Impacts of marine vessel traffic on access to fishing opportunities of the Musqueam Indian Band

November 19, 2018

Prepared for:

Musqueam Indian Band

Prepared by:

ESSA Technologies Ltd.

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Musqueam fishers pulling in fishing gear, courtesy of Larissa Grant

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The information contained in this report is based on research completed by ESSA Technologies Ltd. It reflects the understanding of the authors and is not intended to be a complete depiction of the dynamic and living system of use and knowledge maintained by the Musqueam people. It may be updated, refined, or changed as new information becomes available. Some information contained herein is based on interviews with Musqueam knowledge holders which were conducted within constraints of time, budget, and scope. This information should not be construed as defining, limiting, or otherwise constraining the Aboriginal rights of the Musqueam Indian Band or any other First Nations or Aboriginal peoples.

Executive Summary

The waters within the traditional territory of the Musqueam First Nation are vital to Musqueam's culture, sense of place, and identity. Through the act of fishing, they provide food, a sense of community, and an environment in which Traditional Knowledge is transmitted. In 1990, the Supreme Court of Canada affirmed the rights of Musqueam members to fish in their territory through the *Sparrow* decision. These waters are also some of the busiest and most recreationally active and industrially developed in British Columbia. New large scale industrial activities are being proposed in the territory, and many of these projects have the potential to increase industrial shipping traffic. However, the consequence of proposed increases to industrial shipping for the ability of Musqueam fishers to engage in fisheries is currently unquantified. This purpose of this report is to help address this knowledge gap by assessing the contributing factors and cumulative effect of marine vessel traffic on the ability of Musqueam fishers to navigate on and access fishing opportunities within their territory, estimating the potential future impacts of marine vessel traffic on fishing access, and providing broad recommendations on how restrictions in access to fishing opportunities can be minimized. This report does not provide a determination of the significance of restrictions in access to Musqueam, since the quantitative analysis assumes that all access is equally valuable.

To address this knowledge gap, this study involved three analytical components. The first component focused on understanding the cumulative effect of factors contributing to the baseline impact on access to current specifically salmon, crab, and prawn fishing opportunities, broader development patterns in the region, and recent (i.e., within living memory) use of marine resources by Musqueam. A second component focused on quantifying the impact of recent (2012-2017) marine vessel traffic on access to fishing using available positional data for marine vessels and known fisheries openings provided to Musqueam harvesters by Fisheries and Oceans Canada. Access to fishing opportunities was defined in time by the fisheries openings provided to Musqueam by Fisheries and Oceans Canada, and in space by different areas for the different fisheries of interest. Exclusion effects were then calculated as the proportion of time of an opening across a fishing area within which marine vessel traffic resulted in the exclusion of Musqueam from accessing these opportunities. Estimates of shipping induced exclusion were assessed in different ways to explore differences in effect according to:

- Marine resources (salmon, crab, and prawn)
- Fishing areas: regulatory boundaries (for salmon, crab, and prawn), as well as regularly accessed areas across the Lower Fraser River, and certain high conflict zones, specifically Tilbury Island and Fraser Surrey Docks (for salmon only)
- Tidal windows
- Time periods (across years and within a year)

A third component involved examining the relationship between varying levels of recent marine vessel traffic and restrictions on access. The resulting regression relationships were then used as a basis for exploring the effect of additional future marine vessel traffic and the inferred exclusions associated with 16 future development and fishery scenarios.

The first analytical component found that the status of marine resources across the Musqueam's territory has changed significantly in recent decades and current baseline level of exclusion from fishing opportunities across the territory is elevated due to a variety of factors. A significant part of Musqueam's current fishing in the Lower Fraser River and Salish Sea is directed at salmon (sockeye, chum, pink, coho, and chinook), crabs (particularly dungeness), and to a lesser extent prawns. Musqueam's ability to fish for these resources is influenced by the status of the resources, the impacts of aquatic and land infrastructure development projects, and regulated access to the resources (both spatial and temporal). For instance, decreases in sockeye, coho, and to a lesser extent, chinook abundance over the past decade have resulted in less access to these resources and limited Musqueam harvest of these species. This change has led to an increase in Musqueam effort in crab and prawn fishing for economic opportunity, subsistence, and ceremonial purposes. Moreover, increasing vessel traffic since the 1940s, human population growth, and anthropogenic development such as agriculture and forestry, transportation infrastructure like roads and bridges, river dredging and diking, invasive aquatic species, pollution, environmental and climate change-related ecosystem alterations, habitat loss, and wastewater facilities have additionally affected access to fish resources and impacted fishing quality.

The second analytical component was able to quantify exclusion effects and provided helpful insights about differences in effects across marine resources, fishing areas, and time periods. A first insight was that the level of exclusion depends on the target species (crab, prawn, and salmon), fishing vessel type, and type of fishing gear being used by Musqueam fishers. Within regulatory boundaries for the three fisheries from 2012-2017, vessel traffic led to exclusions from access to fishing for prawn (22% to 25%), crab (18% to 21%), and salmon (7% to 11%). A second insight was that the spatial scale (e.g., entire Lower Fraser River vs. a high conflict zone in the Lower Fraser River) and fishing areas of interest (e.g., Tilbury Island vs. Fraser Surrey Docks) have important influences on understanding exclusion effect. For instance, across years the exclusion of Musqueam salmon fishing opportunities due to vessel traffic was highest in the high conflict zone of Fraser Surry Docks (62% to 78%) and Tilbury Island (39% to 55%), followed by the regularly accessed areas in the Lower Fraser River (39% to 45%), and areas defined by the salmon regulatory boundaries (7% to 11%). The reason for higher exclusion at more localized areas is due to the increasing spatial concentration of the analysis and higher density of vessel traffic in the Lower Fraser River relative to the open waters of the Salish Sea (i.e., more vessels per unit area). A last insight relates to the timing of potential interactions between marine vessel traffic and Musqueam fishing. A summary of the number of vessel per day from 2012-2017 demonstrates year to year and day to day variation in the number of cargo-tanker vessels, tug-towing vessels, and other vessels interacting with different fisheries. Up to a maximum of 40 cargo-tanker vessels, 33 tug-towing vessels, and 61 other vessels are noted as interacting with fisheries on a given day (not necessarily all on the same day). Across years, there appears to be a qualitatively modest seasonal effect on exclusion with slightly higher exclusions from June to September for prawn and crab, and a slightly higher exclusion for salmon in September. As well, the exclusion of Musqueam fishing opportunities for salmon in the Lower Fraser River was slightly higher during slack tide (+/- a 1-hour buffer on either side) when compared to non-slack tide windows from 2012-2017 (2-6% higher average exclusion during slack tides, though 2015 was an exception with the opposite effect noted).

The third analytical component, involving an analysis of the historic relationship between the number of vessels and inaccessible fraction of fishing opportunities, revealed that the influence of vessel traffic on exclusion is statistically significant. Hence, these models are useful tools for estimating the effect of increases in future vessel traffic on access to fishing. In particular, the models indicate that the number and types of marine vessels are important determinants of exclusion. A greater number of vessels leads to greater exclusion and the influence of different types of vessels (e.g., cargo-tanker, tug-towing, or other vessels) depends on the fishery (salmon, crab, or prawn) and fishing areas of interest (e.g., regularly accessed areas or high conflict zones). As a result, five regression models were developed to represent the relationship between vessel traffic and exclusion from fishing (three salmon, one crab, and one prawn model). The effect of cargo-tanker vessels and tug-towing vessels was statistically significant across all models. The effect of other vessels was statistically significant in four of five models; the exception was the salmon model representing regularly accessed areas in the Lower Fraser River in which there was no significant relationship with other vessels. The strength of the effect of different vessel types on inaccessible fraction varies across models. In the prawn model, the magnitude of effect of tug-towing vessels was greatest, followed by cargo-tanker vessels, and other vessels. In the crab model, the magnitude of effect of tug-towing vessels was also greatest, followed by cargo-tanker vessels, and then other vessels. In the salmon model for regularly accessed areas in the Lower Fraser River, the magnitude of effect of cargo-tanker vessels was greatest followed by tug-towing vessels. In the salmon model representing the high conflict zone at Tilbury Island, the magnitude of effect of tug-towing vessels was greatest followed by other vessels and then cargo-tanker vessels. Lastly, in the salmon model representing the high conflict zone at Fraser Surrey Docks, the magnitude of effect of other vessels was greatest followed by cargo-tanker vessels, then tug-towing vessels.

The effects of future vessel traffic were estimated by calculating the inaccessible fraction of fishing opportunities under 16 scenarios for different fisheries with different levels of baseline and future marine vessel traffic. Increases in marine vessel traffic from a low to a high scenario of development are predicted to increase exclusion of Musqueam from fishing opportunities, regardless of the fisheries or locations of interest. Across scenarios, the largest exclusion effects are on salmon fisheries with the greatest effect on fishing near Tilbury Island (an 8-24% increase). Exclusion effects are already very high at Fraser Surrey Docks so the additional effects and percent change of additional marine vessel traffic are less (a 4-9% increase). Regularly accessed areas for salmon demonstrate a 7-16% increase in exclusion effects, while additional traffic leads to a 3-14% increase in exclusion from crab fishing and a 3-16% increase in exclusion from prawn fishing.

