shown as violet-blue dots and anchorages are shown as red dots. Note that transit dots are displayed at 99% transparency and require a great deal of vertical stacking to build opacity in colour.
- *Kernel density map*. Vessel kernel density is shown for all vessels across the full duration of the dataset. Rather than plotting AIS data, which can be used to infer density visually, AIS point density is calculated directly, displaying density as a magnitude.

### 4.2.1 Spatial distribution of vessel traffic

A variety of spatial patterns are visible when inspecting the full vessel traffic dataset (Figure 2). Oceangoing vessels followed designated navigation into and out of the Port of Vancouver. Non-oceangoing vessels navigated along different corridors that converged with the oceangoing vessel corridors at various points. Parts of the Outer Harbour, Central Harbour (including in proximity to TWN's shoreline), Port Moody Arm, and Indian Arm experienced relatively light vessel traffic. The heaviest traffic occurred in the Inner Harbour, which was solid with vessel traffic. Points-of-rest were predictably concentrated at a variety of terminals and moorages along the shoreline as well as at designated anchorages throughout the marine area.

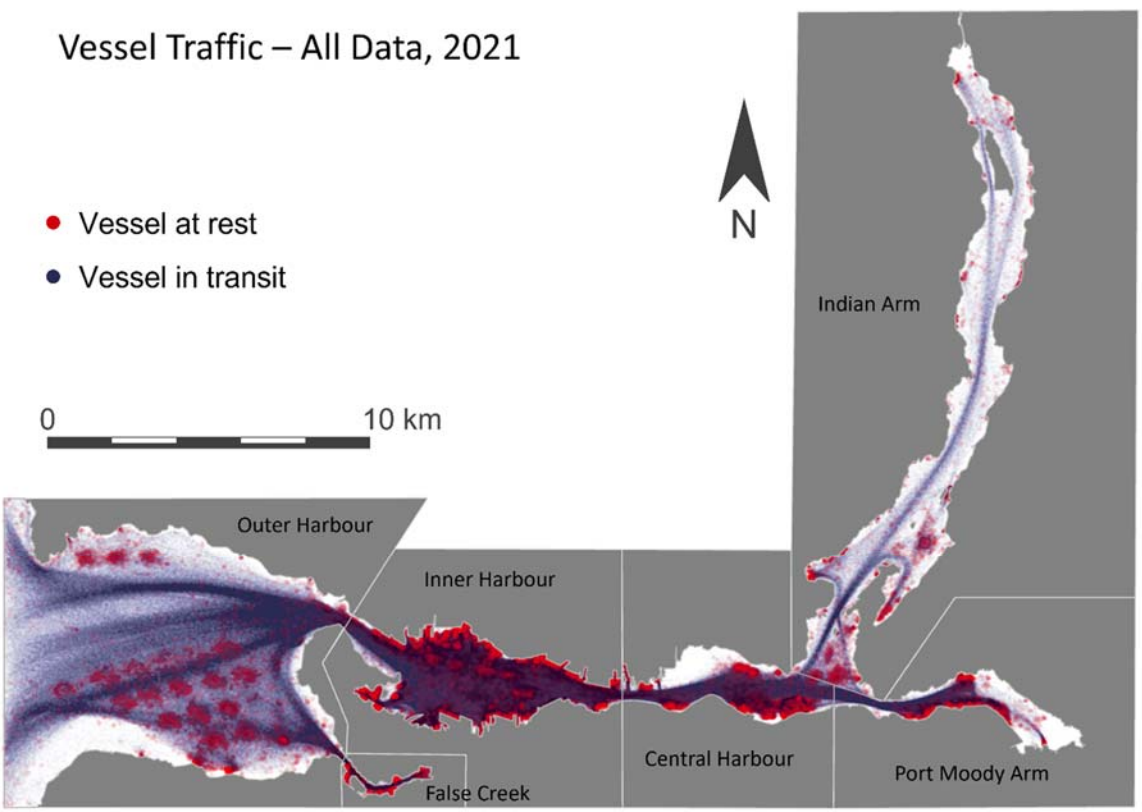


*Figure 2: Vessel traffic across all subregions displayed as points at a one-minute frequency.*

### 4.2.2 Vessel traffic mapped by vessel type

To better understand the spatial patterns observed in the full dataset, vessel traffic is displayed as a kernel density map by vessel type.

#### *Vessel traffic map, Cargo vessels*

Cargo vessels followed predictable behaviours, visiting anchorages and terminals concentrated in the Inner and Outer Harbour subregions (Figure 3). Heavy Cargo vessel traffic was observed all the way to the Port Moody Arm. A single Cargo vessel, that operated year-round, generated the relatively light traffic observed in the Indian Arm.

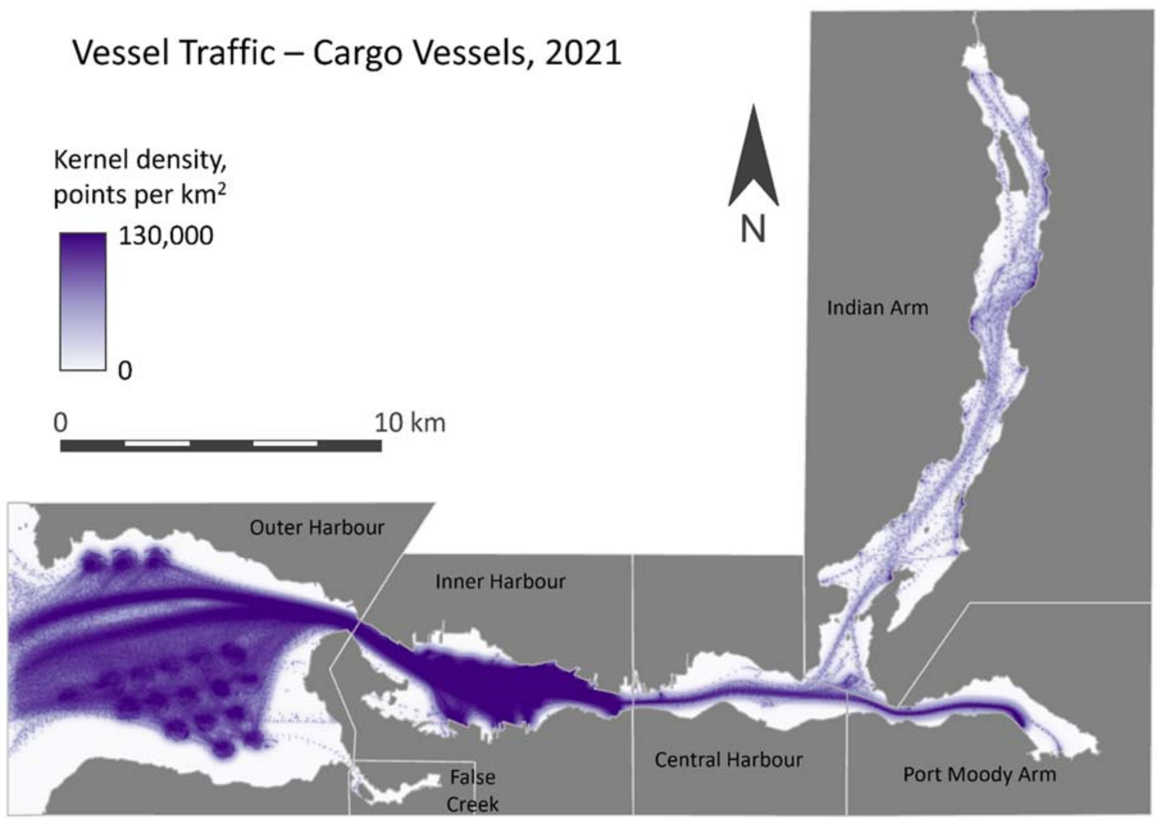


*Figure 3: Vessel traffic map, Cargo vessels.*

*Vessel traffic map, Dredging vessels*

Dredging vessels spent most of their time in specific areas of the Inner Harbour, Central Harbour, Port Moody Arm, and Indian Arm (Figure 4).

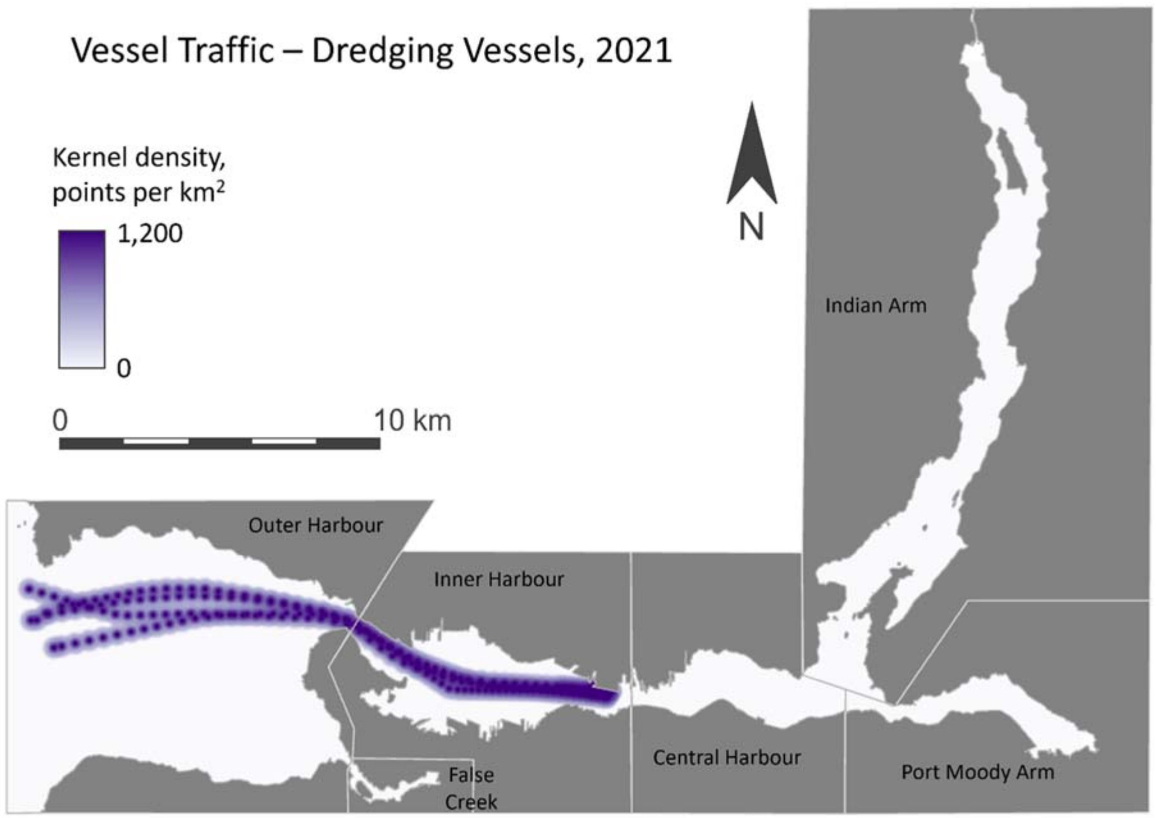


*Figure 4: Vessel traffic map, Dredging vessels.*

*Vessel traffic map, Fishing vessels*

Fishing vessels generated heavy traffic between the Straight of Georgia and a variety of terminals in the Inner Harbour and False Creek (Figure 5). Additional heavy Fishing vessel traffic was observed locally in the Port Moody Arm and Indian Arm. Fishing vessels did not observe strict navigation corridors like oceangoing vessels.

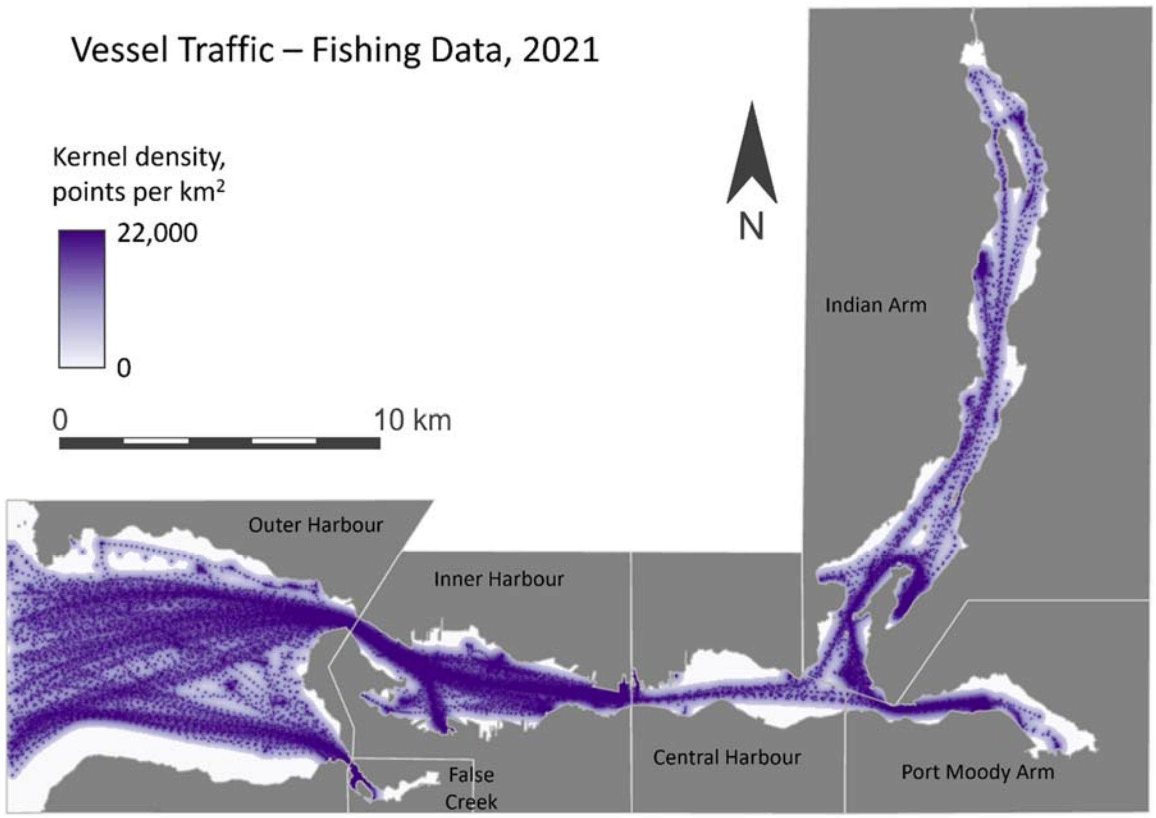


*Figure 5: Vessel traffic map, Fishing vessels.*

*Vessel traffic map, Government/Patrol vessels*

Government/Patrol vessels generated heavy traffic in all the usual locations but also along shorelines with beaches and marine access (Figure 6). Unlike other vessel types, Government/Patrol vessel traffic covered every navigable area on the map. This should be expected, as this class of vessel type includes law enforcement and antipollution vessels, which patrolled waters that may be restricted to other vessel types.

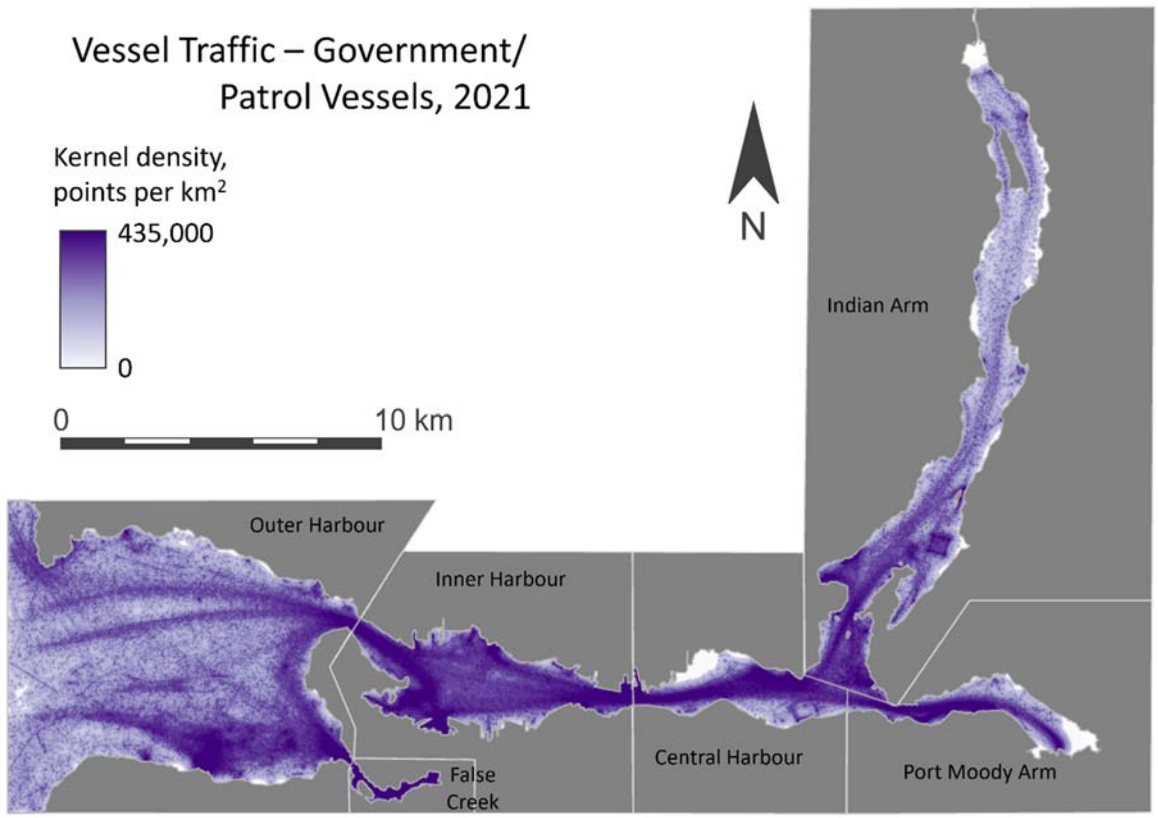


*Figure 6: Vessel traffic map, Government/Patrol vessels.*

*Vessel traffic map, Passenger vessels*

Passenger vessels generated extremely high traffic in the Inner Harbour (Figure 7). The chief contributors to this traffic were the Sea Buses, which ran steadily for most hours of the day and most days of the year. Other areas of heavy traffic are found along a variety of public and private terminals where water taxis transported passengers to and from.