Given these findings, this study is useful for understanding the implications of marine vessel traffic on access to current and future fishing opportunities by Musqueam fishers. There is, however, some unavoidable crudeness to the data and available methods for estimating effects. Understanding the effects of vessel traffic on access to fishing can improved by addressing identified data gaps and advancing methods for estimating effects. In particular, this study implies a need for the following potential improvements:

- Address the gap in tide-current data so as to better quantify the interaction among tides-currents, salmon migration, vessel traffic, and exclusion from fishing;

- Improve the resolution of information / prediction at a project scale by building on the modeling techniques developed here so results can better account for and reflect project-specific interactions between marine traffic and Musqueam fishing vessels;
- Improve the confidence in the cumulative level of future marine vessel traffic given the significant influence of this information on estimating future effects on exclusion;
- Explore improvements to the regression models that estimate exclusion from salmon fishing in the Lower Fraser River since there are other unexplored factors and potentially greater complexity that contribute to unexplained variation in exclusion;
- Be mindful of other factors that may further restrict the timing and location of access to fishing opportunities since these factors may indirectly lead to other exclusion effects that are not accounted for in this analysis (e.g., declines in abundance of target species that lead to further restrictions in the timing and locations of openings for Musqueam); and
- Explore exclusion effects at other focal areas of interest to Musqueam for salmon, crab, and prawn fisheries, and develop methods to evaluate effects on other species around which there is a desire for harvesting, but which are currently inaccessible (e.g., eulachon and sturgeon).

Given the results of this study, the following broad strategies have also been identified to help minimize the magnitude of exclusion and chance of interaction between Musqueam fishing boats and other vessel traffic:

- Reduce the number of vessels interacting with Musqueam fishery openings;
- Monitor incidents of interaction between Musqueam fishing vessels and other vessel traffic;
- Encourage marine vessels to minimize and/or avoid locations of interaction during fishery openings (e.g., high conflict zones in the Lower Fraser River, such as Tilbury Island and Fraser Surrey Docks);
- Encourage marine vessels to minimize interactions during fisheries with gear types that require more time to deploy (e.g., crab and prawn fisheries, salmon seine fisheries);
- Engage with project proponents to design projects and adopt mitigation strategies that will minimize interactions with Musqueam fishing opportunities; and
- Promote communication with marine vessels operators to encourage the implementation and adherence to measures that will minimize interference with Musqueam fishing opportunities.

The intent of this study has been to develop a better understanding about the historic, recent, and future effects of marine vessel traffic on Musqueam's access to fishing opportunities in their Territory. Results in this report provide a strong foundation of information for understanding these effects, which complements the knowledge of Musqueam fishers, although it does not reflect the significance of restrictions on access to Musqueam. Ideally these insights can be used to inform and facilitate more detailed discussions about strategies for reducing impacts as development pressures continue into the future.

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1.0 Introduction

The waters within the traditional territory of the Musqueam First Nation within and adjunct to Metro Vancouver, and include all waters of the Fraser River downstream from the Port Mann Bridge to, and including, the Salish Sea, as well as Howe Sound and Burrard Inlet. The region is one of the most densely populated regions in Canada and these waters are some of the busiest recreational and most industrially developed in British Columbia. The human population in the region has increased by about 150% between 1990 and 2011. New large scale industrial activities are also proposed for the Port of Vancouver and surrounding waters, including the BHP Billiton Potash export facility at Fraser Surrey Docks, the WesPac LNG Marine Jetty, and the Fraser Grain Terminal, the Roberts Bank Terminal 2 expansion, among others. If developed, these projects would increase industrial shipping traffic in the waters of the traditional territory of the Musqueam First Nation, waters that also support myriad other uses including Food, Social and Ceremonial, as well as commercial fisheries. The consequence of the proposed increases to industrial shipping for the ability of Musqueam fishers to engage in fisheries is currently unquantified.

This purpose of this report is to help address this knowledge gap by (1) assessing historic / recent impacts of marine vessel traffic on the ability of Musqueam fishers to navigate on and access fishing opportunities within their territory, (2) estimating the potential future impacts of marine vessel traffic on fishing access given proposals for increases in industrial shipping, and (3) providing broad recommendations on how any existing and potential impacts on access to fishing opportunities can be reduced. This report does not include a consideration of other potential impacts on fisheries such as habitat changes and allocations to non-Indigenous fisheries, among other factors.

1.1 Limitations of this study

In undertaking this assessment, there was recognition that this study does not reflect complete information about Musqueam fishing, interaction with marine vessel traffic, future development patterns, and broader factors that affect availability and access to fisheries resources within their traditional territory. As such, this study has the following limitations (which are distinct from the specific analytical limitations discussed in Seciton 4.0):

- Not all Musqueam knowledge holders were able to participate in this study. Efforts were made to include key knowledge holders, but some Musqueam members with important knowledge were unable to participate.
- The information gathered from Musqueam knowledge holders is limited by what an individual is able and willing to share within the limited time available for this study.
- This study focuses on salmon, crab, and prawn as the species are most frequently fished by Musqueam. This study does, however, not consider impacts to other fisheries (i.e., limited eulachon fishery), or to Musqueam's ability to fish other culturally important species like sturgeon, for instance.
- The study area used to assess impacts on access to fishing opportunities should be understood to be a small portion of the actual area required for the meaningful practice of a Musqueam

way of life, as well as Aboriginal rights. The resource use data represented here are from Knowledge and Use Studies that represent current use/recent past use, not Musqueam historical use (e.g., Tam et al. 2016a; 2016b; 2017; 2018). As well, mapped representations of fishing reflect aggregations of use that are anchored in a wider set of rights-based cultural and livelihood practices that are exercised across the Musqueam traditional territory. For example, a single salmon catch-site represents a precise location (i.e., a drift), but that location does not capture the time and knowledge required to prepare for fishing, successfully catch fish, or travel to the fishing site; knowledge transmission while fishing and in preparation to fish; nor the areas of good quality habitat needed to sustain fish populations.

- Data regarding the detailed timing and frequency of marine vessel traffic of future development projects were not available at the time of completion of this study. A lack of detail about the final design of projects, agreed-upon mitigation measures, and the precise location of ancillary development and activities means that the results from this analysis should be considered a conservative estimate (i.e., effects are likely to be greater than predicted here). The results reported here are not specific to a particular project. Hence, Musqueam may require further supplementary research as project details become available.
- This Report does not include detailed recommendations on the best ways to monitor and mitigate impacts on access to fishing opportunities. The process of collaboration and discussion between Musqueam and any project proponents about appropriate monitoring and mitigation measures should be decided upon in dialogue with Musqueam and agreed to by Musqueam.

Given these limitations, this report represents only some of the impacts on access to fishing opportunities by Musqueam. This study does not reflect all Musqueam fishing uses in the study area; an absence of data does not signify an absence of use or value.

This report should not be used in place of other studies that may be required to more comprehensively characterize the implications of recent and future development on Musqueam way of life and rights-based practices, such as studies or assessments based on socio-economics, diet, health and well-being, governance, or planning and policy.

This report is based on the research and analysis of the authors. It is not intended as a complete depiction of the dynamic way of life and living system of use and knowledge maintained by the Musqueam people. This report is non-confidential and intended for consideration by Musqueam, the Crown, and project proponents within regulatory processes (e.g., environmental assessment). However, all data included in this report is the property of Musqueam and may not be used or reproduced without the written consent of Musqueam.

Nothing in this report should be construed as to waive, reduce, or otherwise constrain Musqueam rights within, or outside of, regulatory processes. Nor should this Report be construed as to define, limit, or otherwise constrain the Aboriginal or Treaty rights of other First Nations or Aboriginal peoples. It should not be relied upon to inform other projects or initiatives without the written consent of Musqueam.

2.0 Approach to evaluating the impacts of marine vessel traffic on access to fishing opportunities

This study involved three analytical components to understand the impacts of marine vessel traffic on Musqueam's access to fishing opportunities. These different components focused on understanding different temporal dimensions to impacts on access. The first component focused on understanding the cumulative effect of factors contributing to the historic baseline impact on access to fishing opportunities (see Section 2.1). A second component focused on quantifying the impact of recent (2009-2017) marine vessel traffic on access to fishing using available positional data for marine vessels and known fisheries openings provided to Musqueam harvesters (see Section 2.2). A third component involved examining the relationship between varying levels of recent marine vessel traffic and the resulting restrictions on access as a basis for exploring the effect of additional future marine vessel traffic and the inferred exclusions to future access (see Section 2.3). Our approach to evaluating impacts at these different time horizons is summarized below, with results from these analyses provided in Section 3.0.

2.1 Analysis of factors contributing to baseline impacts on access

The first analytical component involved engaging directly with Musqueam fishers. This step was accomplished during focus group meetings on March 2, 2018 and July 5, 2018 during which we learned about historic and current pressures on fishery resources, restraints to Musqueam in accessing fisheries, and the factors that have contributed to restrictions in access to fishing. At the March 2 meeting, we provided maps on which fishers were able to directly outline current commonly utilized crab, prawn, shrimp, and salmon fishing areas, and identify accessible areas and current/future access restrictions within living memory of the fishers particiatping in this meeting. We also developed timelines around availability and use in marine resources across recent decades and across the seasons. We discussed factors that have contributed to changing trends in marine resources and fishing opportunities, including shoreline developments, vessel traffic, pressures from other fishing sectors, and population trends of the focal resources for this study (i.e., crab, prawn, shrimp, salmon). The purpose of the second focus group meeting on July 5, 2018 was to validate the methods and results to-date, and identify where additional information (e.g., related to tide windows, amount of time to haul nets) was necessary to refine the analyses described in Sections 2.1 and 2.2.

During these meetings, we heard accounts of the interactions between marine vessel traffic and Musqueam fishers, and how these interactions affect the timing and location of fishing opportunities. Interruptions to the duration of active fishing efforts by other vessels can affect the safety of Musqueam harvesters, result in the loss of fishing gear, and/or reduce catch. The meeting resulted in a better understanding of the locations of recent and historic access to marine resources, seasonality and timelines of access to fishery resources and fishing trends, and a better understanding of the cumulative effect of factors that contribute to changes in marine resources and fishing opportunities available to Musqueam harvesters. This knowledge led to a better understanding around how to characterize baseline impacts in Section 3.1, as well it helped frame and characterize the quantitative analysis of recent marine vessel traffic summarized in Section 3.2.

Following our meeting, we performed a literature review which summarized technical reports and academic literature to understand factors that have contributed to baseline impacts on marine resources and access to fishing opportunities. We also compiled fishery, environmental, and human development data provided by the Musqueam Indian Band, Fisheries and Oceans Canada (DFO), and others. The scope of the literature review included summarizing trends in aquatic resources; human population growth; historical, current, and projected aquatic and near-shore development projects; changes to channel morphology, and changes to marine vessel traffic. Data provided by Musqueam fishers included information about numbers of fishing vessels, fisheries openings and types, and target species between 2011 and 2017. Other data included summaries of fisheries opening times and lengths, fishing boundaries, and marine vessel traffic from 1925 to 2017 (see Appendix A for data sources). Results are summarized in Section 3.1.

2.2 Analysis of impacts of recent marine vessel traffic on access

As confirmed through focus group discussions, access to salmon, crab, and prawn is dependent on, among other factors, the abundance of the resource, the timing and length of fisheries openings, the ability of fishers to navigate waters and physically access desired fishing sites, and the ability to engage in more or less uninterrupted fishing with minimal perturbations from passing vessels. Musqueam fishers revealed that their activities near the shoreline are affected by the proximity of passing vessels and that they must regularly pull up fishing nets and move to allow the safe passage of vessels. Through these discussions, Musqueam fishers also emphasized the need to frequently pull up drift nets and move their vessel to avoid colliding with approaching shipping vessels along the narrow stretches of channels. The process of pulling up nets and recasting them can take from a few minutes to several hours depending on the fishery and type of fishing gear being used. Interactions between Musqueam fishing vessels and other marine traffic represent a hazard to fishing gear and personal safety. Moreover, unfavourable fishery opening times, openings that follow neighbouring fishing areas that are very productive with their fishing, openings that do not factor in environmental conditions such as unfavourable tides, or openings that coincide with times of competing sectors, may limit the efficiency of Musqueam fishers. For example, the commercial fishery access to crab coincides with Musqueam Aboriginal Day (June 21), which reduces Musqueam's access to crab harvesting for ceremonial purposes. As well, constraints on fishing locations in other sectors can put pressure on recreational crabbers to move into locations where Musqueam harvest, thereby increasing interactions and competition with Musqueam fishers for the same resource.

Given the known impact of marine vessel traffic on Musqueam fishing opportunities, this study involved a second component focused on a quantitative analysis to estimate the effect of recent levels of marine traffic on access to Musqueam fishing opportunities. Critical to this analysis was the availability of Automatic Identification System (AIS) data, which provided locational information for all tracked vessels occupying the traditional territory of the Musqueam from 2009-2017 at either 1-hour (2009-2011) or 5-minute intervals (2012-2017). The analysis then focused on quantifying the effect of marine vessel traffic on the ability of Musqueam fishers to access fishing opportunities. Access to fishing opportunities was defined in time by the fisheries openings provided to Musqueam by Fisheries and Oceans Canada, and in space by different areas for the different fisheries of interest (a subset of locations within their traditional territory). Exclusion effects were then calculated as the proportion of time of an opening across a fishing area within which marine vessel traffic resulted in the exclusion of Musqueam from accessing these opportunities.

Exclusion effects (or inaccessible fraction) were examined based on fisheries for different marine resources (i.e., salmon, crab, and prawn), for different fishing areas (i.e., regulatory boundaries for salmon, crab and prawn, as well as regularly accessed areas (Lower Fraser River), and two high conflict zones, specifically Tilbury Island and Fraser Surrey Docks, for salmon only), for different tide windows (i.e., slack tide (+/- 1-hr buffer) vs. non-slack tide), and across years / within a year. The analysis also considered, separately, the effect of marine vessel traffic on regularly accessed (for salmon and crab) and high conflict fishing areas in the Lower Fraser River (for salmon only) due to the importance of these areas to Musqueam harvesters. The analysis also considered the effect of tidal influence on exclusion because river currents associated with a strong rising tide are preferable to salmon migrating up-river, Musqueam harvesters, and other vessels seeking to take advantage of the river's energy to aid in their movement. As such, tidal windows are known to Musqueam as being times of greater conflict between fishers and marine vessels.

Impacts on access were quantified as an inaccessible fraction of the total area and duration of a fishing opportunity provided (i.e., values between 0.0 and 1.0). In other words, if marine vessel traffic were to have no effect on access to fishing, the inaccessible fraction would be 0 (zero). Alternatively, if vessel traffic were to have its greatest possible effect on access to fishing across all hours and places within an opening, the inaccessible fraction would be 1 (one).

The analysis of impacts of traffic on access to fishing opportunities involved the following tasks:

- Task 1: Acquisition of non-spatial and spatial data
- Task 2: Pilot analysis to determine appropriate time-step
- Task 3: Data processing
- Task 4: Validation of methods and results

A complete list of data sources is summarized in Appendix A. Appendix B provides a description of these tasks and related activities. In essence, this analysis reproduced the position and path of AIS-reporting vessels in the study area and estimated their effect on Musqueam fishing opportunities by generating an effective exclusion footprint for each vessel, projected to either side of the vessel and forward down the vessel's path of movement. Only a subset of all AIS-reporting vessels were included in the analysis (see Table 1). The size of the exclusion footprint in space and time was determined by the approximate time required to haul fishing gear from the water (see Table 2), and the safe distance from vessels required by fishing activity and fishing gear (i.e., a distance of 250m to the port and starboard of the vessel was used as a spatial buffer to represent a zone of safety for fishing vessels and their lines and gear).

The analysis was performed separately for each individual fishery opening, with exclusion distances determined by the species (salmon, crab, or prawn) and gear types (trap, drift net, etc.) allowed for that opening. The level of exclusion, or inaccessible fraction, was summarized according to target fisheries. Fishing areas for prawn, crab, and salmon were delineated by the regulatory boundaries for these fisheries. Two additional spatial boundaries were used for the assessment of exclusion effects on salmon fishing. One area focused exclusively on fishing areas across the Lower Fraser River since this is an area of high activity and interest to Musqueam. An additional area focused on a subset of high conflict zones identified by Musqueam fishers on the

Lower Fraser River and around which more intense salmon fishing-vessel interactions are known to occur (e.g., Tilbury Island and Fraser Surrey Docks).

The exclusion analysis was performed once for every hour across the timespan of available data (April 2009 to December 2011 with 1-hour time resolution data, January 2012 to June 2017 with 5-minute time resolution data). A simulation of vessel distribution was performed and the exclusion effect calculated at the start of every hour within the timespan of the analysis. A 1-hour time-step was used in this analysis based on a pilot analysis on a subset of the data, which used multiple time-step lengths to understand the effect of the time step on results (see Task 2 in Appendix B).

A discrete and repeated time-step of 1-hour was used rather than calculating exclusion at a finer temporal scale along the entire length of each vessel discretely, for two reasons:

- It allowed us to include not just the effect of the actual presence of vessels at any given moment, but also the effect on fishing of the anticipated presence of approaching vessels.
- At each time-step the estimated footprints were dissolved together, such that if more than one vessel was preventing fishing for a particular location at a particular time (e.g., clustered vessels in the centre channel of the Fraser River), that location would only be counted once toward the total exclusion amount, and not double counted.

Using this time-step, a calculation of the inaccessible fraction was then generated by multiplying the measured excluded area by the length of the time-step and summing over all the time-steps for an individual vessel. This calculation then allowed for an estimate of total time and area excluded from fishing when summed across all vessel traffic. Figure 1 illustrates the areas of conflict on a day in which there was a high level of traffic and a high conflict with available Musqueam salmon fishing opportunities (i.e., a relatively high inaccessible fraction, 18%), while Figure 2 illustrates the areas of conflict on a day in which there was a lower level of traffic and lower level of conflict with available Musqueam salmon fishing opportunities (i.e., a relatively low inaccessible fraction, 5%). Results are summarized in Section 3.2.

Table 1. Summary of AIS vessel types included in this analysis.[1] Codes for vessel type are listed here: http://catb.org/gpsd/AIVDM.html#_type_5_static_and_voyage_related_data (Table 11)

AIS type group	Included in exclusion analysis
Cargo	Y
Tug	Y
Pleasure Craft	Y
Towing	Y
Passenger	Y
Towing: length exceeds 200m or breadth exceeds 25m	Y

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[1] Vessels required to have AIS include: (1) every ship of 150 tons or more that is carrying more than 12 passengers and engaged on an international voyage shall be fitted with AIS, (2) every ship, other than a fishing vessel, of 300 tons or more that is engaged on an international voyage shall be fitted with an AIS, and (3) every ship, other than a fishing vessel, of 500 tons or more that is not engaged on an international voyage shall be fitted with an AIS, but if it was constructed before July 1, 2002 it need not be so fitted until July 1, 2008. Source: Canadian Coast Guard AIS Guidelines http://www.ccg-gcc.gc.ca/eng/CCG/Maritime-Security/AIS

AIS type group	Included in exclusion analysis
Tanker	Y
Dredging or underwater ops	Y
Military ops	Y
High speed craft (HSC)	Y
Wing in ground (WIG)	Y
Reserved for future use	N
Diving ops	N
Law Enforcement	N
Noncombatant ship according to RR Resolution No. 18	N
Medical Transport	N
Fishing	N
Not available (default)	N
Other Type	N
Sailing	N
Search and Rescue vessel	N
Port Tender	N
Pilot Vessel	N
Spare - Local Vessel	N
Reserved	N
Anti-pollution equipment	N

Table 2. Summary of fishing gear types and times required to set and haul these gear types. Note that these times represent a best estimate. There are some situations where more time would be required, depending on local hydrology and hydrodynamics. For instance, there are safety concerns associated the strong back eddy on the south side of the river in front of Sudbury Cedar near the Alex Fraser Bridge which, when coupled with marine traffic, can create heightened safety concerns during a fishery.