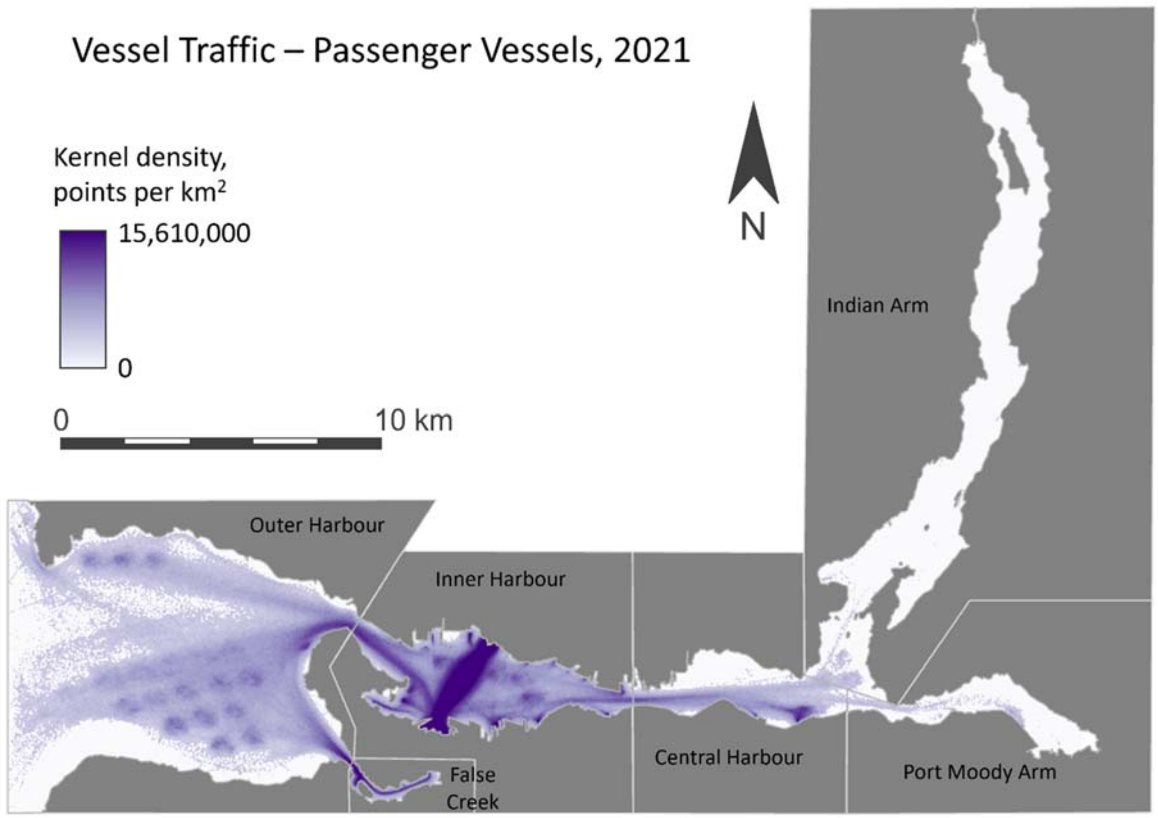


*Figure 7: Vessel traffic map, Passenger vessels.*

### *Vessel traffic map, Pleasure Craft vessels*

Pleasure Craft vessels were responsible for high traffic areas throughout each subregion (Figure 8). Spatial patterns demonstrate that, while Pleasure Craft will go anywhere, they preferred to navigate along corridors. All high-traffic corridors terminate at moorages, which, in most cases, are marinas. It should be noted that Pleasure Craft traffic is vastly underestimated by AIS as the AIS equipment is not a requirement for most Pleasure Craft.

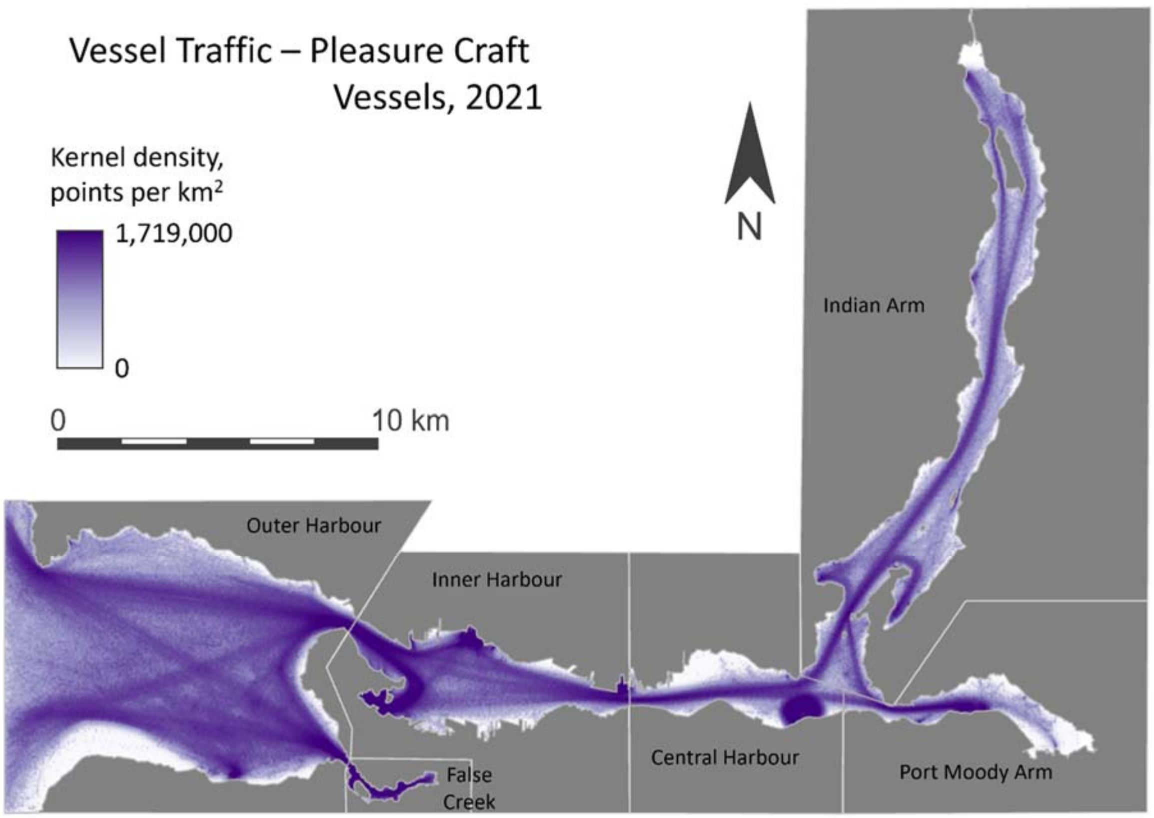


*Figure 8: Vessel traffic map, Pleasure Craft vessels.*

### *Vessel traffic map, Port Operations vessels*

Port Operations vessels generated heavy traffic in all the same locations as oceangoing vessels: along the spine of Burrard Inlet and into the Outer Harbour (Figure 9). The highest traffic areas were concentrated around terminals associated with the Port of Vancouver and, additionally, extend to locations in the southern part of the Indian Arm.

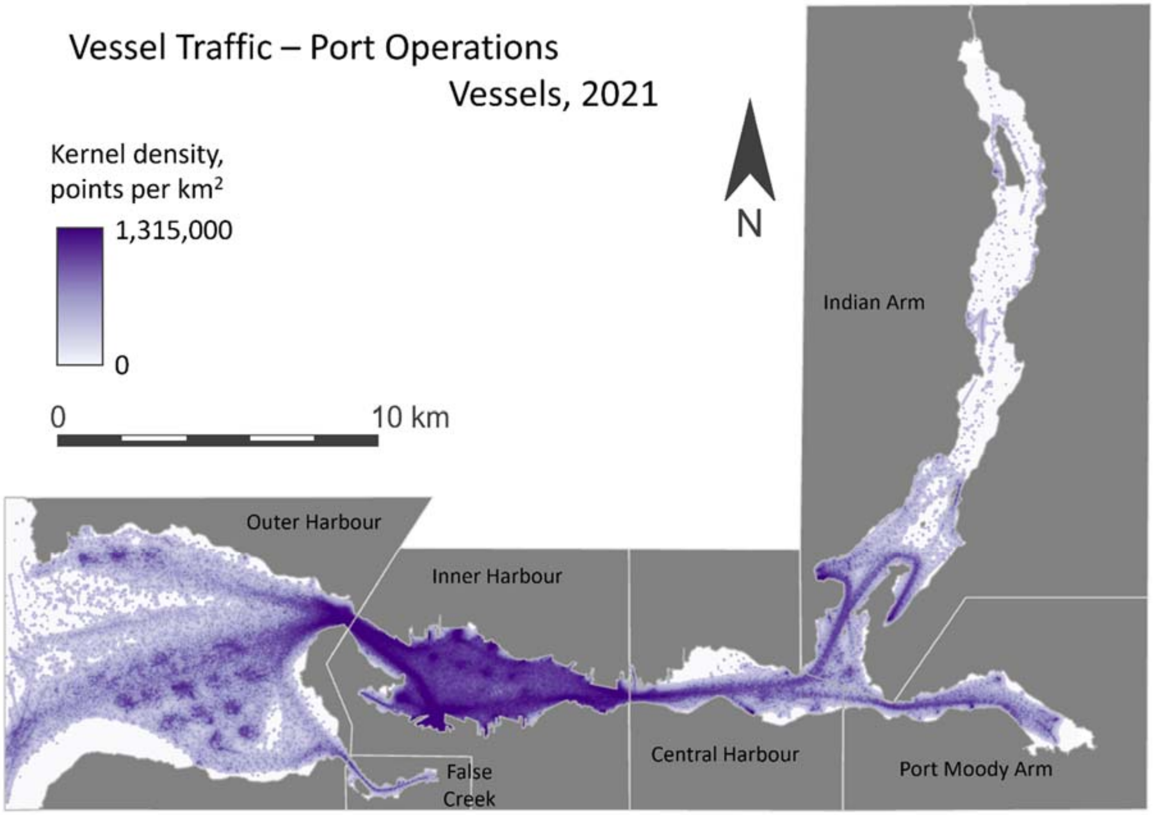


*Figure 9: Vessel traffic map, Port Operations vessels.*

### *Vessel traffic map, Special vessels*

Special vessels generated traffic well distributed throughout the AOI (Figure 10). This is expected as Special vessels cover a wide variety of watercraft covering a range of purposes. Special vessels do not fit neatly in the other classes, including such vessel type labels as cable laying, buoy laying, surveying, research, diving and underwater operations, and reserved.

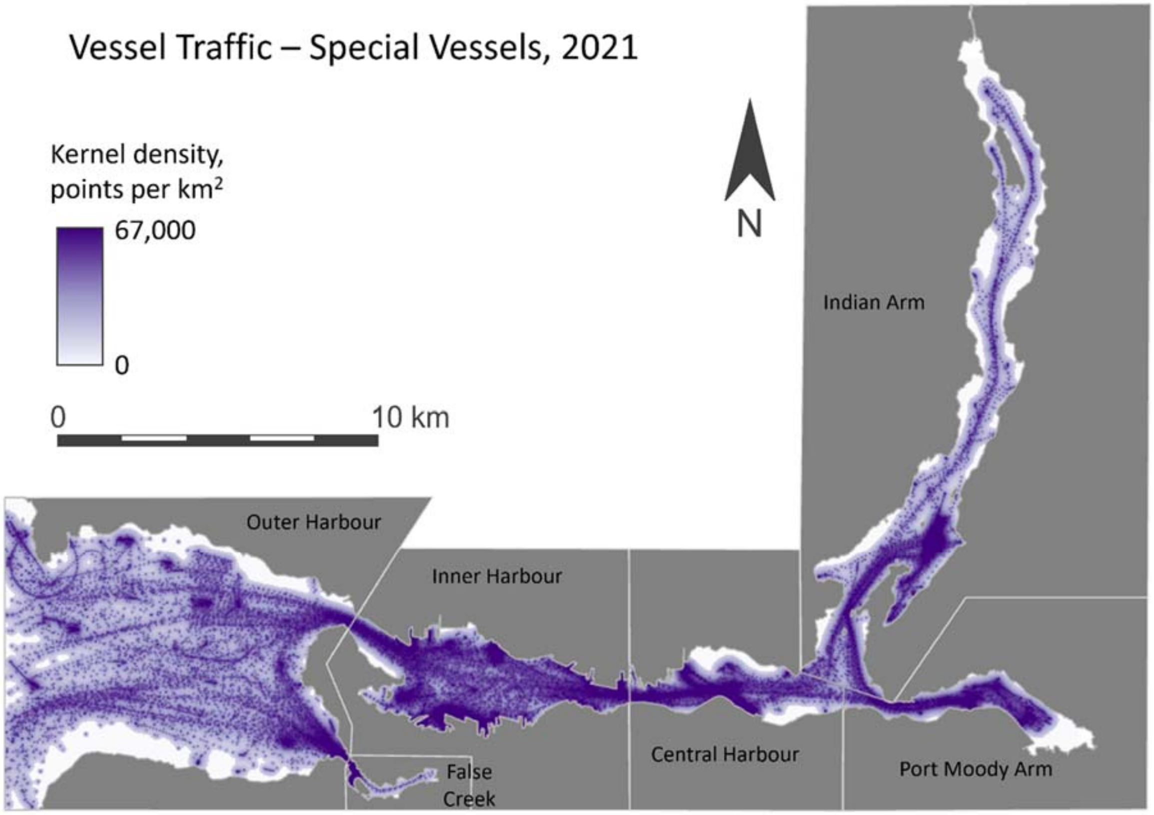


*Figure 10: Vessel traffic map, Special vessels.*

### *Vessel traffic map, Tanker vessels*

Tanker vessel traffic was like Cargo vessel traffic, but with much of the vessel traffic visiting terminals in the Central Harbour and Port Moody Arm rather than Inner Harbour (Figure 11).

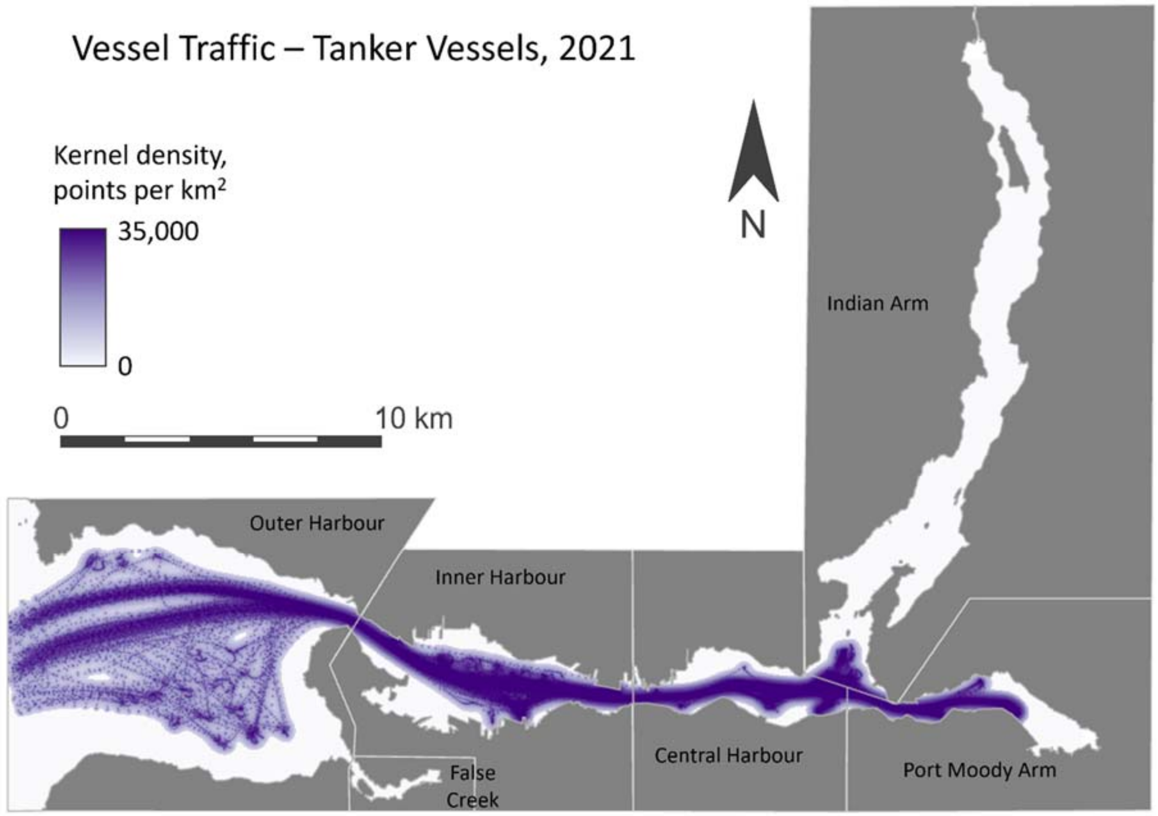


*Figure 11: Vessel traffic map, Tanker vessels.*

### *Vessel traffic map, Tug vessels*

Tug vessels generated heavy traffic in all the same locations as oceangoing vessels: along the spine of Burrard Inlet and into the Outer Harbour (Figure 12). The highest traffic areas were concentrated around industrial locations in the Inner and Central Harbours.

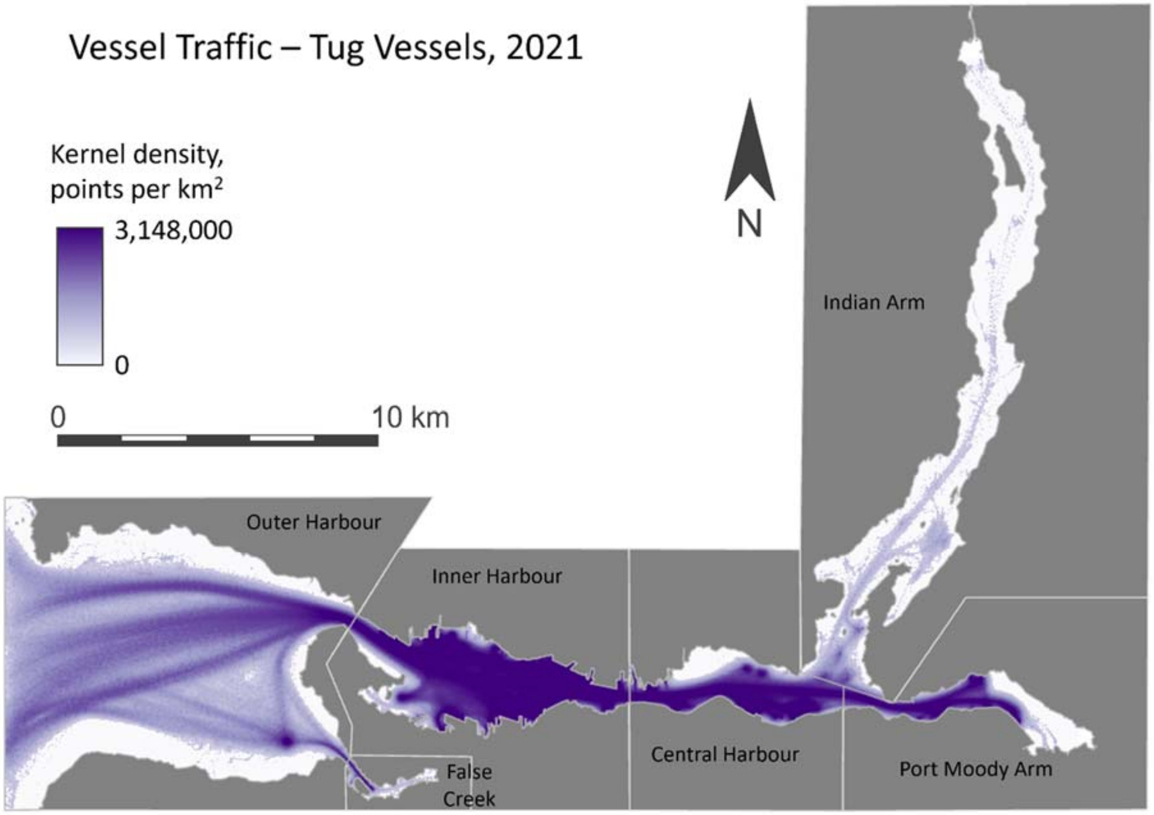


*Figure 12: Vessel traffic map, Tug vessels.*

### 4.2.3 Vessel traffic in each subregion

#### *Vessel traffic, Outer Harbour*

The Outer Harbour was dominated by Cargo and Pleasure Craft vessel traffic (Table 4, Figure 13). Pleasure Craft vessels demonstrated a seasonal signal (peaking in the summer), while Cargo vessels were relatively constant throughout the year.

*Table 4: Residence hours, vessels at rest in the Outer Harbour.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 12087 | 0 | 5 | 278 | 658 | 1838 | 10 | 0 | 274 | 60 | 15210 |
| **FEB** | 10794 | 0 | 0 | 962 | 721 | 4999 | 15 | 1 | 326 | 72 | 17890 |
| **MAR** | 11140 | 0 | 0 | 1282 | 66 | 9598 | 3 | 5 | 475 | 589 | 23159 |
| **APR** | 9510 | 0 | 0 | 1474 | 90 | 12887 | 0 | 27 | 808 | 902 | 25696 |
| **MAY** | 9207 | 0 | 132 | 2137 | 435 | 13060 | 6 | 1 | 119 | 578 | 25674 |
| **JUN** | 9644 | 0 | 584 | 2562 | 138 | 13434 | 1 | 0 | 304 | 336 | 27003 |
| **JUL** | 10045 | 0 | 0 | 2804 | 228 | 12663 | 1 | 89 | 298 | 175 | 26303 |
| **AUG** | 8938 | 0 | 0 | 2825 | 527 | 16676 | 1 | 2 | 18 | 175 | 29162 |
| **SEP** | 9050 | 0 | 0 | 2277 | 718 | 16449 | 35 | 19 | 246 | 417 | 29210 |
| **OCT** | 11739 | 0 | 0 | 1134 | 806 | 11461 | 5 | 33 | 131 | 338 | 25647 |
| **NOV** | 11067 | 0 | 17 | 1468 | 745 | 7854 | 11 | 32 | 266 | 146 | 21606 |
| **DEC** | 12476 | 0 | 1 | 989 | 619 | 3448 | 16 | 1 | 50 | 242 | 17841 |
| **2021** | 125697 | 0 | 739 | 20191 | 5751 | 124364 | 104 | 210 | 3315 | 4031 | 284401 |

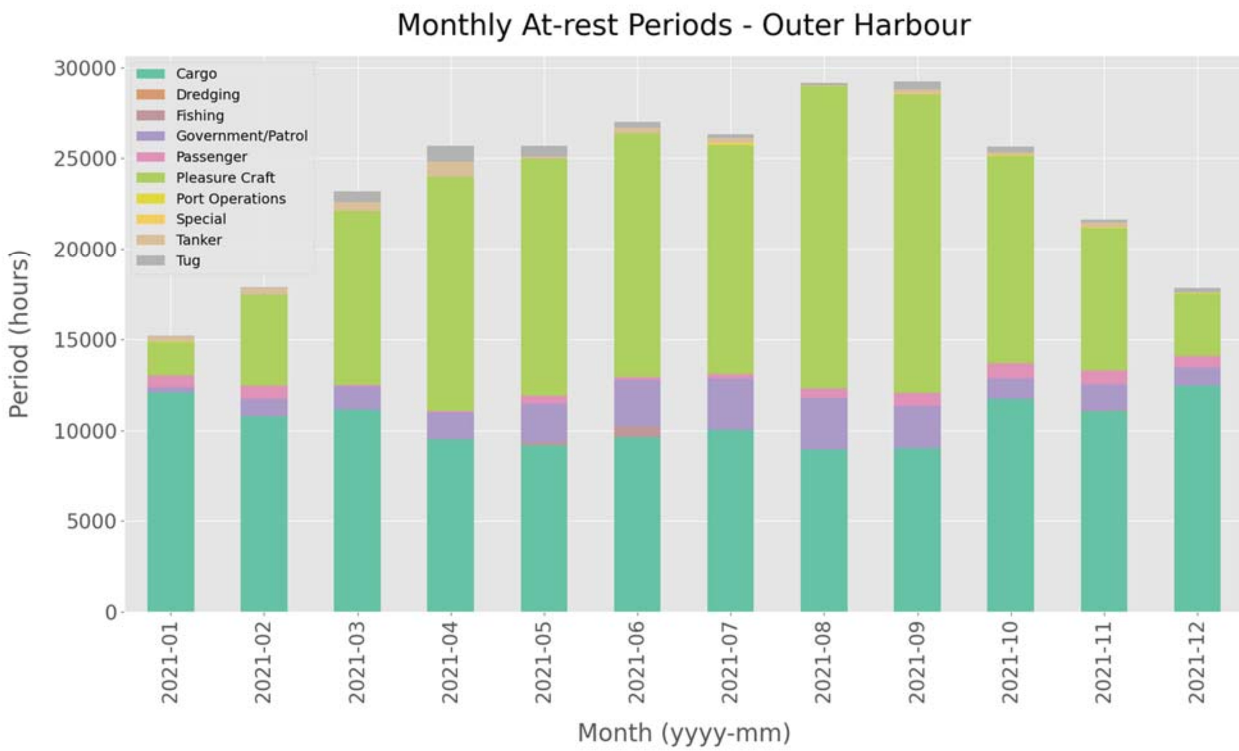


*Figure 13: Residence hours, vessels at rest in the Outer Harbour.*

Pleasure Craft and Passenger vessels had a seasonal signal, with increased activity during the summer months (a trend we will observe repeatedly), while Cargo, Tug, and Port Operations vessel traffic remained relatively consistent across the year (Table 5, Figure 14).

*Table 5: Residence hours, vessels in transit in the Outer Harbour.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 314 | 0 | 7 | 55 | 129 | 92 | 80 | 1 | 26 | 494 | 1199 |
| **FEB** | 278 | 2 | 9 | 55 | 150 | 125 | 58 | 11 | 21 | 382 | 1090 |
| **MAR** | 289 | 0 | 4 | 63 | 195 | 224 | 36 | 24 | 26 | 517 | 1380 |
| **APR** | 244 | 0 | 14 | 55 | 193 | 451 | 15 | 41 | 29 | 428 | 1470 |
| **MAY** | 244 | 0 | 21 | 101 | 163 | 749 | 32 | 18 | 17 | 442 | 1789 |
| **JUN** | 244 | 0 | 17 | 172 | 229 | 858 | 16 | 21 | 20 | 495 | 2073 |
| **JUL** | 201 | 0 | 19 | 140 | 361 | 1028 | 27 | 9 | 32 | 529 | 2344 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **AUG** | 216 | 0 | 16 | 144 | 470 | 1031 | 31 | 10 | 14 | 565 | 2498 |
| **SEP** | 259 | 0 | 16 | 105 | 384 | 779 | 32 | 5 | 15 | 573 | 2168 |
| **OCT** | 286 | 0 | 17 | 84 | 241 | 398 | 43 | 11 | 23 | 637 | 1739 |
| **NOV** | 242 | 0 | 14 | 54 | 143 | 175 | 41 | 5 | 16 | 494 | 1185 |
| **DEC** | 211 | 0 | 9 | 48 | 129 | 101 | 51 | 14 | 19 | 511 | 1093 |
| **2021** | 3028 | 2 | 164 | 1077 | 2786 | 6012 | 462 | 170 | 259 | 6067 | 20027 |

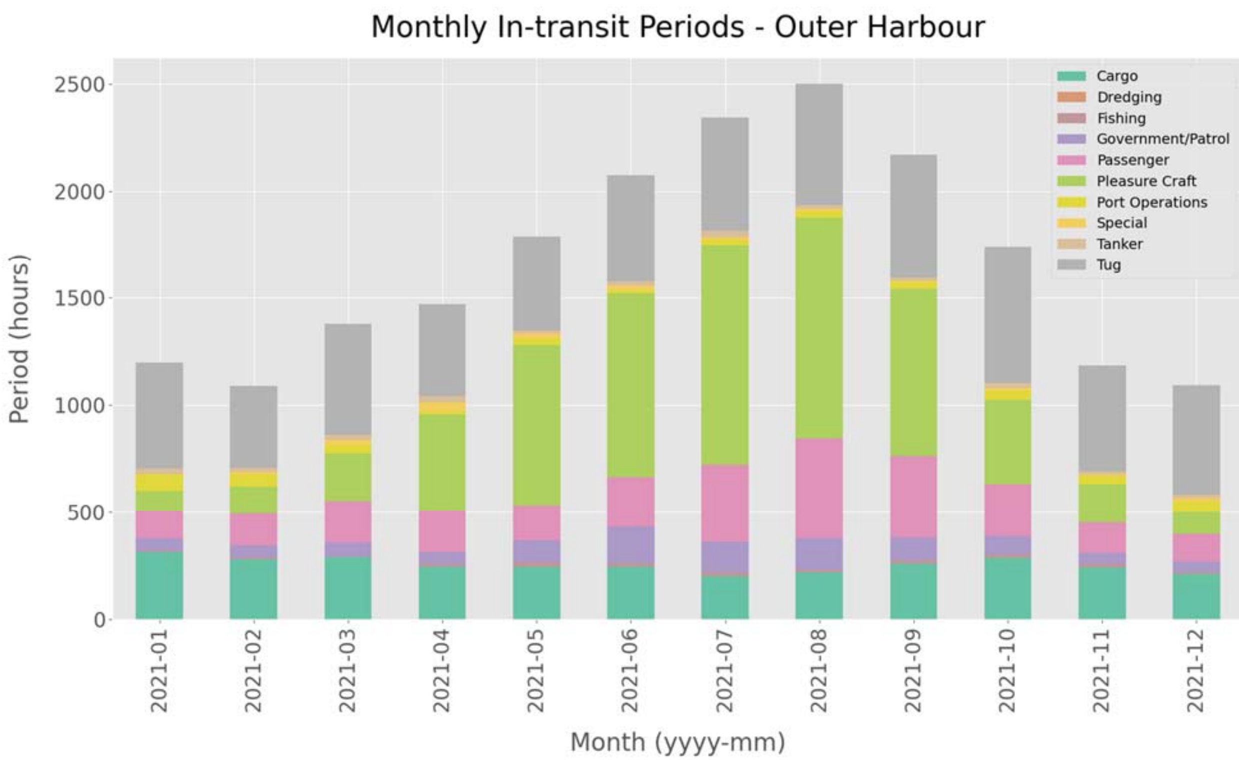


*Figure 14: Residence hours, vessels in transit in the Outer Harbour.*

Cargo and Tug vessels dominated vessel counts during winter and autumn months, but Pleasure Craft and Passenger vessels dominated vessel counts during spring and summer months (Table 6, Figure 15).