Resource	Gear type	Approximate set time	Approximate haul time	Value used in analysis (minutes)
crab	trap	4 hrs	5 hrs	300
prawn	shrimp & prawn	n/a	n/a	300
prawn	trap	4 hrs	5 hrs	300
salmon	beach seine	30 min	45 min	45
salmon	drift net	5-10 minutes	10min - 1 hr	35
salmon	purse	30 min	2 hrs	120
salmon	salmon	n/a	n/a	35
salmon	seine	30 min	2 hrs	120
salmon	tangletooth	5-10 minutes	10min - 1 hr	35
shrimp	shrimp trawl	8 hrs		30

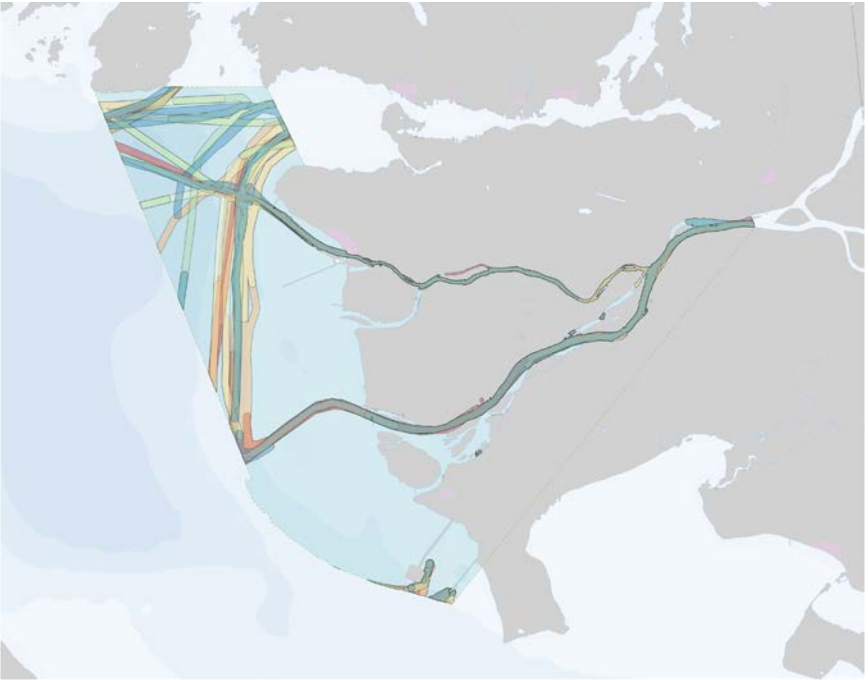

Figure 1. Map illustrating a level of marine vessel traffic and areas of potential interaction on September 28, 2013 that resulted in a relatively **high** exclusion (inaccessible fraction) of Musqueam fishing opportunities for salmon (18% exclusion).

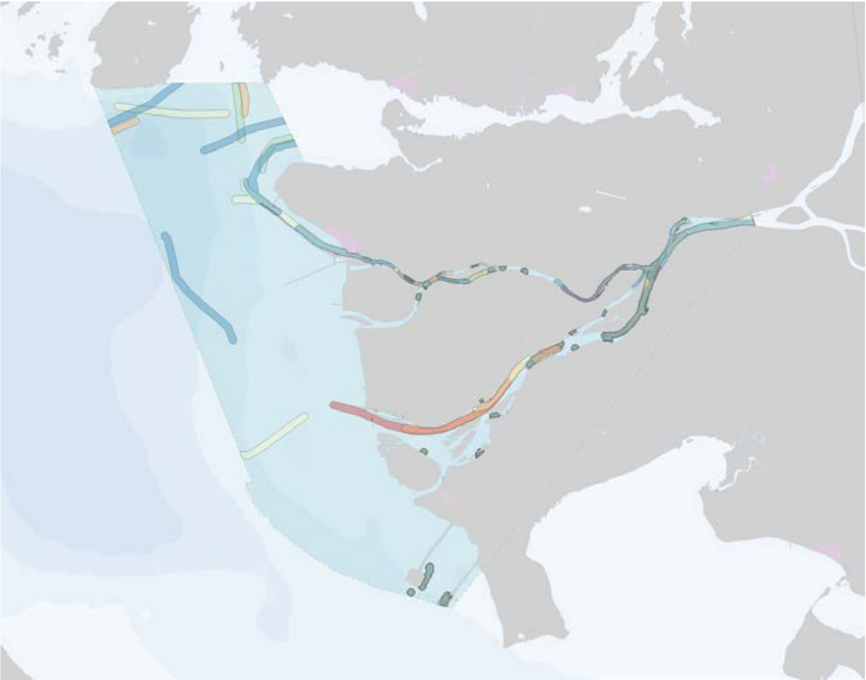

Figure 2. Map illustrating a level of marine vessel traffic and areas of potential interaction on October 15, 2016 that resulted in a relatively **low** exclusion (inaccessible fraction) of Musqueam fishing opportunities for salmon (5% exclusion).

2.3 Analysis of impacts of future marine vessel traffic on access

Several proponents have proposed to develop projects in the region in the future that have the potential to add to the baseline impact of marine vessels on Musqueam's access to fishing opportunities for salmon, prawn, and crab. The locations of these projects are illustrated in Figure 3 and the level of additional vessel traffic is summarized in Table 3 with anticipated interactions between potential projects and different fishing areas summarized in Table 4.

Figure 3. Map with locations of all major proposed projects in the region with proposals to increase marine vessel traffic (also summarized in Table 3).

Table 3. List of future projects with increased shipping and the potential for interaction with Musqueam fishing opportunities. Note that this information is based on the best available information / interpretation as summarized in project proposals available at the time of this study. Total vessel traffic per year and per day across potential projects are summarized in Appendix C based on the different fisheries and project interactions identified in Table 4.

Project name	Year of operation	Change in cargos / tankers per year	Change in tugs per year	Location	References for vessel numbers
Kinder-Morgan Westridge Transfer Facility	2020	120 to 480	240 to 960 (2 per tanker)	Westridge Marine Terminal	Kinder Morgan Canada (2016)
VAFFC Marine Transfer Station (jet fuel)	2020?	60	50 to 76	Across from Tilbury Island	Vancouver Fraser Port Authority (2018)
Woodfibre LNG Marine Terminal	2020 or later	36 to 48	108 to 144	Howe Sound (Woodfibre pulp mill)	Woodfibre LNG Project (2014)
Fraser Grain Terminal	2020 or later	63 to 80	126 to 160	Fraser Surrey Docks	Vancouver Fraser Port Authority (2018)
WesPac LNG Terminal	2021	137 (68 export vessels, 69 bunker vessels)	273 to 342	Tilbury Island	WesPac Midstream (2018)
BHP Potash Terminal	2021 or later	187	374 (minimum)	Fraser Surrey Docks	BHP (2017)
Lehigh	Phase 1: 2021 Phase 2: 2022 or later	Phase 1: 100 Phase 2: 35 to 45	?	Tilbury Island	Lehigh Hanson Canada (2018)
Roberts Bank Terminal 2	2024	260	520 to 780 (large berthing / escort tugs)	Roberts Bank (Delta)	Roberts Bank Terminal 2 Project (2015)
Centerm	?	52	?	Burrard Inlet (north side)	Vancouver Fraser Port Authority (2016)

Project name	Year of operation	Change in cargos / tankers per year	Change in tugs per year	Location	References for vessel numbers
Burnco Mine	?	182	182	Howe Sound	Canadian Environmental Assessment Agency (2016)
Fibre Co.	?	9	9 (minimum)	Burrard Inlet (north side)	Vancouver Fraser Port Authority (2017)
G3 Terminal	?	112	?	Burrard Inlet (north side)	G3 Terminal Vancouver (2016)
Derwent	?	52	52 to 104	Fraser River (north side)	Summit Earthworks Inc. (2017)
FSD Direct Coal Transfer Facility	?	? (possibly 80 ocean going vessels)	? (possibly 640 barges)	Texada Island (ocean going vessels only) Fraser Surrey Docks (barges only)	SNC Lavalin (2013); Vancouver Fraser Port Authority (2018)

Table 4. Summary of potential interactions (X) between proposed projects and different fishing areas. Note use of the following abbreviations: T = Tilbury Island, FSD = Fraser Surrey Docks, ? = unknown though possible future interaction.

Project name	Salmon fishing in high conflict zones	Salmon fishing in regularly accessed areas	Salmon fishing within regulatory boundaries	Crab fishing within regulatory boundaries	Prawn fishing within regulatory boundaries
Kinder-Morgan Westridge Transfer Facility			X	X	X
VAFFC Marine Transfer Station	X (T)	X	X	X	X
Woodfibre LNG Marine Terminal			X	X	X
Fraser Grain Terminal	X (FSD & T)	X	X	X	X
WesPac LNG Terminal	X (T)	X	X	X	X
BHP Potash Terminal	X (FSD & T)	X	X	X	X
Lehigh	X (T)	X	X	X	X
Roberts Bank Terminal 2			X	X	X
Centerm			X	X	X
Burnco Mine			X	X	X
Fibre Co.			X	X	X
G3 Terminal			X	X	X
Derwent			X	X	X
FSD Direct Coal Transfer Facility	? (FSD & T)	?	?	?	?

To explore the potential effect of new projects and the vessel traffic induced by these projects, a third analytical component to this study involved developing a statistical regression model using recent / historical data to represent the relationship between the number of vessels per day and exclusion or inaccessible fraction. This regression model could then be used to explore the effect of additional traffic in the future through a scenario analysis (Duinker and Greig 2007).

As a result of the analysis described in Section 2.2, daily summaries of the fraction of available fishing area precluded by vessel traffic, termed inaccessible fraction, were calculated. For those days for which there was an opening of a given fishery, a count was made of the number of vessels which were present within the boundaries of that fishery at some point during the day. The number of vessels was also grouped into three categories of vessel type to better allow for the exploration of the relationship between fishing exclusion (or inaccessible fraction) and the types of vessels associated with proposed projects separately from the relationship with other vessels that would not necessarily be changed by these projects. The first category of vessels included tankers and cargos, a second category of vessels tugs and towing vessels, and the final category included all others within scope of the analysis (see Table 1).