*Table 6: Vessel counts in the Outer Harbour.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 197 | 0 | 5 | 21 | 10 | 80 | 3 | 2 | 20 | 82 | 420 |
| **FEB** | 184 | 2 | 11 | 22 | 11 | 87 | 3 | 3 | 17 | 81 | 421 |
| **MAR** | 197 | 0 | 7 | 26 | 10 | 142 | 3 | 6 | 18 | 97 | 506 |
| **APR** | 171 | 0 | 14 | 21 | 14 | 246 | 3 | 8 | 19 | 86 | 582 |
| **MAY** | 183 | 0 | 12 | 26 | 17 | 324 | 4 | 8 | 16 | 83 | 673 |
| **JUN** | 175 | 0 | 15 | 31 | 23 | 373 | 3 | 8 | 15 | 87 | 730 |
| **JUL** | 148 | 0 | 14 | 29 | 26 | 450 | 4 | 8 | 20 | 92 | 791 |
| **AUG** | 162 | 0 | 10 | 24 | 29 | 489 | 4 | 7 | 12 | 83 | 820 |
| **SEP** | 173 | 0 | 15 | 25 | 28 | 385 | 3 | 5 | 11 | 89 | 734 |
| **OCT** | 204 | 0 | 16 | 26 | 24 | 212 | 3 | 6 | 18 | 96 | 605 |
| **NOV** | 183 | 0 | 15 | 28 | 18 | 120 | 3 | 4 | 12 | 81 | 464 |
| **DEC** | 152 | 0 | 8 | 25 | 19 | 79 | 3 | 7 | 15 | 86 | 394 |
| **2021** | 1302 | 2 | 50 | 64 | 48 | 877 | 6 | 18 | 118 | 188 | 2673 |

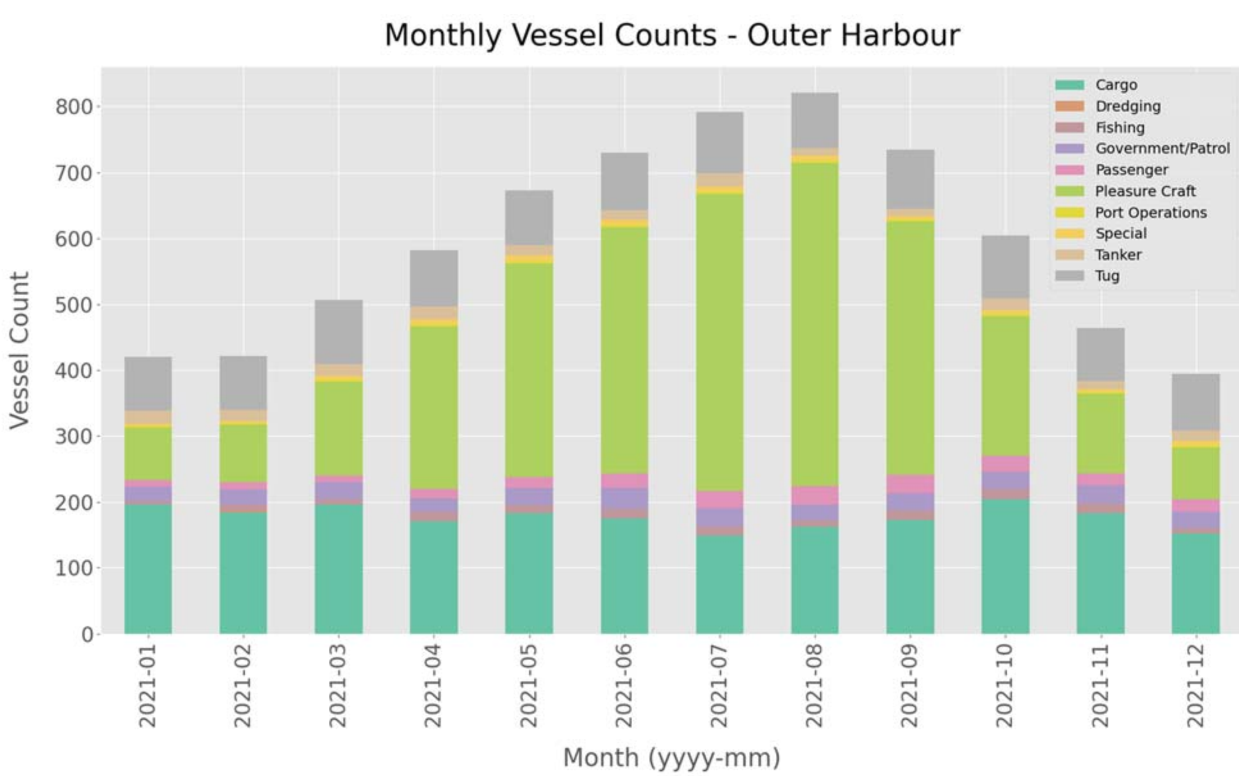


*Figure 15: Vessel counts in the Outer Harbour.*

### *Vessel traffic, False Creek*

False Creek is a small but busy waterway with numerous marinas and docks. It is confined and passes under relatively low bridges and, consequently, will not admit large vessels. Therefore, it is not surprising that False Creek vessel traffic was dominated by Pleasure Craft vessels at-rest (Table 7, Figure 16).

*Table 7: Residence hours, vessels at rest in False Creek.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 0 | 0 | 1255 | 2365 | 2515 | 17631 | 0 | 406 | 0 | 5 | 24177 |
| **FEB** | 0 | 0 | 2391 | 2145 | 3687 | 31248 | 0 | 579 | 0 | 10 | 40059 |
| **MAR** | 0 | 0 | 1550 | 3013 | 4485 | 38069 | 201 | 958 | 0 | 8 | 48284 |
| **APR** | 0 | 0 | 1480 | 3101 | 7298 | 46889 | 720 | 836 | 0 | 3 | 60326 |
| **MAY** | 0 | 0 | 2157 | 3564 | 7468 | 49255 | 744 | 456 | 0 | 7 | 63651 |
| **JUN** | 0 | 0 | 2432 | 3167 | 8634 | 46387 | 720 | 940 | 0 | 9 | 62289 |
| **JUL** | 0 | 0 | 2896 | 2622 | 9541 | 40764 | 393 | 471 | 0 | 6 | 56693 |
| **AUG** | 0 | 0 | 1119 | 2576 | 8813 | 39347 | 34 | 689 | 0 | 381 | 52957 |
| **SEP** | 0 | 0 | 805 | 2794 | 8360 | 43375 | 85 | 707 | 0 | 89 | 56215 |
| **OCT** | 0 | 0 | 3015 | 3758 | 7069 | 41638 | 0 | 461 | 0 | 9 | 55949 |
| **NOV** | 0 | 0 | 3195 | 2641 | 4342 | 35045 | 0 | 286 | 0 | 215 | 45724 |
| **DEC** | 0 | 0 | 2902 | 2136 | 2601 | 22063 | 0 | 327 | 0 | 41 | 30071 |
| **2021** | 0 | 0 | 25197 | 33882 | 74813 | 451709 | 2897 | 7115 | 0 | 784 | 596395 |

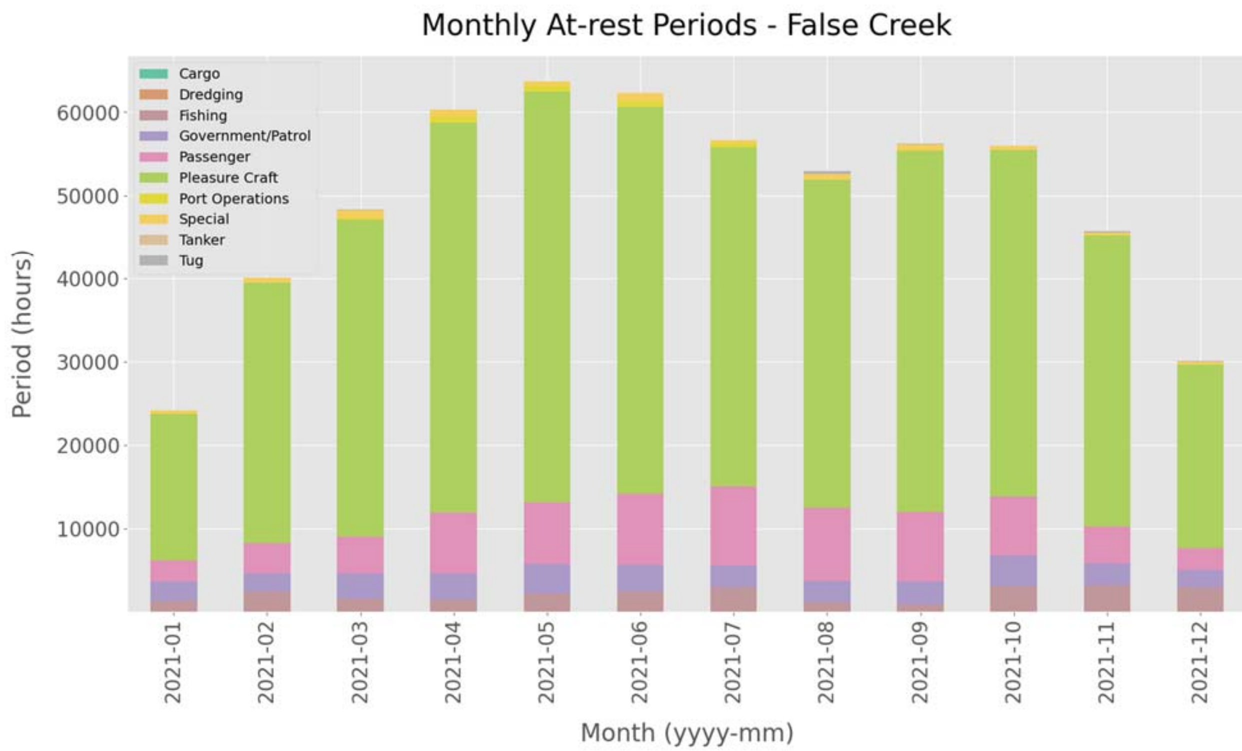


*Figure 16: Residence hours, vessels at rest in False Creek.*

At-rest residence times far exceeded in-transit residence times in False Creek (Table 8, Figure 17). Pleasure Craft vessels dominated in-transit residence times and showed a strong seasonal signal. Passenger vessels exhibited the same seasonal signal and contributed significantly to summer vessel traffic.

*Table 8: Residence hours, vessels in transit in False Creek.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 0 | 0 | 0 | 20 | 2 | 17 | 1 | 0 | 0 | 10 | 49 |
| **FEB** | 0 | 0 | 0 | 14 | 0 | 14 | 1 | 2 | 0 | 8 | 39 |
| **MAR** | 0 | 0 | 0 | 17 | 1 | 31 | 0 | 4 | 0 | 11 | 63 |
| **APR** | 0 | 0 | 1 | 27 | 4 | 59 | 2 | 4 | 0 | 5 | 101 |
| **MAY** | 0 | 0 | 1 | 22 | 16 | 98 | 1 | 2 | 0 | 9 | 148 |
| **JUN** | 0 | 0 | 1 | 24 | 26 | 112 | 1 | 3 | 0 | 16 | 182 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JUL** | 0 | 0 | 2 | 18 | 78 | 142 | 2 | 1 | 0 | 11 | 254 |
| **AUG** | 0 | 0 | 0 | 22 | 124 | 128 | 1 | 1 | 0 | 10 | 287 |
| **SEP** | 0 | 0 | 1 | 31 | 80 | 92 | 0 | 1 | 0 | 9 | 213 |
| **OCT** | 0 | 0 | 1 | 40 | 29 | 52 | 0 | 1 | 0 | 9 | 131 |
| **NOV** | 0 | 0 | 0 | 30 | 15 | 19 | 1 | 1 | 0 | 7 | 74 |
| **DEC** | 0 | 0 | 1 | 17 | 32 | 18 | 1 | 1 | 0 | 10 | 79 |
| **2021** | 0 | 0 | 7 | 283 | 406 | 781 | 9 | 19 | 0 | 115 | 1619 |

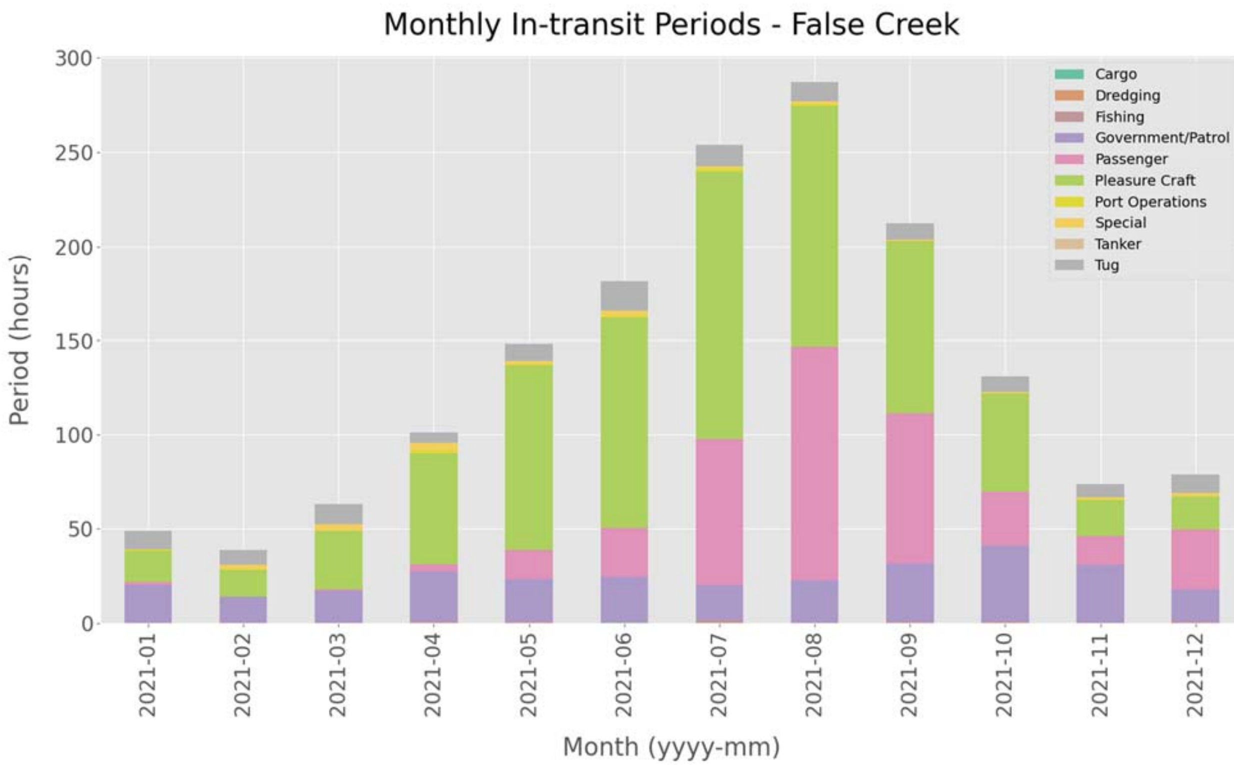


*Figure 17: Residence hours, vessels in transit in False Creek.*

Like residence times in False Creek, vessel counts showed Pleasure Craft to be dominant in all months, with a strong seasonal signal peaking in the summer months (Table 9, Figure 18).

*Table 9: Vessel counts in False Creek.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 0 | 0 | 4 | 10 | 7 | 60 | 1 | 1 | 0 | 5 | 88 |
| **FEB** | 0 | 0 | 4 | 8 | 8 | 68 | 1 | 2 | 0 | 6 | 97 |
| **MAR** | 0 | 0 | 3 | 12 | 8 | 85 | 1 | 2 | 0 | 5 | 116 |
| **APR** | 0 | 0 | 5 | 9 | 11 | 127 | 3 | 2 | 0 | 6 | 163 |
| **MAY** | 0 | 0 | 5 | 14 | 13 | 157 | 3 | 1 | 0 | 6 | 199 |
| **JUN** | 1 | 0 | 7 | 17 | 16 | 176 | 2 | 2 | 0 | 6 | 227 |
| **JUL** | 0 | 0 | 7 | 12 | 21 | 186 | 2 | 2 | 0 | 7 | 237 |
| **AUG** | 0 | 0 | 5 | 13 | 21 | 188 | 2 | 2 | 0 | 6 | 237 |
| **SEP** | 0 | 0 | 5 | 11 | 22 | 157 | 1 | 1 | 0 | 6 | 203 |
| **OCT** | 0 | 0 | 8 | 14 | 19 | 116 | 1 | 2 | 0 | 5 | 165 |
| **NOV** | 0 | 0 | 7 | 12 | 16 | 81 | 1 | 1 | 0 | 6 | 124 |
| **DEC** | 0 | 0 | 7 | 8 | 10 | 68 | 1 | 2 | 0 | 8 | 104 |
| **2021** | 1 | 18 | 36 | 27 | 470 | 3 | 3 | 13 | 1 | 4 | 571 |

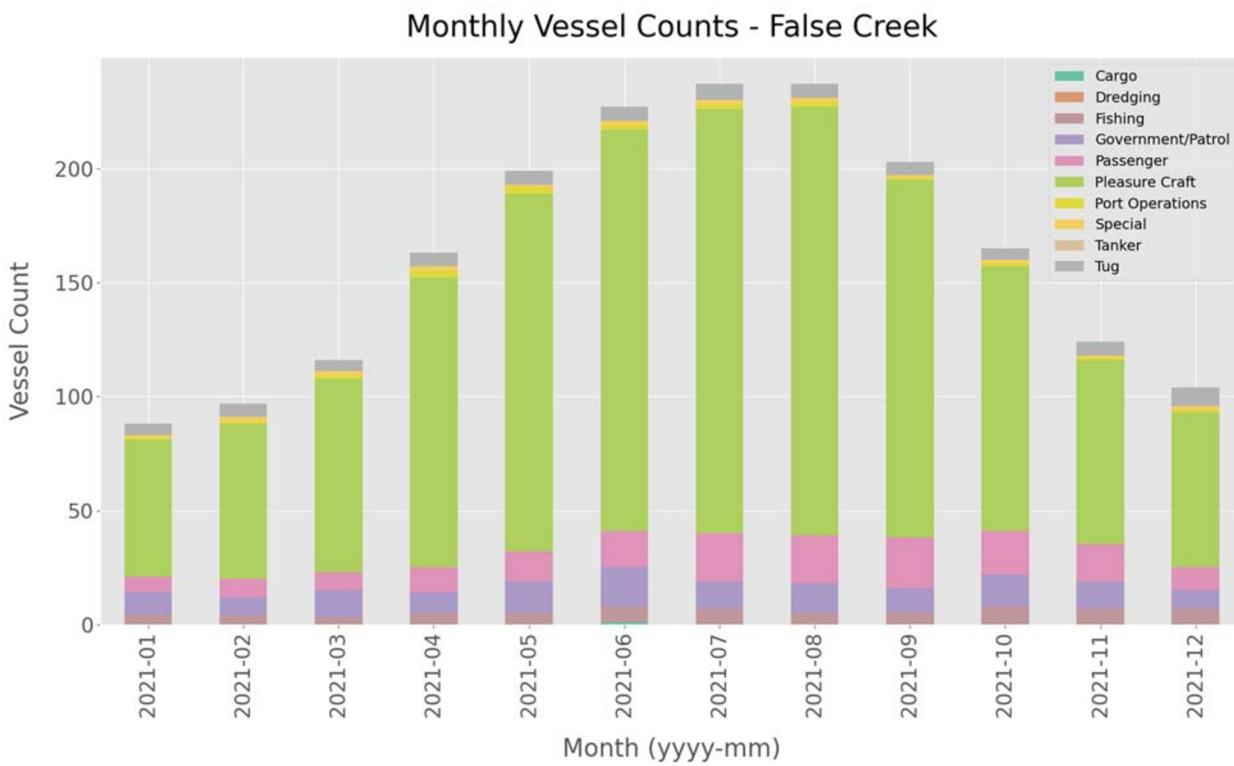


*Figure 18: Vessel counts in False Creek.*

### *Vessel traffic, Inner Harbour*

The Inner Harbour is the heart of the Port of Vancouver and was the destination of well over a thousand oceangoing vessels. However, oceangoing vessels represented a small portion of the residence time here, in terms of vessels at at-rest and vessels in-transit (Table 10, Figure 19, Table 11, Figure 20). Once again, Pleasure Craft, dominated at-rest residence times in the Inner Harbour whereas Tug and Passenger vessels dominated in-transit residence times.

*Table 10: Residence hours, vessels at rest in the Inner Harbour.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 13212 | 0 | 1219 | 3192 | 5002 | 46599 | 1885 | 1139 | 1291 | 18720 | 92260 |
| **FEB** | 12313 | 209 | 2551 | 3516 | 6741 | 76700 | 1705 | 1908 | 1036 | 21364 | 128041 |
| **MAR** | 14644 | 0 | 3912 | 4077 | 7437 | 98173 | 1699 | 2884 | 1361 | 22131 | 156317 |
| **APR** | 13003 | 0 | 4090 | 3408 | 7100 | 113607 | 1347 | 3019 | 1462 | 22833 | 169868 |
| **MAY** | 13237 | 0 | 2797 | 3492 | 7551 | 126281 | 2462 | 2164 | 1256 | 22477 | 181716 |
| **JUN** | 13429 | 0 | 2465 | 2841 | 8590 | 122166 | 2729 | 1549 | 642 | 20009 | 174420 |
| **JUL** | 14221 | 0 | 1625 | 2843 | 9240 | 96081 | 2745 | 2039 | 482 | 20860 | 150137 |
| **AUG** | 10196 | 0 | 1858 | 3432 | 9989 | 97666 | 2446 | 2022 | 133 | 23557 | 151300 |
| **SEP** | 11128 | 0 | 1299 | 4245 | 9358 | 117949 | 2643 | 1378 | 183 | 22020 | 170202 |
| **OCT** | 13937 | 0 | 2237 | 3146 | 10220 | 105008 | 2394 | 2495 | 328 | 20008 | 159772 |
| **NOV** | 13032 | 0 | 3919 | 3416 | 10025 | 87003 | 1904 | 1667 | 283 | 19057 | 140308 |
| **DEC** | 11716 | 0 | 1533 | 1844 | 7864 | 49250 | 1886 | 1785 | 379 | 14914 | 91169 |
| **2021** | 154066 | 209 | 29505 | 39452 | 99118 | 1136484 | 25845 | 24048 | 8835 | 247949 | 1765510 |

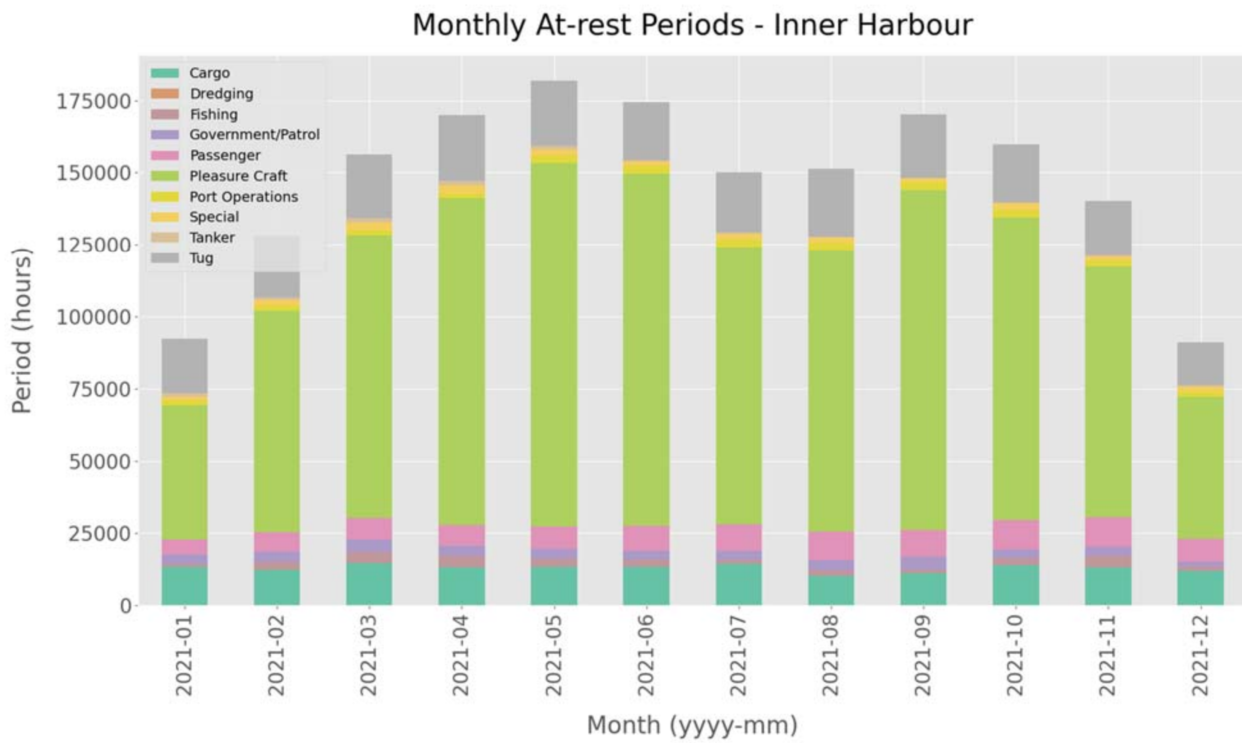


*Figure 19: Residence hours, vessels at rest in the Inner Harbour.*

Residence times demonstrated considerable variability throughout the year, at-rest residence time dropping steeply toward the end of 2021. In transit residence times were more consistent throughout the year.

*Table 11: Residence hours, vessels in transit in the Inner Harbour.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 284 | 0 | 3 | 71 | 1213 | 129 | 181 | 28 | 31 | 2145 | 4086 |
| **FEB** | 252 | 2 | 7 | 67 | 1125 | 126 | 134 | 25 | 25 | 1848 | 3611 |
| **MAR** | 272 | 0 | 4 | 85 | 1363 | 172 | 96 | 17 | 31 | 2113 | 4153 |
| **APR** | 233 | 0 | 12 | 43 | 1210 | 244 | 69 | 28 | 40 | 1889 | 3767 |
| **MAY** | 231 | 0 | 12 | 68 | 1132 | 423 | 108 | 18 | 21 | 1856 | 3868 |
| **JUN** | 227 | 0 | 12 | 70 | 1255 | 423 | 87 | 12 | 25 | 1893 | 4003 |
| **JUL** | 179 | 0 | 10 | 77 | 1248 | 475 | 106 | 11 | 36 | 1730 | 3871 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **AUG** | 171 | 0 | 10 | 64 | 1193 | 472 | 98 | 8 | 18 | 1753 | 3787 |
| **SEP** | 211 | 0 | 11 | 74 | 1432 | 340 | 93 | 11 | 16 | 1859 | 4047 |
| **OCT** | 278 | 0 | 11 | 64 | 1433 | 237 | 122 | 28 | 27 | 2187 | 4387 |
| **NOV** | 209 | 0 | 10 | 62 | 1318 | 145 | 124 | 9 | 21 | 1837 | 3734 |
| **DEC** | 198 | 0 | 8 | 53 | 1394 | 161 | 170 | 12 | 26 | 1809 | 3831 |
| **2021** | 2743 | 2 | 113 | 798 | 15315 | 3347 | 1387 | 208 | 314 | 22918 | 47146 |

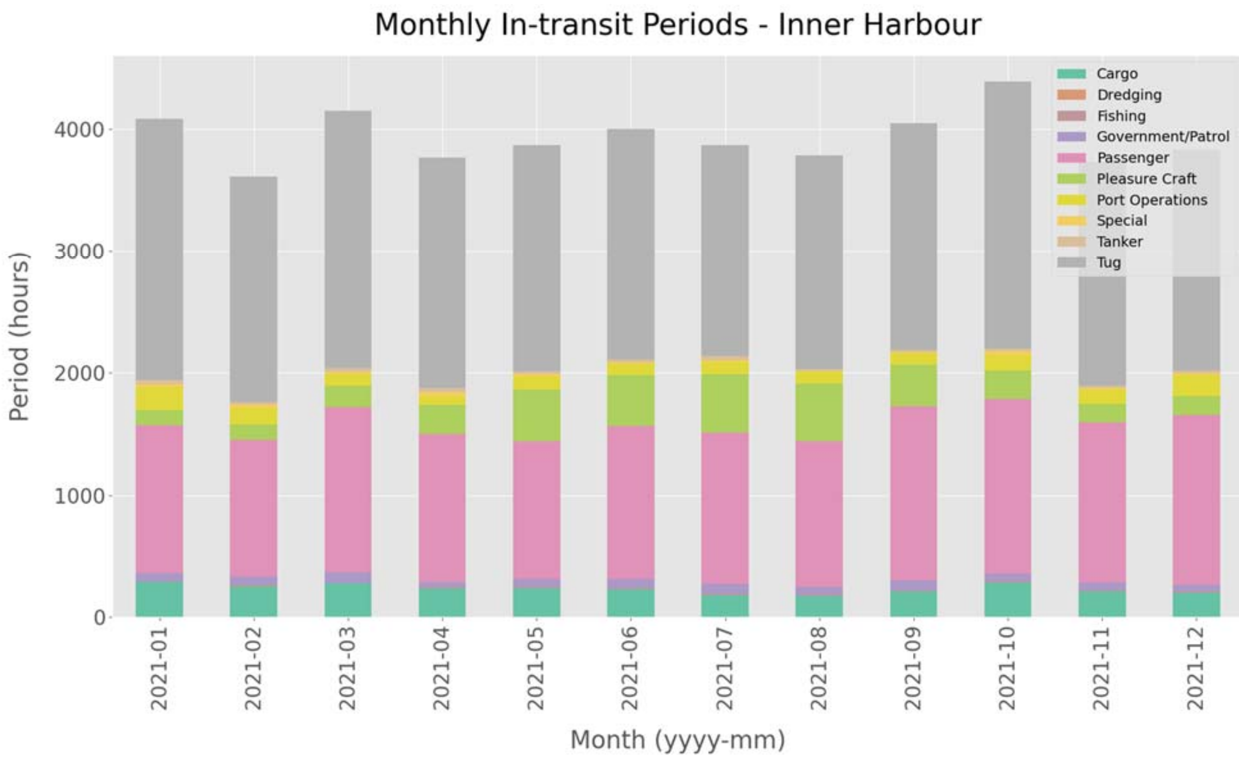


*Figure 20: Residence hours, vessels in transit in the Inner Harbour.*

Unlike residence times in the Inner Harbour, vessel counts were not dominated by Pleasure Craft throughout the year (Table 12, Figure 21). During the winter and autumn months, Cargo represented the highest proportion of vessels present, with Tugs approaching Pleasure Craft counts. However, during the spring and summer, Pleasure Craft dominated vessel counts in the Inner Harbour.

*Table 12: Vessel counts in the Inner Harbour.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 168 | 0 | 6 | 21 | 13 | 130 | 3 | 4 | 21 | 86 | 452 |
| **FEB** | 158 | 2 | 13 | 19 | 15 | 167 | 3 | 5 | 17 | 90 | 489 |
| **MAR** | 166 | 0 | 10 | 22 | 14 | 206 | 3 | 9 | 18 | 99 | 547 |
| **APR** | 151 | 0 | 12 | 23 | 19 | 265 | 3 | 10 | 20 | 89 | 592 |
| **MAY** | 153 | 0 | 10 | 21 | 22 | 315 | 4 | 9 | 17 | 91 | 642 |
| **JUN** | 148 | 0 | 12 | 19 | 23 | 324 | 4 | 8 | 14 | 95 | 647 |
| **JUL** | 125 | 0 | 10 | 21 | 26 | 332 | 4 | 9 | 20 | 100 | 647 |
| **AUG** | 134 | 0 | 9 | 22 | 24 | 353 | 5 | 7 | 12 | 90 | 656 |
| **SEP** | 145 | 0 | 12 | 21 | 27 | 319 | 4 | 7 | 11 | 94 | 640 |
| **OCT** | 171 | 0 | 11 | 21 | 22 | 253 | 4 | 10 | 17 | 97 | 606 |
| **NOV** | 139 | 0 | 15 | 26 | 21 | 177 | 4 | 7 | 11 | 89 | 489 |
| **DEC** | 121 | 0 | 11 | 20 | 26 | 143 | 4 | 8 | 16 | 85 | 434 |
| **2021** | 1128 | 2 | 35 | 57 | 44 | 617 | 6 | 18 | 118 | 174 | 2199 |

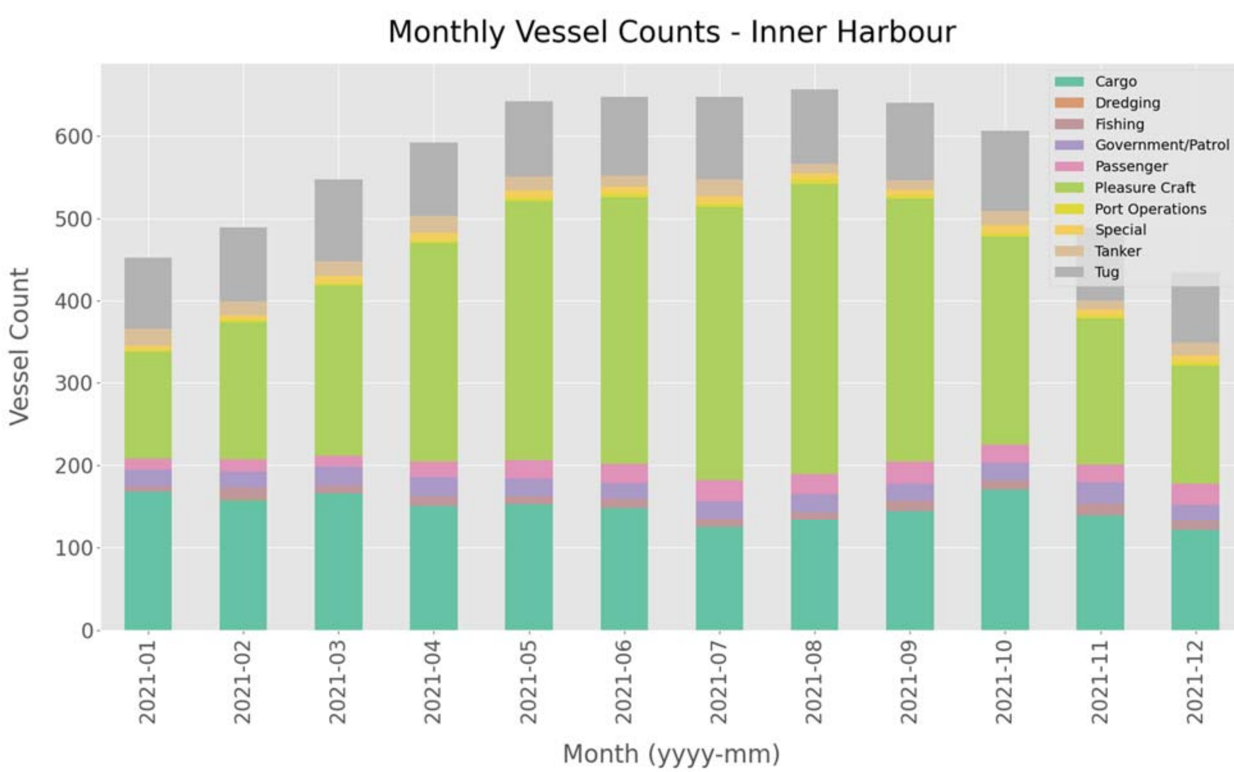


*Figure 21: Vessel counts in the Inner Harbour.*

*Vessel traffic, Central Harbour*

At-rest vessel residence time was dominated throughout the year by Tug vessels in the Central Harbour (Table 13, Figure 22).