Total inaccessible fraction per day per fishery type (the response variable) and number / types of vessels present in the boundaries of that fishery opening on that day (the predictor variables), were then used as the basis for a regression analysis to understand the relationship between vessels and exclusion of Musqueam from the fishing opportunities being provided to them. Due to variation in vessel-fishing interactions, different regression models were developed for the different species and locations of fishing of interest to Musqueam.

The following steps were completed to undertake this statistical analysis and develop regression models to support the assessment of potential impacts associated with future development:

- A logit transformation of response variable (inaccessible fraction) was used to improve normality of the data as is required with values constrained between 0 and 1.0.
- A General Linear Model (GLM) was then developed to fit a relationship between inaccessibility to salmon, crab, and prawn fisheries, and the number / types of vessels interacting with different fishing areas of interest. For crab and prawn a model was developed for the areas delineated by the regulatory boundaries, while for salmon a model was developed for the regulatory boundaries, regularly accessed areas, and high conflict zones in the Lower Fraser River, specifically Tilbury Island and Fraser Surrey Docks. GLMs were developed to examine whether cargo/tanker vessels, tug / towing vessels, and/or other vessels had a significant effect on exclusion. The best models were selected based on the statistical significance of the vessel predictor variables and an Akaike information criterion (AIC) as a measure of model fit.
- A set of plausible future scenarios (see Table 5) were defined based on different combinations of species of interest, fishing areas for those species, levels of baseline marine vessel traffic, and levels of future marine vessel traffic. The scenario analysis requires explicitly stating different assumptions about the future marine vessel traffic because future traffic cannot be predicted with certainty. Assumptions about baseline marine vessel traffic are also required since the relationship between vessel traffic and exclusion is non-linear (i.e., the exclusion effect is different at different levels of baseline traffic). Lastly, a scenario requires specifying the marine resource and fishing area of interest since the regression models vary based on these conditions, and there are different interactions between potential future projects and different fishing areas. The interactions between potential future projects and different fishing areas were summarized based on readily available project proposal reports and are summarized in Table 4.
- Table 5 also summarizes the values for the future and baseline traffic values used in each scenario in the scenario analysis. A low baseline level of marine vessel traffic was defined as the 25th percentile of historic vessel traffic from 2012-2017 for a particular species and fishing location of interest, while a high baseline level of marine vessel traffic was defined as the 75th percentile of historic vessel traffic from 2012-2017.

Scenarios with a low level of future marine vessel traffic were defined as situations with only one potential project being active on a given day in a particular fishing area based on the interactions identified in Table 4, and as such leading to an increase in one cargo / tanker and one tug / towing vessel per day. The specific project in this scenario was not specified since the regression model cannot differentiate the effect of different projects (i.e., beyond a consideration of vessel types, all potential projects are treated equally in terms of their exclusion effect). Scenarios with a high level of future traffic were defined as including all possible projects being active on a given day in a particular fishing area based on the number of vessels summarized in Table 3 and interactions identified in Table 4. Appendix C summarizes how future vessel traffic was used to develop low and high traffic scenarios for the scenario analysis.

- GLMs with statistically significant coefficients were then used in a scenario analysis to estimate exclusion or inaccessible fraction under the different combination of conditions and values in Table 5. The effect of future traffic on exclusion was then compared to exclusion under a baseline level of marine vessel traffic (i.e., without future traffic).

Results of the regression and scenario analyses are summarized in Section 3.3.

Table 5. Combination of conditions and values used to explore potential impacts of future marine vessel traffic on fishing exclusion. Note use of the following abbreviations: C-T = cargo / tanker vessels, T-T = tug / towing vessels, OV = other vessels. Baseline number of vessels generated using a summary of historic vessel traffic from 2012-2017 (see Table 6). Appendix C summarizes the source for low and high future traffic scenarios.

Scenario	Marine resource	Fishing area	Baseline marine vessel traffic	Future marine vessel traffic (additional)
1	Salmon	Regularly accessed areas	Low (25th percentile) C-T = 5 per day T-T = 19 per day OV = 8 per day	Low C-T = 1 per day T-T = 1 per day
2	Salmon	Regularly accessed areas	Low (25th percentile) C-T = 5 per day T-T = 19 per day OV = 8 per day	High C-T = 2 per day T-T = 2 per day
3	Salmon	Regularly accessed areas	High (75th percentile) C-T = 8 per day T-T = 24 per day OV = 12 per day	Low C-T = 1 per day T-T = 1 per day
4	Salmon	Regularly accessed areas	High (75th percentile) C-T = 8 per day T-T = 24 per day OV = 12 per day	High C-T = 2 per day T-T = 2 per day
5	Salmon	High conflict zone: Tilbury Island	Low (25th percentile) C-T = 3 per day T-T = 5 per day OV = 0 per day	Low C-T = 1 per day T-T = 1 per day

Scenario	Marine resource	Fishing area	Baseline marine vessel traffic	Future marine vessel traffic (additional)
6	Salmon	High conflict zone: Tilbury Island	Low (25th percentile) C-T = 3 per day T-T = 5 per day OV = 0 per day	High C-T = 2 per day T-T = 2 per day
7	Salmon	High conflict zone: Tilbury Island	High (75th percentile) C-T =5 per day T-T = 9 per day OV = 1 per day	Low C-T = 1 per day T-T = 1 per day
8	Salmon	High conflict zone: Tilbury Island	High (75th percentile) C-T =5 per day T-T = 9 per day OV = 1 per day	High C-T = 2 per day T-T = 2 per day
9	Salmon	High conflict zone: Fraser Surry Docks	Low (25th percentile) C-T = 3 per day T-T = 8 per day OV = 0 per day	Low and high are the same C-T = 1 per day T-T = 1 per day
10	Salmon	High conflict zone: Fraser Surry Docks	High (75th percentile) C-T = 5 per day T-T = 11 per day OV = 2 per day	Low and high are the same C-T = 1 per day T-T = 1 per day
11	Crab	Regulatory boundaries	Low (25th percentile) C-T = 19 per day T-T = 25 per day OV = 13 per day	High C-T = 4 per day T-T = 5 per day
12	Crab	Regulatory boundaries	High (75th percentile) C-T = 25 per day T-T = 20 per day OV = 28 per day	High C-T = 4 per day T-T = 5 per day
13	Crab	Regulatory boundaries	High (75th percentile) C-T = 25 per day T-T = 20 per day OV = 28 per day	Low C-T = 1 per day T-T = 1 per day
14	Prawn	Regulatory boundaries	Low (25th percentile) C-T = 14 per day T-T = 12 per day OV = 8 per day	High C-T = 4 per day T-T = 5 per day
15	Prawn	Regulatory boundaries	High (75th percentile) C-T = 20 per day T-T = 17 per day OV = 21 per day	High C-T = 4 per day T-T = 5 per day
16	Prawn	Regulatory boundaries	High (75th percentile) C-T = 20 per day T-T = 17 per day OV = 21 per day	Low C-T = 1 per day T-T = 1 per day

3.0 Summary of findings

3.1 Factors contributing to baseline impacts on access

Over the past several decades, traditional Musqueam fishing areas have undergone many changes that have altered fishing opportunities. These changes include anthropogenic development such as agriculture and forestry, transportation infrastructure like roads and bridges, human population size and density, river dredging and diking, invasive aquatic species, pollution, environmental and climate change-related ecosystem alterations, habitat loss, and wastewater facilities (Labelle 2009, Johannes et al. 2011). Further, vessel traffic in the British Columbia South Coast marine areas has increased significantly over the last 100 years in terms of vessel size, frequency, and type.

A significant part of Musqueam's current fishing in the Lower Fraser River and Salish Sea is directed at salmon (sockeye, chum, pink, coho, and chinook), crabs (particularly dungeness), and to a lesser extent prawns (Tam et al. 2016b).[2] The ability to fish for these resources is influenced by the status of these resources, the impacts of aquatic and land infrastructure development projects, Musequeam's access to fishing opoortunities (both spatial and temporal, as determined by DFO management areas and windows), and level of marine vessel traffic.

3.1.1 Salmon resources

Salmon within the Fraser River Basin are, in general, at relatively low abundance (Labelle 2009). Figure 4 below provides an overview of relatively recent salmon abundance for sockeye, pink, chum, chinook, and coho salmon in the Fraser River Basin. These data and trends also need to be considered in the context of longer term declines in salmon abundance in the Fraser River. For example, in 1892 Charlie qiyəplenəxʷ states how low the numbers were in comparison to earlier years (Department of Fisheries of Canada 1893). As well, the Hell's Gate rock slide in 1914 contributed to declines in abundance (Roos 1991).

More specifically, sockeye salmon stocks have been declining since around 1993, with 2009 representing the lowest sockeye return year since 1947 stocks, potentially resulting from low survival of the 2005 salmon entering the ocean with some runs, such as Cultus Lake and Late Stuart sockeye, having extremely low abundance (Labelle 2009, Marmorek et al. 2011). Pink salmon returns to the Fraser River reached a record high abundance in 2003 but have since declined. A lack of funding since 2001 has prevented adequate estimations of pink returns and resulted in tremendous forecasting uncertainty (Labelle 2009). According to Musqueam fishers, pink abundance has severely dropped off over the past few years (interview with Musqueam members, March 2, 2018). Coho abundance has significantly fluctuated over the last few decades, with moderate returns (catch plus escapement) in the mid 1970s to early 1980s, higher returns between the mid 1980s to early 1990s, towards a more recent decline since 1990 (see Figure 4e).

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[2] In the past, a much wider range of species was accessed (e.g., sturgeon, eulachon, shellfish); these other fisheries can either not be accessed or there is limited access due to a variety of factors.