*Table 13: Residence hours, vessels at rest in the Central Harbour.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 70 | 0 | 113 | 43 | 1 | 1272 | 0 | 730 | 497 | 3582 | 6307 |
| **FEB** | 162 | 0 | 393 | 33 | 5 | 1161 | 0 | 1321 | 97 | 5419 | 8592 |
| **MAR** | 54 | 0 | 230 | 73 | 3 | 957 | 0 | 738 | 263 | 5773 | 8090 |
| **APR** | 0 | 0 | 999 | 108 | 56 | 1055 | 0 | 1 | 181 | 6381 | 8781 |
| **MAY** | 129 | 0 | 744 | 213 | 55 | 567 | 0 | 99 | 195 | 6396 | 8398 |
| **JUN** | 49 | 0 | 832 | 126 | 8 | 427 | 0 | 932 | 152 | 6283 | 8808 |
| **JUL** | 48 | 0 | 129 | 47 | 15 | 598 | 3 | 704 | 397 | 6564 | 8506 |
| **AUG** | 220 | 0 | 135 | 76 | 19 | 1301 | 4 | 663 | 128 | 6833 | 9381 |
| **SEP** | 396 | 0 | 42 | 43 | 11 | 585 | 0 | 360 | 197 | 6658 | 8291 |
| **OCT** | 426 | 0 | 0 | 56 | 17 | 1199 | 2 | 30 | 250 | 7102 | 9081 |
| **NOV** | 83 | 0 | 0 | 144 | 27 | 1017 | 1 | 0 | 172 | 7177 | 8621 |
| **DEC** | 74 | 0 | 0 | 540 | 20 | 1255 | 2 | 76 | 481 | 5394 | 7842 |
| **2021** | 1712 | 0 | 3617 | 1501 | 235 | 11394 | 14 | 5655 | 3009 | 73562 | 100697 |

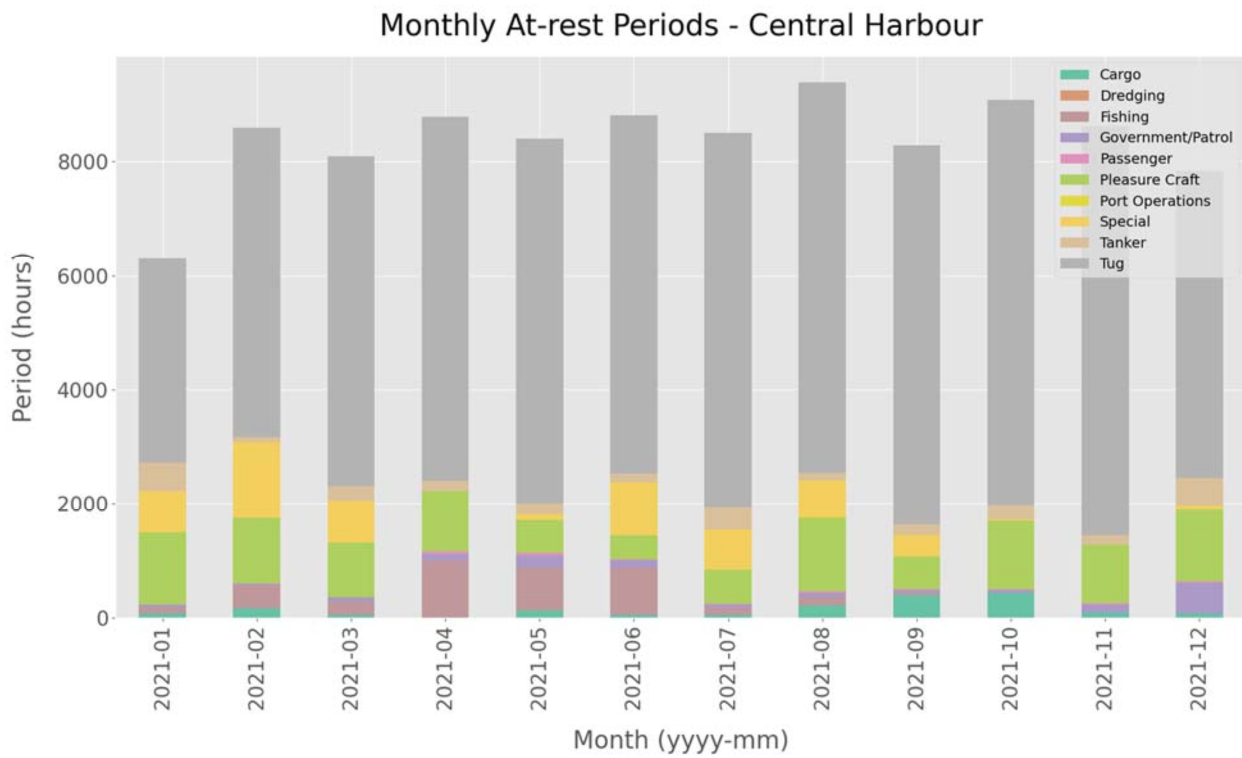


*Figure 22: Residence hours, vessels at rest in the Central Harbour.*

Like at-rest residence times, in-transit residence times were dominated by Tug vessels in the Central Harbour (Table 14, Figure 23).

*Table 14: Residence hours, vessels in transit in the Central Harbour.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 12 | 0 | 0 | 26 | 10 | 193 | 13 | 9 | 24 | 679 | 966 |
| **FEB** | 9 | 0 | 2 | 27 | 15 | 203 | 10 | 6 | 15 | 671 | 958 |
| **MAR** | 7 | 0 | 1 | 46 | 25 | 67 | 6 | 6 | 26 | 853 | 1037 |
| **APR** | 7 | 0 | 1 | 24 | 55 | 229 | 5 | 9 | 21 | 786 | 1136 |
| **MAY** | 6 | 0 | 1 | 31 | 54 | 278 | 7 | 6 | 15 | 790 | 1188 |
| **JUN** | 9 | 0 | 1 | 33 | 41 | 223 | 8 | 19 | 16 | 823 | 1175 |
| **JUL** | 8 | 0 | 1 | 32 | 38 | 227 | 10 | 13 | 24 | 795 | 1147 |
| **AUG** | 8 | 0 | 1 | 32 | 50 | 160 | 9 | 8 | 14 | 770 | 1050 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **SEP** | 8 | 0 | 2 | 29 | 48 | 268 | 8 | 3 | 12 | 761 | 1137 |
| **OCT** | 10 | 0 | 0 | 36 | 60 | 211 | 10 | 4 | 17 | 875 | 1224 |
| **NOV** | 9 | 0 | 0 | 33 | 50 | 179 | 8 | 1 | 15 | 819 | 1113 |
| **DEC** | 8 | 0 | 1 | 24 | 31 | 182 | 14 | 4 | 26 | 779 | 1068 |
| **2021** | 101 | 0 | 11 | 372 | 475 | 2421 | 107 | 86 | 225 | 9400 | 13198 |

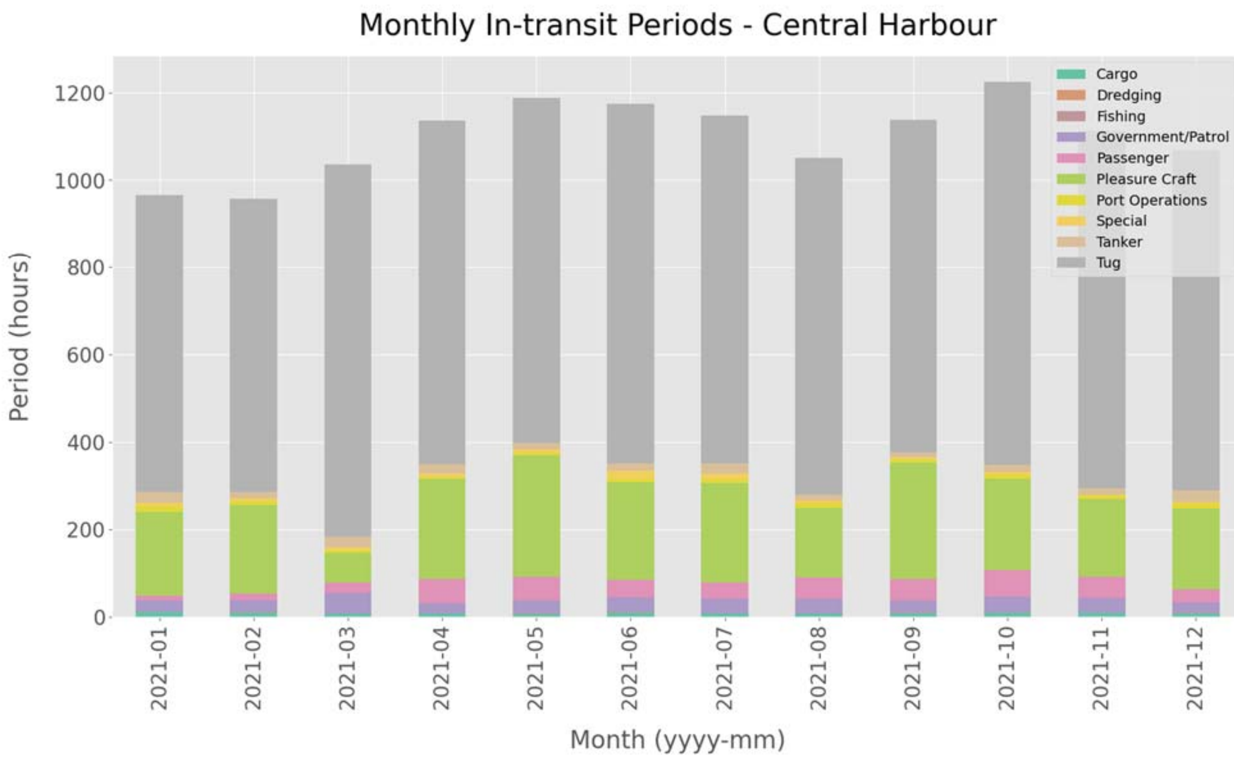


*Figure 23: Residence hours, vessels in transit in the Central Harbour.*

Vessel counts in the Central Harbour tell a slightly different story (Table 15, Figure 24). Pleasure Craft vessels, once again, dominated during the summer. This suggests that a relatively small number of local Tug vessels contributed greatly to the residence time. A large number Pleasure Craft vessels, on the other hand, were transient.

*Table 15: Vessel counts in the Central Harbour.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 9 | 0 | 2 | 15 | 5 | 26 | 3 | 4 | 18 | 59 | 141 |
| **FEB** | 8 | 0 | 4 | 12 | 6 | 28 | 3 | 3 | 12 | 62 | 138 |
| **MAR** | 7 | 0 | 2 | 17 | 5 | 45 | 3 | 6 | 16 | 66 | 167 |
| **APR** | 7 | 0 | 2 | 16 | 7 | 67 | 3 | 5 | 13 | 62 | 182 |
| **MAY** | 6 | 0 | 3 | 17 | 6 | 115 | 3 | 7 | 13 | 66 | 236 |
| **JUN** | 10 | 0 | 5 | 15 | 9 | 107 | 3 | 5 | 11 | 65 | 230 |
| **JUL** | 6 | 0 | 2 | 14 | 8 | 93 | 3 | 6 | 16 | 69 | 217 |
| **AUG** | 6 | 0 | 2 | 12 | 8 | 103 | 3 | 4 | 10 | 65 | 213 |
| **SEP** | 8 | 0 | 2 | 12 | 7 | 73 | 3 | 5 | 9 | 70 | 189 |
| **OCT** | 10 | 0 | 1 | 15 | 5 | 56 | 3 | 7 | 11 | 66 | 174 |
| **NOV** | 8 | 0 | 1 | 14 | 6 | 33 | 2 | 2 | 11 | 63 | 140 |
| **DEC** | 5 | 0 | 2 | 15 | 6 | 21 | 2 | 4 | 15 | 64 | 134 |
| **2021** | 63 | 0 | 13 | 39 | 18 | 310 | 4 | 12 | 100 | 127 | 686 |

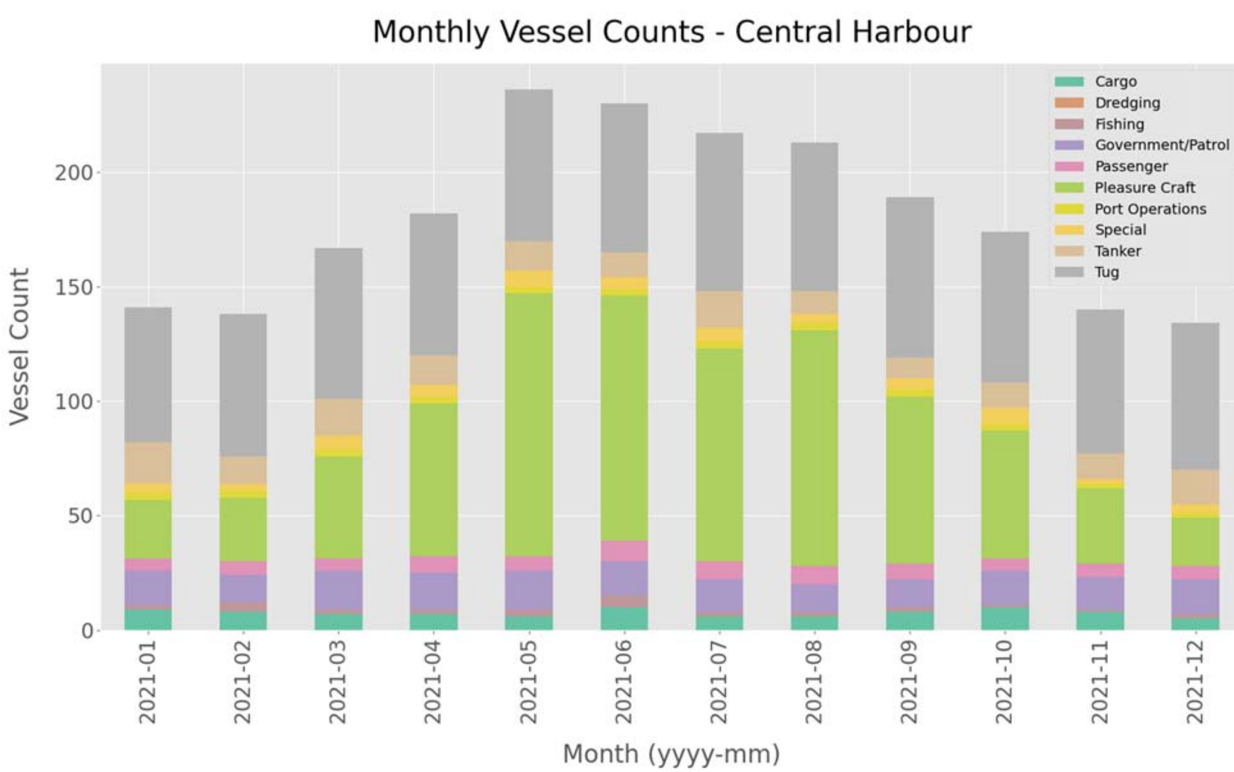


*Figure 24: Vessel counts in the Central Harbour.*

### *Vessel traffic, Port Moody Arm*

In the Port Moody Arm, at-rest residence time was dominated by Pleasure Craft vessels (Table 16, Figure 25). Government/Patrol and Tugs formed a consistent base for residence times, but these residence times were minor in proportion to Pleasure Craft times.