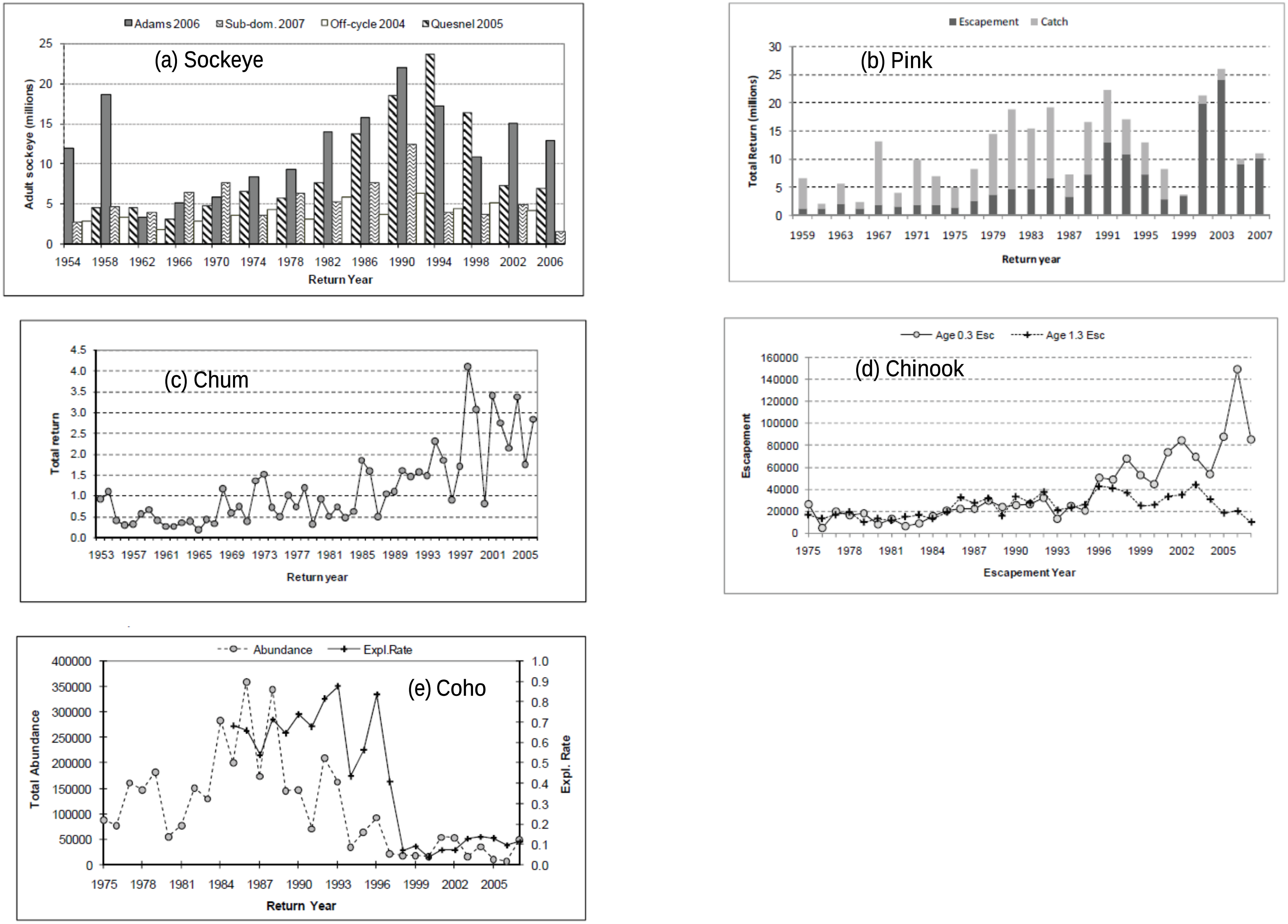

Figure 4. Annual trends in (a) Fraser River sockeye (upper left), (b) Fraser River pink (upper right), (c) Fraser River chum (centre left), (d) Fraser River summer-run chinook (centre right), and (e) Thompson River coho (bottom left). All graphs taken from Labelle (2009).

Coho abundance in the past decade has reached the lowest level historically recorded, and its COSEWIC assessed status of “threatened” has driven significant conservation efforts in Southern British Columbia (COSEWIC 2016). Fraser River stream-type chinook stocks have severely declined since 2004 according to the Department of Fisheries and Oceans (DFO)-verified data dating back to 1995 (DFO 2010). The decrease in abundance of Lower Strait of Georgia chinook is most obvious, with a slight decrease in Late Fraser stocks, and a fluctuation about a fairly stable mean for other stocks (Riddell et al. 2013). Chum hatchery augmentation and enhancement programs since the 80’s have significantly influenced Fraser River populations. Returns of chum have generally increased since 1998, likely resulting from lower exploitation rates or higher survival rates (Labelle 2009).

While most salmon species have been on the decline, the combined, total abundance of sockeye, chum, and pink salmon in the Pacific ocean are estimated to have increased since 1925 through hatchery augmentation of certain species (Figure 5). Salmon abundance was low until 1977, at which point a persistent decadal shift in ocean conditions occurred, and populations began to increase; despite the general increasing trend, species composition has not remained static. Pink salmon were more abundant than chum and sockeye during the 1934-1943 period compared to earlier records, which has contributed to the observed increase in Pacific salmon abundance (Ruggerone and Irvine 2018). Similarly, hatchery augmentation of salmon between 1990 and 2015 contributed 60% of chum, 15% of pink, and 4% of sockeye, with pink and chum production primarily explaining the observed increasing trend in Figure 5 (*ibid*). Hatchery releases of chum salmon in the 1990’s averaged at around 21 million fish per year. After 1998, hatchery production decreased substantially to an average 9 million per year (Labelle 2009).

Salmon that live in and migrate through the Fraser River are threatened by changes in development patterns like agriculture and other industries, and local and global habitat changes like climate change. Low water levels and increased water temperatures have also been noted to affect salmon populations. Late-run sockeye salmon that spend a longer period of time in fresh water prior to spawning exhibit higher mortality rates, and the occurrence of some salmon species entering the Fraser River earlier in the season has increased since 1995. The current dire status of coho has been mostly attributed to overexploitation and changes to freshwater and marine habitats (Labelle 2009). Predation by harbour seals on chinook salmon has been observed in the Strait of Georgia, and Musqueam fishers have identified seals as having significant impacts on salmon fisheries in this area (Labelle 2009, interview with Musqueam members, March 2, 2018).

Exploitation rates in the Fraser River average around 8% for pink salmon, with most harvest limitations resulting from restrictions placed on the harvest of other salmon stocks with overlapping run times. Because Southern BC coho salmon exist in mixed-stock fisheries, they are caught both intentionally, and as bycatch in fisheries targeting other species, and the unprecedented restrictions placed on coho fisheries since 1997 have impacted the productivity of fisheries targeting other species (TCCOHO 2013). For example, restrictions on ocean fisheries of coho have significantly benefited the productivity of chinook in the Fraser River, as fishers work to reduce their unintended impact on coho (Labelle 2009).

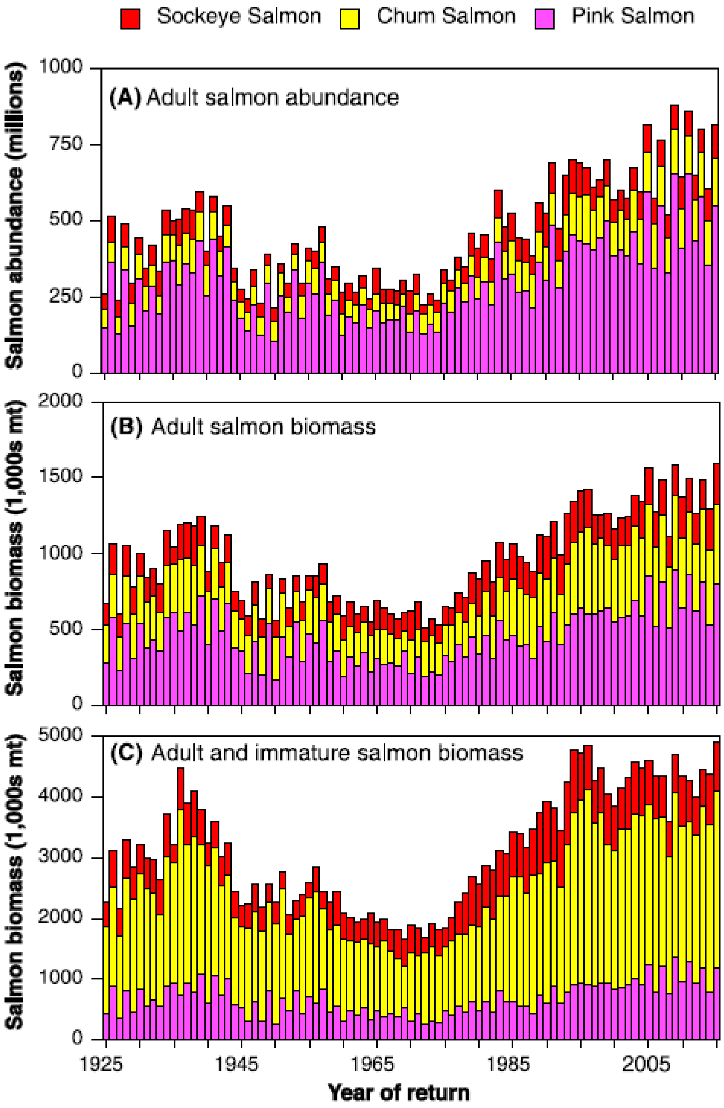

Figure 5. Abundance and biomass of adult and juvenile sockeye (red), chum (yellow), and pink (pink) salmon between 1925 and 2016. Graph taken from Ruggerone and Irvine (2018).