*Table 16: Residence hours, vessels at rest in the Port Moody Arm.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 265 | 0 | 0 | 2243 | 0 | 9783 | 1 | 13 | 560 | 1881 | 14745 |
| **FEB** | 202 | 0 | 640 | 1996 | 2 | 15583 | 2 | 17 | 349 | 2532 | 21323 |
| **MAR** | 150 | 0 | 198 | 2619 | 0 | 21712 | 3 | 0 | 621 | 2239 | 27541 |
| **APR** | 220 | 0 | 0 | 2129 | 0 | 24555 | 0 | 444 | 360 | 2280 | 29988 |
| **MAY** | 153 | 0 | 319 | 2717 | 0 | 24479 | 0 | 622 | 611 | 2028 | 30929 |
| **JUN** | 335 | 0 | 196 | 1890 | 0 | 22798 | 0 | 0 | 1057 | 2235 | 28512 |
| **JUL** | 302 | 0 | 374 | 2280 | 0 | 16297 | 0 | 1 | 1079 | 2210 | 22542 |
| **AUG** | 234 | 0 | 536 | 2205 | 2 | 16048 | 0 | 0 | 766 | 2054 | 21846 |
| **SEP** | 231 | 0 | 885 | 2491 | 0 | 17811 | 1 | 0 | 115 | 1935 | 23470 |
| **OCT** | 214 | 0 | 104 | 2737 | 0 | 18262 | 1 | 2 | 223 | 2208 | 23751 |
| **NOV** | 208 | 0 | 0 | 2141 | 0 | 16376 | 2 | 0 | 250 | 2038 | 21014 |
| **DEC** | 345 | 0 | 6 | 1630 | 0 | 11264 | 0 | 0 | 394 | 1752 | 15392 |
| **2021** | 2859 | 0 | 3258 | 27077 | 5 | 214969 | 11 | 1099 | 6385 | 25390 | 281052 |

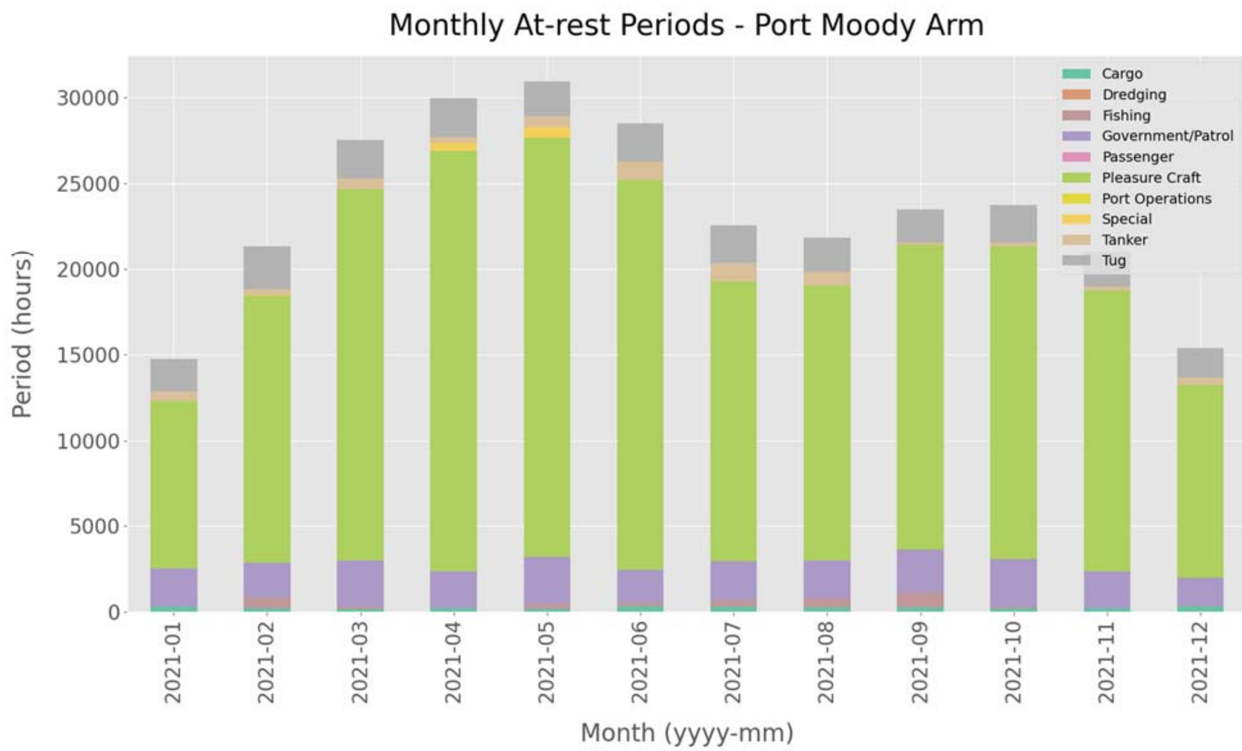


*Figure 25: Residence hours, vessels at rest in the Port Moody Arm.*

In-transit residence times were dominated by Tug vessels (Table 17, Figure 26).

*Table 17: Residence hours, vessels in transit in the Port Moody Arm.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 11 | 0 | 0 | 11 | 3 | 19 | 7 | 15 | 18 | 335 | 418 |
| **FEB** | 11 | 0 | 5 | 11 | 2 | 21 | 5 | 18 | 10 | 279 | 361 |
| **MAR** | 8 | 0 | 1 | 22 | 4 | 24 | 6 | 0 | 20 | 290 | 374 |
| **APR** | 9 | 0 | 0 | 20 | 3 | 36 | 4 | 3 | 12 | 256 | 343 |
| **MAY** | 6 | 0 | 2 | 29 | 1 | 52 | 3 | 11 | 12 | 228 | 343 |
| **JUN** | 10 | 0 | 2 | 29 | 2 | 55 | 4 | 0 | 12 | 265 | 380 |
| **JUL** | 8 | 0 | 3 | 19 | 1 | 50 | 4 | 0 | 11 | 236 | 332 |
| **AUG** | 8 | 0 | 2 | 23 | 3 | 59 | 4 | 1 | 8 | 217 | 324 |
| **SEP** | 7 | 0 | 4 | 26 | 1 | 45 | 3 | 0 | 6 | 208 | 300 |
| **OCT** | 9 | 0 | 0 | 25 | 3 | 31 | 4 | 2 | 10 | 272 | 356 |

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **NOV** | 7 | 0 | 0 | 22 | 1 | 25 | 4 | 0 | 8 | 225 | 291 |
| **DEC** | 6 | 0 | 1 | 21 | 2 | 21 | 5 | 0 | 13 | 239 | 306 |
| **2021** | 99 | 0 | 19 | 255 | 26 | 437 | 52 | 50 | 140 | 3050 | 4126 |

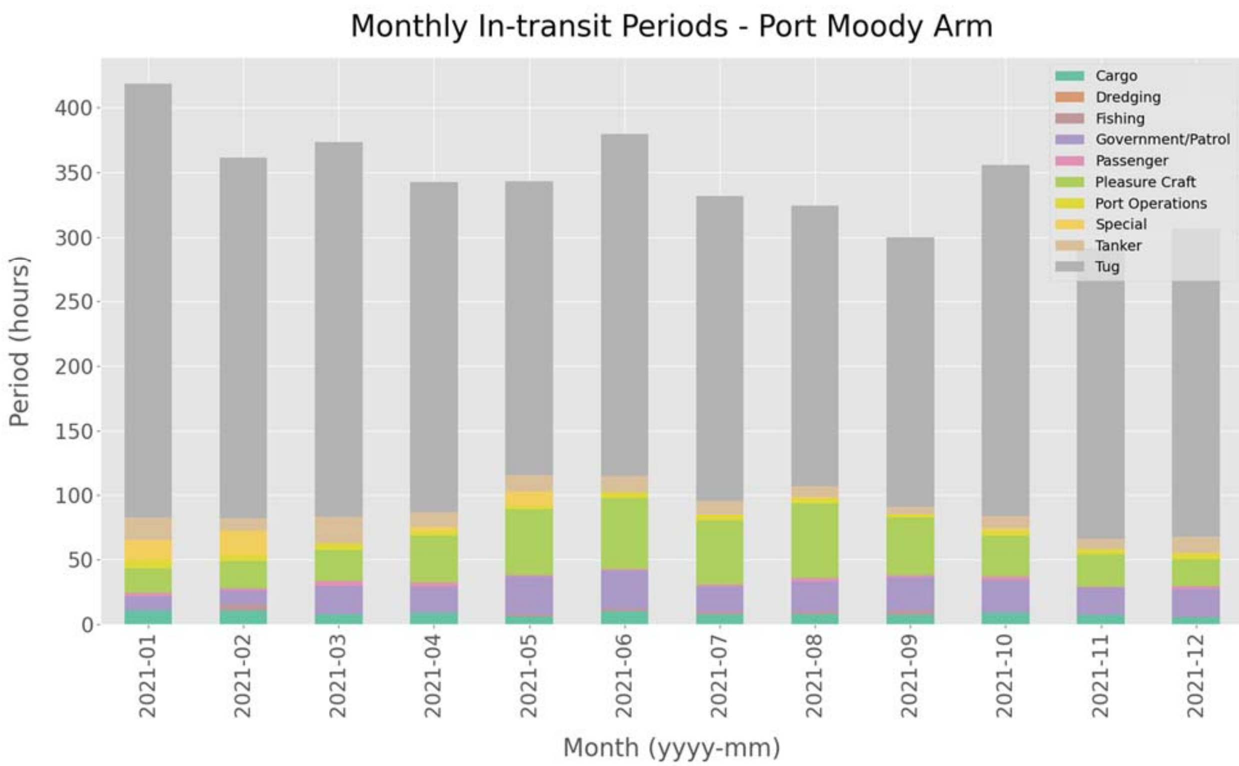


*Figure 26: Residence hours, vessels in transit in the Port Moody Arm.*

Vessel counts in the Port Moody Arm were characterized by consistently high counts of Pleasure Craft and Tug vessels followed by smaller but steady counts of Tanker, Cargo, Government/Patrol, and Passenger vessels (Table 18, Figure 27).

*Table 18: Vessel counts in the Port Moody Arm.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 8 | 0 | 0 | 7 | 3 | 28 | 2 | 1 | 15 | 32 | 96 |
| **FEB** | 7 | 0 | 3 | 9 | 3 | 36 | 2 | 1 | 10 | 34 | 105 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **MAR** | 5 | 0 | 1 | 7 | 4 | 45 | 3 | 0 | 14 | 37 | 116 |
| **APR** | 7 | 0 | 0 | 9 | 4 | 54 | 2 | 4 | 9 | 35 | 124 |
| **MAY** | 5 | 0 | 2 | 11 | 2 | 57 | 1 | 3 | 10 | 31 | 122 |
| **JUN** | 7 | 0 | 2 | 9 | 3 | 57 | 3 | 1 | 11 | 31 | 124 |
| **JUL** | 5 | 0 | 1 | 9 | 3 | 49 | 2 | 1 | 12 | 32 | 114 |
| **AUG** | 5 | 0 | 2 | 7 | 5 | 59 | 3 | 2 | 8 | 34 | 125 |
| **SEP** | 5 | 0 | 2 | 7 | 3 | 48 | 2 | 2 | 5 | 33 | 107 |
| **OCT** | 7 | 0 | 1 | 10 | 5 | 43 | 3 | 3 | 8 | 35 | 115 |
| **NOV** | 5 | 0 | 0 | 8 | 2 | 38 | 2 | 0 | 6 | 32 | 93 |
| **DEC** | 4 | 0 | 1 | 8 | 4 | 26 | 2 | 1 | 11 | 37 | 94 |
| **2021** | 60 | 0 | 5 | 22 | 8 | 119 | 4 | 9 | 74 | 67 | 368 |

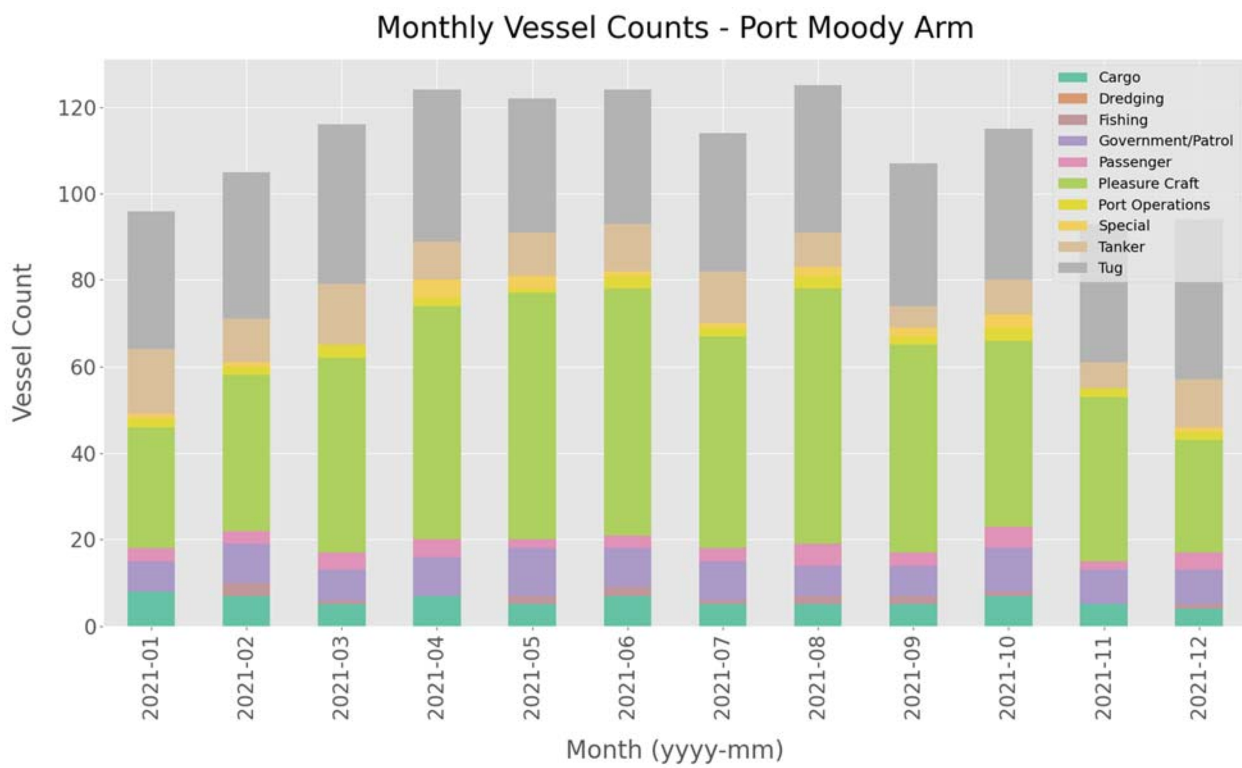


*Figure 27: Vessel counts in the Port Moody Arm.*

### *Vessel traffic, Indian Arm*

At-rest residence times in the Indian Arm were dominated by Pleasure Craft vessels (Table 19, Figure 28). This comes as no surprise, as the Indian Arm has little industry and no major port facilities. The small contributions to at-rest residence times made by Tanker and Cargo vessels are attributable to anchorages at the south end the Indian Arm where it meets Burrard Inlet.

*Table 19: Residence hours, vessels at rest in the Indian Arm.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 65 | 0 | 0 | 16 | 0 | 1773 | 3 | 7 | 419 | 25 | 2307 |
| **FEB** | 82 | 0 | 3 | 135 | 1 | 3495 | 5 | 13 | 209 | 64 | 4006 |
| **MAR** | 265 | 0 | 1 | 18 | 1 | 4921 | 21 | 1 | 280 | 25 | 5533 |
| **APR** | 323 | 0 | 0 | 291 | 2 | 5892 | 1 | 3 | 442 | 25 | 6978 |
| **MAY** | 25 | 0 | 109 | 146 | 1 | 7298 | 0 | 47 | 203 | 63 | 7893 |
| **JUN** | 24 | 0 | 67 | 203 | 1 | 7390 | 6 | 107 | 170 | 59 | 8028 |
| **JUL** | 179 | 0 | 88 | 164 | 3 | 7477 | 2 | 8 | 405 | 67 | 8393 |
| **AUG** | 22 | 0 | 18 | 170 | 4 | 5197 | 1 | 14 | 181 | 363 | 5970 |
| **SEP** | 167 | 0 | 59 | 28 | 1 | 5225 | 2 | 0 | 147 | 240 | 5869 |
| **OCT** | 80 | 0 | 0 | 36 | 2 | 6858 | 3 | 59 | 284 | 29 | 7351 |
| **NOV** | 25 | 0 | 0 | 35 | 0 | 5208 | 1 | 0 | 390 | 10 | 5669 |
| **DEC** | 271 | 0 | 2 | 15 | 0 | 2890 | 1 | 3 | 553 | 36 | 3771 |
| **2021** | 1528 | 0 | 346 | 1257 | 16 | 63624 | 45 | 262 | 3683 | 1006 | 71768 |

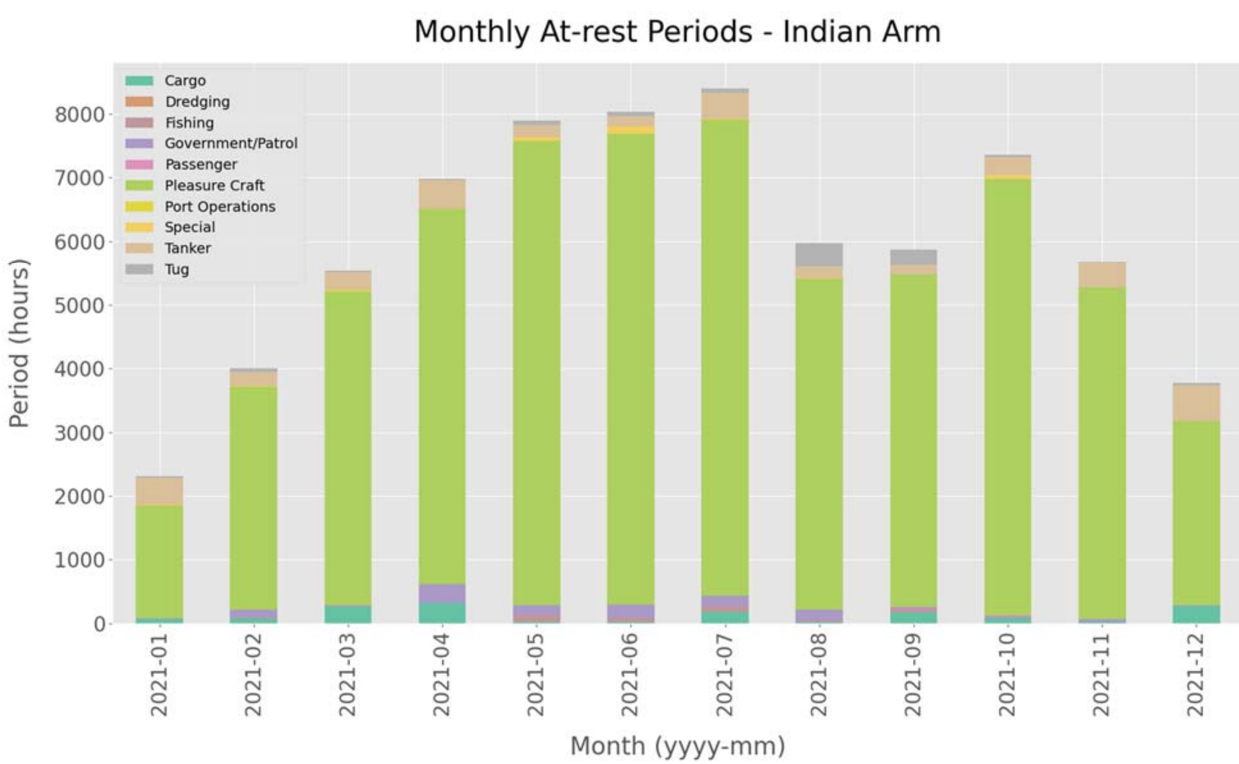


*Figure 28: Residence hours, vessels at rest in the Indian Arm.*

In-transit residence times in the Indian Arm were, like at-rest residence times, dominated by Pleasure Craft vessels (Table 20, Figure 29). However, significant contributions to in-transit residence times were made by Government/Patrol vessels.

*Table 20: Residence hours, vessels in transit in the Indian Arm.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 11 | 0 | 0 | 21 | 1 | 45 | 12 | 22 | 4 | 8 | 125 |
| **FEB** | 19 | 0 | 13 | 54 | 6 | 49 | 10 | 46 | 2 | 24 | 222 |
| **MAR** | 13 | 0 | 2 | 33 | 3 | 69 | 8 | 4 | 1 | 5 | 139 |
| **APR** | 6 | 0 | 0 | 33 | 2 | 154 | 8 | 5 | 3 | 10 | 221 |
| **MAY** | 7 | 0 | 6 | 43 | 2 | 277 | 4 | 3 | 2 | 15 | 357 |
| **JUN** | 8 | 0 | 9 | 41 | 3 | 241 | 16 | 7 | 2 | 8 | 335 |
| **JUL** | 7 | 0 | 9 | 46 | 6 | 177 | 12 | 1 | 4 | 25 | 285 |
| **AUG** | 1 | 0 | 1 | 32 | 4 | 231 | 8 | 7 | 2 | 79 | 366 |
| **SEP** | 9 | 0 | 13 | 35 | 4 | 122 | 9 | 0 | 2 | 17 | 210 |
| **OCT** | 8 | 0 | 0 | 29 | 3 | 105 | 12 | 7 | 3 | 14 | 182 |
| **NOV** | 0 | 0 | 0 | 20 | 1 | 35 | 10 | 0 | 2 | 11 | 79 |
| **DEC** | 12 | 0 | 1 | 16 | 1 | 26 | 9 | 7 | 4 | 22 | 98 |
| **2021** | 101 | 0 | 54 | 401 | 34 | 1531 | 118 | 110 | 31 | 239 | 2619 |

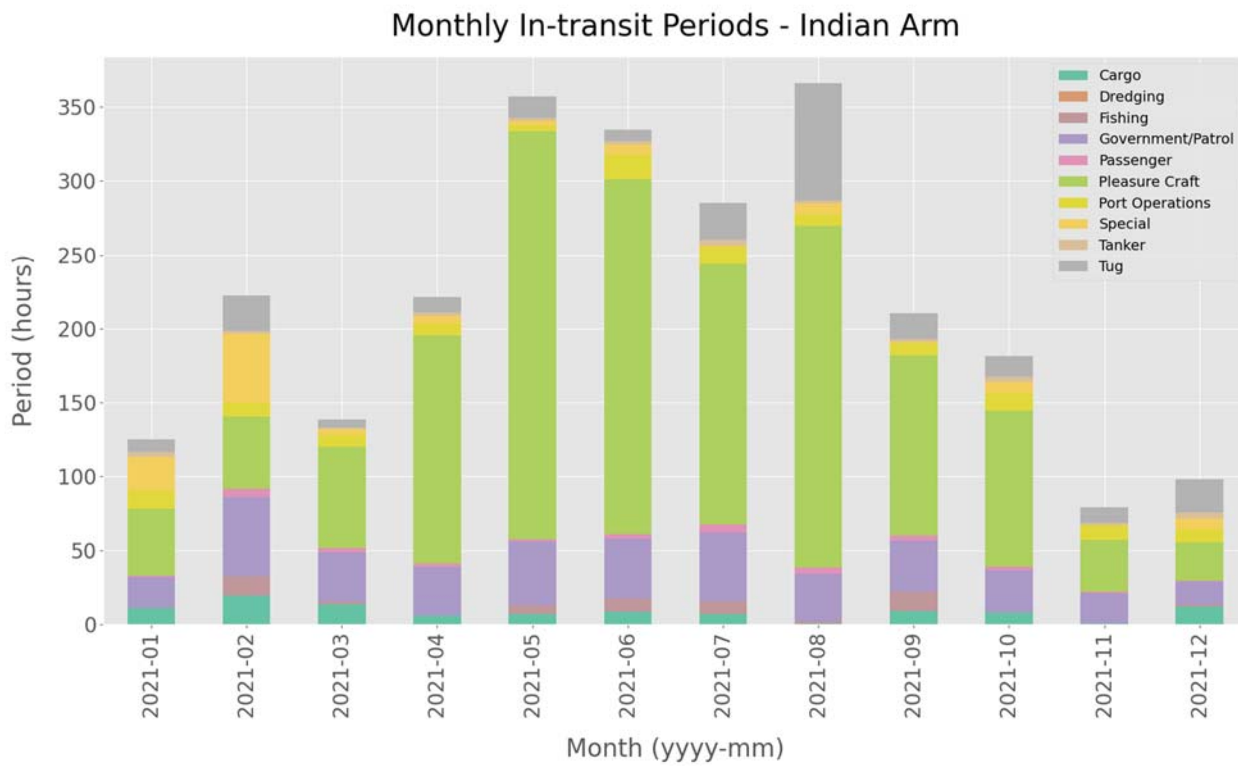


*Figure 29: Residence hours, vessels in transit in the Indian Arm.*

Vessel counts in the Indian Arm demonstrated a consistent count of Cargo, Government/Patrol, Tugs, Port Operations, Passenger, and Tanker vessels throughout the year and a seasonally variable count of Pleasure Craft vessels during that same period (Table 21, Figure 30). Pleasure Craft vessel numbers peaked in the summer months and far exceeded the other vessel type counts during that period.

*Table 21: Vessel counts in the Indian Arm.*

| | CARGO | DREDGING | FISHING | GOV./ PATROL | PASSENGER | PLEASURE CRAFT | PORT OPS. | SPECIAL | TANKER | TUG | TOTAL |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JAN** | 2 | 0 | 0 | 10 | 3 | 24 | 3 | 3 | 11 | 22 | 78 |
| **FEB** | 4 | 0 | 1 | 11 | 5 | 33 | 3 | 1 | 6 | 23 | 87 |
| **MAR** | 3 | 0 | 1 | 12 | 3 | 40 | 3 | 3 | 5 | 18 | 88 |
| **APR** | 2 | 0 | 0 | 10 | 5 | 76 | 2 | 1 | 7 | 19 | 122 |
| **MAY** | 2 | 0 | 2 | 14 | 4 | 100 | 3 | 4 | 6 | 23 | 158 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **JUN** | 1 | 0 | 1 | 13 | 3 | 91 | 3 | 3 | 5 | 22 | 142 |
| **JUL** | 3 | 0 | 1 | 11 | 6 | 82 | 2 | 2 | 9 | 22 | 138 |
| **AUG** | 2 | 0 | 1 | 10 | 4 | 82 | 3 | 3 | 6 | 27 | 138 |
| **SEP** | 3 | 0 | 2 | 12 | 6 | 61 | 3 | 1 | 8 | 24 | 120 |
| **OCT** | 3 | 0 | 0 | 12 | 3 | 61 | 3 | 3 | 9 | 23 | 117 |
| **NOV** | 3 | 0 | 0 | 9 | 3 | 28 | 2 | 1 | 5 | 17 | 68 |
| **DEC** | 4 | 0 | 1 | 13 | 4 | 19 | 2 | 2 | 10 | 20 | 75 |
| **2021** | 15 | 0 | 4 | 31 | 12 | 269 | 4 | 7 | 62 | 67 | 471 |

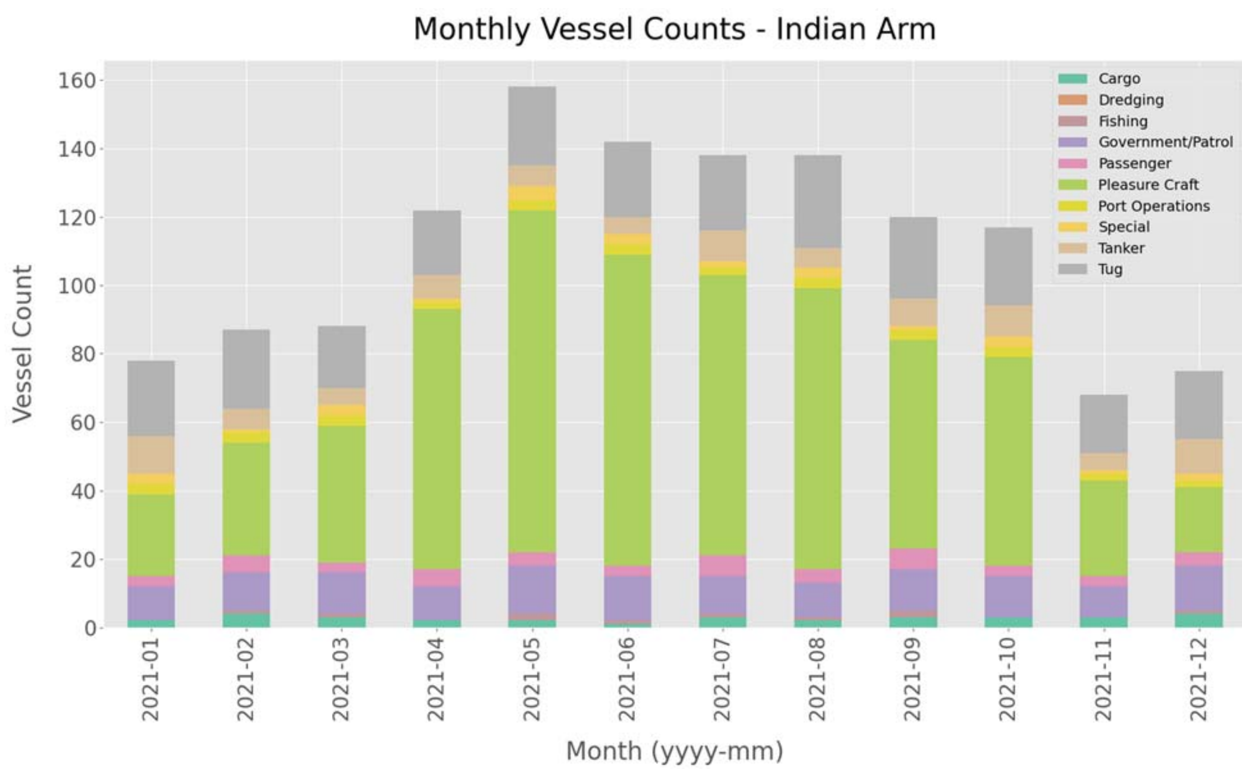


*Figure 30: Vessel counts in the Indian Arm.*

# 5 Discussion

It is self-evident that Burrard Inlet hosts heavy marine vessel traffic. This work provides a useful illustration of that traffic – albeit vastly underestimated due to the lack of accurate pleasure craft data. The AIS dataset for Burrard Inlet is extensive. Specific successes and recommendations stemming from working with such a large dataset are provided below.

## 5.1 Vessel Traffic

*Successes*. We successfully repeated a generic workflow developed previously—parsing, processing, and slicing AIS data—to perform analysis on marine vessel traffic. Performing the work on AIS data in Burrard Inlet presented some new challenges, all of which we were able to overcome.

*Recommendations*. It has become evident that we must introduce a step between data cleaning and data interpolation that checks the vessel path between consecutive points for intersections with land. If a vessel path intersects land, a routine using Graph Analysis techniques that reroutes the path around the land must be invoked. We have developed a portion of these tools but did not have the time or budget to complete them during this project. Future work should leverage Graph Analysis techniques to reroute bad vessel paths around land.

## 5.2 Labelling points-of-rest

*Successes*. While verifying good data labels for vessel activity status, it became clear that gaining confidence in a training dataset sampled from such a vast and challenging dataset would be prohibitively time consuming. Turning to a simple, rule-based method for labelling points-of-rest was a good decision. Based on a lot of visual inspection, the method delivered acceptable results and provides the added benefits of being very easy to understand compared to some of the Machine Learning alternatives.

*Recommendations*. The performance of the method used to label points-of-rest is not known because we do not have a representative truth set to evaluate the result against. Future work should include effort toward developing a truth set so that the performance of several methods can be compared. Ultimately, we want to deliver the best performing model. Without a truth set, this is not possible.

## 5.3 Slicing and visualization data

*Successes*. Working with such a large dataset required us to make changes to our processes that ultimately improved efficiency and the product. For example, collapsing continuous at-rest points into a single point at-rest reduced the data by an order of magnitude. Converting 60 points into one line for display in Dashboard reduced the data by another order of magnitude.

*Recommendations*. Data size has been challenging problem at every stage of the project; however, the most difficult challenge is related to Dashboard. A dataset with the resolution desired for detailed interrogation is prohibitively large. A dataset that performs well on Dashboard does not provide adequate resolution to perform detailed interrogation. Future work should include further effort to resolve this issue.

# 6 References


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# 7 Appendix A

Vincenty's method for calculating distance between two points on the surface of the earth.

Given the coordinates of the two points ($\Phi_1$, $L_1$) and ($\Phi_2$, $L_2$), the inverse problem finds the azimuths $\alpha_1$, $\alpha_2$ and the ellipsoidal distance s. Calculate $U_1$, $U_2$ and L, and set the initial value of $\lambda = L$. Then iteratively evaluate the following equations until $\lambda$ converges:

$$sin\,\sigma = \sqrt{(cos\,U_2\,sin\,\lambda)^2 + (cos\,U_1\,sin\,U_2 - sin\,U_1\,cos\,U_2\,cos\,\lambda)^2}$$

$$cos\,\sigma = \, sin\,U_1\,sin\,U_2 - \, cos\,U_1\,cos\,U_2\,cos\,\lambda$$

$$\sigma = arctan\frac{sin\,\sigma}{cos\,\sigma}$$

$$sin\,\alpha = \frac{cos\,U_1\,cos\,U_2\,sin\,\lambda}{sin\,\sigma}$$

$$cos^2\,\alpha = \,1 - \,sin^2\,\alpha$$

$$cos(2\,\sigma_m) = \cos\sigma - \,\frac{2\,sin\,U_1\,sin\,U_2}{cos^2\,\sigma}$$

$$C = \frac{f}{16}\,cos^2\,\alpha\,[4 + f(4 - 3\,cos^2\,\alpha)]$$

$$\lambda = L + \,(1 + C)\,f\sin\alpha\,\{\sigma + C\sin\sigma\,[cos\,(2\,\sigma_m) + C\cos\sigma\,(-1 + 2\,cos^2\,(2\,\sigma_m))]\}$$

When $\lambda$ has converged to the desired degree of accuracy (10-12 corresponds to approximately 0.06 mm), evaluate the following:

$$u^2 = \,cos^2\,\alpha\,\left(\frac{a^2 - \,b^2}{b^2}\right)$$

$$A = 1 + \,\frac{u^2}{16384}\,\{4096 + \,u^2\,[-768 + \,u^2\,(320 - 175\,u^2)]\}$$

$$B = \frac{u^2}{1024}\,\{256 + \,u^2\,[-128 + \,u^2\,(74 - 47\,u^2)]\}$$

$$\Delta\,\sigma = B\sin\sigma\,\left\{cos(2\,\sigma_m) + \frac{1}{4}\,B\,\left[\cos\sigma\,\left(-1 + 2\,cos^2\,(2\,\sigma_m)\right) - \,\frac{B}{6}\,cos(2\,\sigma_m)(-3 + 4\,sin^2\sigma(2\,\sigma_m))\right]\right\}$$

$$s \,= \,b\,A\,(\sigma - \,\Delta\,\sigma)$$

$$\alpha_1 = \,arctan\,\left(\frac{\cos U_2\sin\lambda}{\cos U_1\sin U_2 - \sin U_1\cos U_2\cos\lambda}\right)$$

$$\alpha_2 = \,arctan\,\left(\frac{\cos U_1\sin\lambda}{-\sin U_1\cos U_2 - \cos U_1\sin U_2\cos\lambda}\right)$$