3.1.2 Prawn and crab resources

Commercial trapping of prawn and shrimp, one of the most economically valuable fisheries in the Pacific Region, began in the Howe Sound in 1914 and peaked in the 1970s. Spot prawns (*Pandalus platyceros*) are the primary target of this fishery, with Coonstripe shrimp (*P. danae*) and Humpback shrimp (*P. hypsinotus*) comprising a smaller portion of the catch. Recreational fishing of prawn, shrimp, and crab increased by 13% between the years 2005 and 2010. This increase is partly explained by recent declines in salmon abundance and the related fishing opportunities. These declines in salmon have similarly resulted in a larger dependence on prawn and shrimp for food, social, and ceremonial purposes (DFO 2018a). Figure 6 shows the pattern in prawn landings from 1990 to 2016 and subsequent variability, a reasonable proxy for stock abundance. Over this period of record, landings of prawn have generally increased from 1990 to 2009 with declines and larger year-to-year variability noted since the peak in 2009 (DFO 2018a).

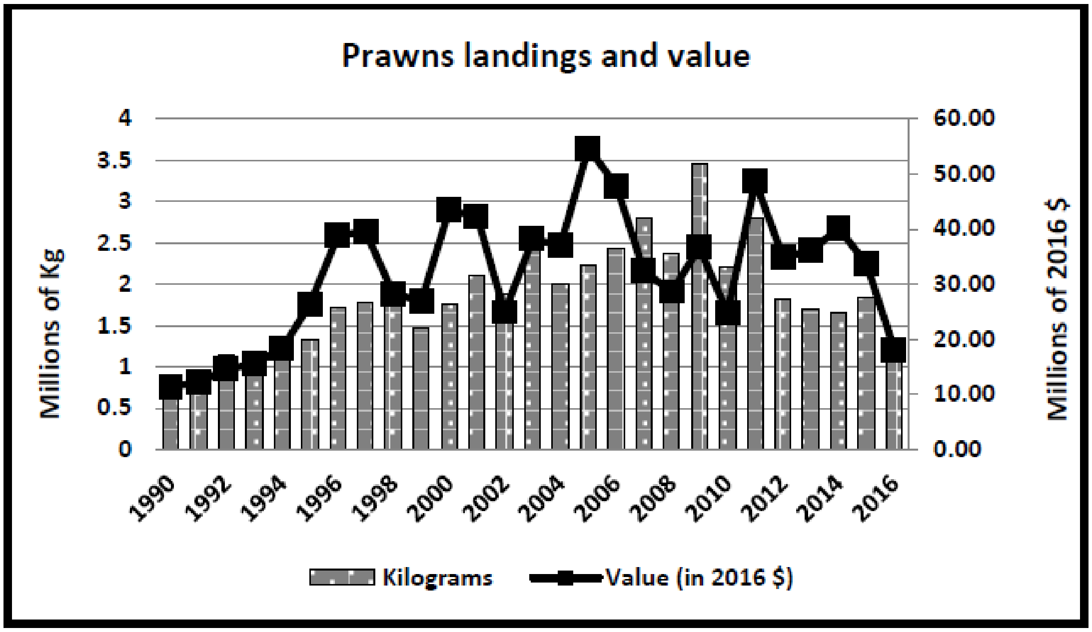

Figure 6. Annual BC commercial logbook-recorded prawn landings, and value based on fish slips (not including post-season price adjustments). Graph taken from DFO (2018a).

Crab fisheries in the Pacific Region primarily target Dungeness crab (*Cancer magister*), Red Rock crab (*C. productus*), Red King crab (*Paralithodes camtschatic*), and Golden King crab (*Lithodes aequispinus*) (DFO 2018b). The commercial crab fishery is currently one of BC's most valuable shellfish fisheries. Figure 7 shows the annual Dungeness crab landings between 2004 and 2016 (DFO 2018b). Based on conversations with Musqueam fishers, there is a general concern that crabs are being over-fished by others due to declining salmon populations, and the associated shift to fishing other species, like crab, as well as the length of time the commercial crab fishery is open. Limited stock assessment information is available to quantitatively evaluate the status of available prawn and crab resources.

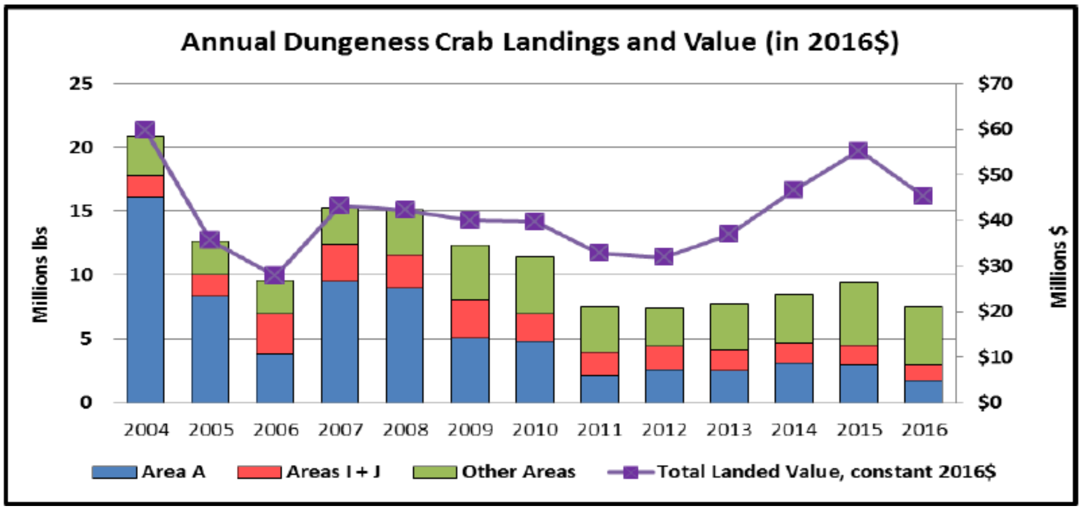

Figure 7. Annual BC commercial logbook-recorded Dungeness crab landings, and total landed value based on fish slips. Graph taken from DFO (2018b).

3.1.3 Historic and recent use of marine resources by Musqueam

Fishing represents a vital component of Musqueam culture, providing food, a sense of community, and an environment in which traditional knowledge is transmitted. The transmission of cultural knowledge among Musqueam members occurs during preparation for fishing, fishing on the water, and processing fish after they are caught and through the social occasions that accompany their use. This knowledge transfer depends on the availability of fish, the time spent fishing, and the frequency of opportunities to fish (Tam et al. 2017). In 1990, the Supreme Court of Canada affirmed the rights of Musqueam members to fish in their territory through the *Sparrow* decision.[3]

Communication with Musqueam fishers has shed light on the historic patterns of productivity of commercial, ceremonial, and subsistence fishing. Fishing on the Fraser River was noted by Musqueam fishers as fairly unproductive in the 1960s and 1970s, but picked up in the 1980s due to a variety of environmental and human factors (Labelle 2009). The 1990s were some of the most productive years in recent history, with large numbers of fish caught. There was general consensus that 2010 was also a good fishing year, in part due to the historic abundance of sockeye salmon returning to the Fraser River (interview with Musqueam members, March 2, 2018).

Towards the end of the 1990s, a decline in salmon catch triggered increased effort in fishing for crab and prawn. While prawn fisheries were a traditional fishery for Musqueam, fishing for prawn declined prior to the 1990s. Recently, amidst reductions in salmon catch, the practice of prawning has become more popular with Musqueam members. However, additional restrictions to prawn fishing access in the Howe Sound and at Bowen Island have made it difficult for Musqueam fishers to practice prawning and pass along knowledge to others.

Musqueam current traditional use areas include all arms of the Fraser River, and much of the adjacent marine areas, including sites in Burrard Inlet, Howe Sound and Boundary Bay, which supplied specific resources not as easily obtained in the Fraser River delta. Many of these areas are now inaccessible which puts increased importance on the delta, meanting that the Lower Fraser River is the current primary location of Musqueam fishing for food, social, and ceremonial (FSC) purposes (Tam et al. 2017). However, the Lower Fraser River and the marine areas near its confluence are used by the Musqueam much less today than in the past due to increased land development and marine vessel traffic. For instance, Figure 8 provides an aerial view of the Fraser Surrey Docks area, or the section of the Fraser adjacent to New Westminster and Delta prior to and with current levels of nearshore development and traffic. This area of the Fraser River is an important and productive salmon fishing and cultural heritage location for the Musqueam.

The Fraser Surrey Docks area is characterized by a narrowing of the South Arm, which serves to funnel fish, including the five species of salmon (sockeye, chum, pink, coho, and chinook) and sturgeon, into a small area. The presence of a back eddy, or a pool of calm water in which fish aggregate, benefits fishers in the area who are faced with strong tidal flows elsewhere throughout the Lower Fraser River. Marine vessel traffic in the Fraser Surrey Docks area has increasingly made fishing in the region problematic, and there has been tremendous concern regarding the protection of heritage sites in this area in light of on-going developments (Tam et al. 2017).

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[3] See https://scc-csc.lexum.com/scc-csc/scc-csc/en/item/609/index.do

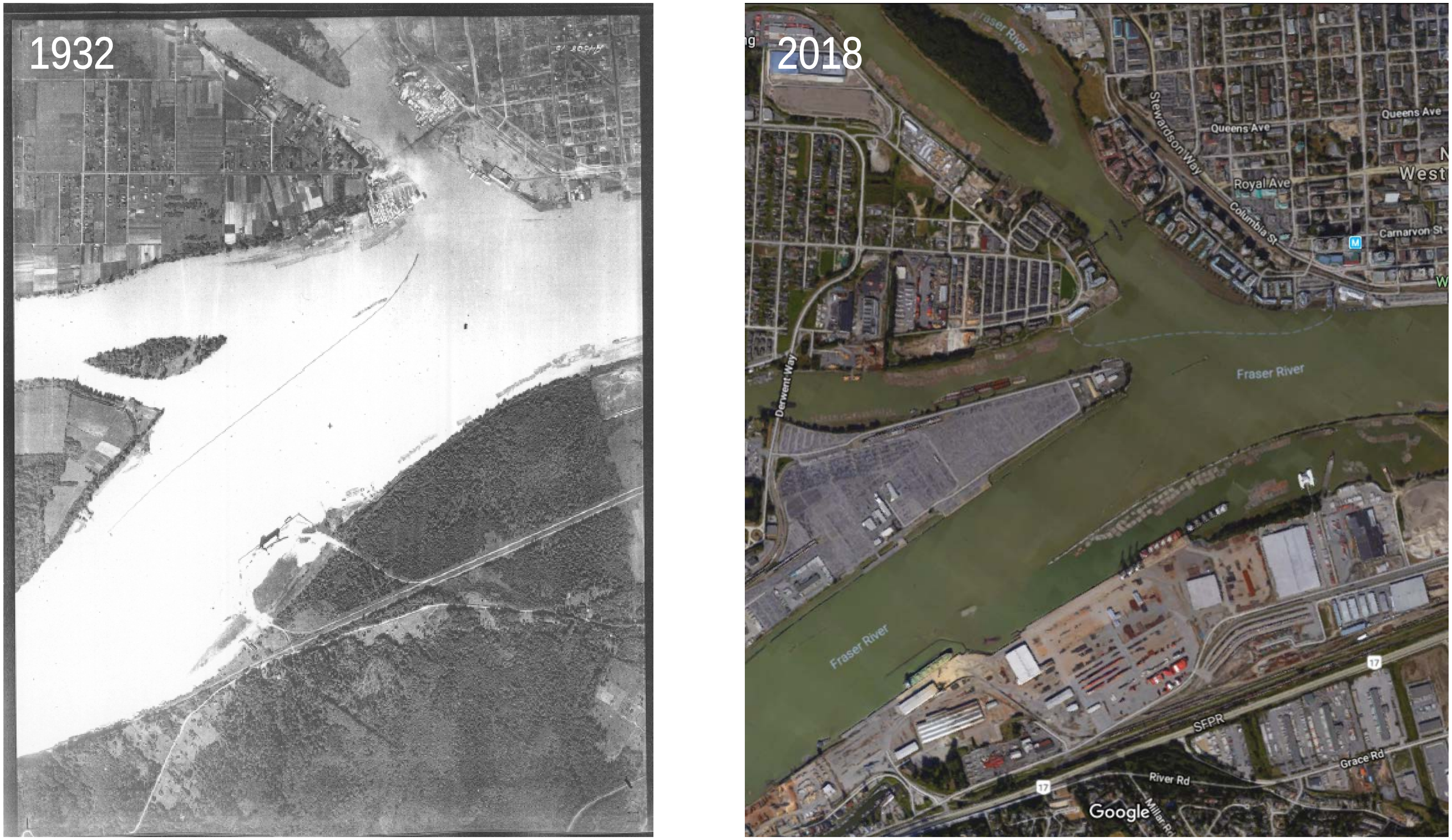

Figure 8. Aerial images of Fraser Surrey Docks in 1932 and 2018. Images taken from Tam et al. (2017) and Google Maps.

The area surrounding the George Massey Tunnel is a similarly important location for fishing, as salmon, sturgeon, and eulachon are funneled into the area; waters are calm; it has not been dredged to the same extent as other areas of the Fraser River; and there is little debris on which fishing nets could become caught (Tam et al. 2016a). In a recent study, Musqueam knowledge holders noted that the area around the proposed WesPac Marine Jetty Project is an important fishing location due to its unique environmental characteristics, which create favourable habitat for salmon and eulachon as a holding area. It is also a frequent fishing location especially when fishing efficiencies are reduced and competition for fish is high from marine mammals, such as seals and sea lions (Tam et al. 2018).

Figure 9 shows Musqueam's statement of intent and consultation, accommodation, and resource access boundaries. Within this broader area, Figure 10, Figure 11, and Figure 12 depict the current extent of Musqueam fishing areas for salmon, prawn, and crab (darker shaded areas) and the currently regulated areas (opaque shaded areas) as defined by current fishing boundaries provided by DFO to Musqueam. Currently, salmon fishing occurs throughout the Lower Fraser River and surrounding marine areas, while prawn fishing is more concentrated near, and constrained to, Bowen Island. Although the entire fishing area is important, crabbing currently occurs extensively in flat and shallow shelf areas of the Salish Sea. Canoe Pass, the Tsawwassen area, and the Roberts Bank area are notable sites for fishing salmon and crab, with Canoe Pass being a culturally significant area in which migratory salmon are caught (Tam et al. 2016b).

An important note is that these depictions of current use come from knowledge and use studies previously completed by Musqueam (Tam et al. 2016a; 2017a; 2017b; 2018), none of which focused on Burrard Inlet and Howe Sound and none of which summarize historic use. The data depicted here are of current regulated and constrained use, whereas past traditional use was more extensive. For example, a reserve (Inlailawatash) was established at the head of Indian Arm for Musqueam and the Tsleil-Waututh Nation[4] jointly, for their chum and coho salmon fishing (Indian Reserve Commission 1877; NAC 1926). In addition, Musqueam historically harvested shellfish (clams, mussels. etc) in Howe Sound, Burrard Inlet, and Boundary Bay. Today, shellfish opportunities are limited in these areas due to declining habitat for clams and mussels coupled with paralytic shellfish poisoning. A loss of access to these traditional and historic sites means that remaining opportunities to harvest shellfish and other resources are much more vital to Musqueam.

Despite currently having access to these regulated areas, Musqueam fishers are also concerned about potential governmental restrictions to current fishing boundaries given the history of DFO shifting boundaries, including restricted access to the entrance of the Howe Sound and along the coast near Sechelt. Moreover, there is also concern regarding increased pressure from Fisheries and Oceans Canada (DFO) for Musqueam to fish for prawn further into Howe Sound (interview with Musqueam members, March 2, 2018).

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[4] Individuals belonging to the Tsleil-Waututh Nation (then-called "Burrard Indian Band") were originally mis-identified as Squamish.

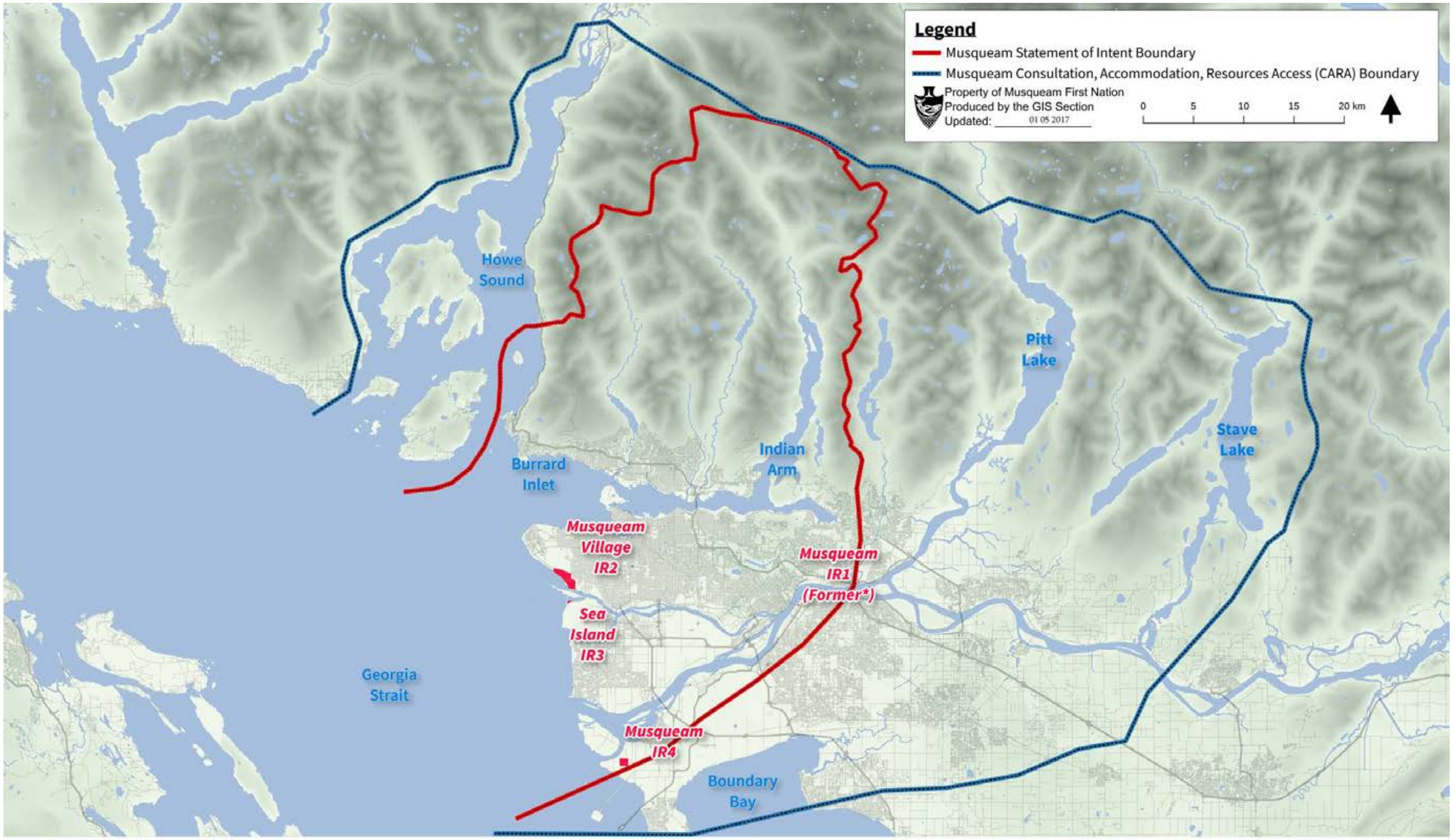

Figure 9. Musqueam's statement of intent (SOI) and consultation, accommodation, and resource access (CARA) boundaries.

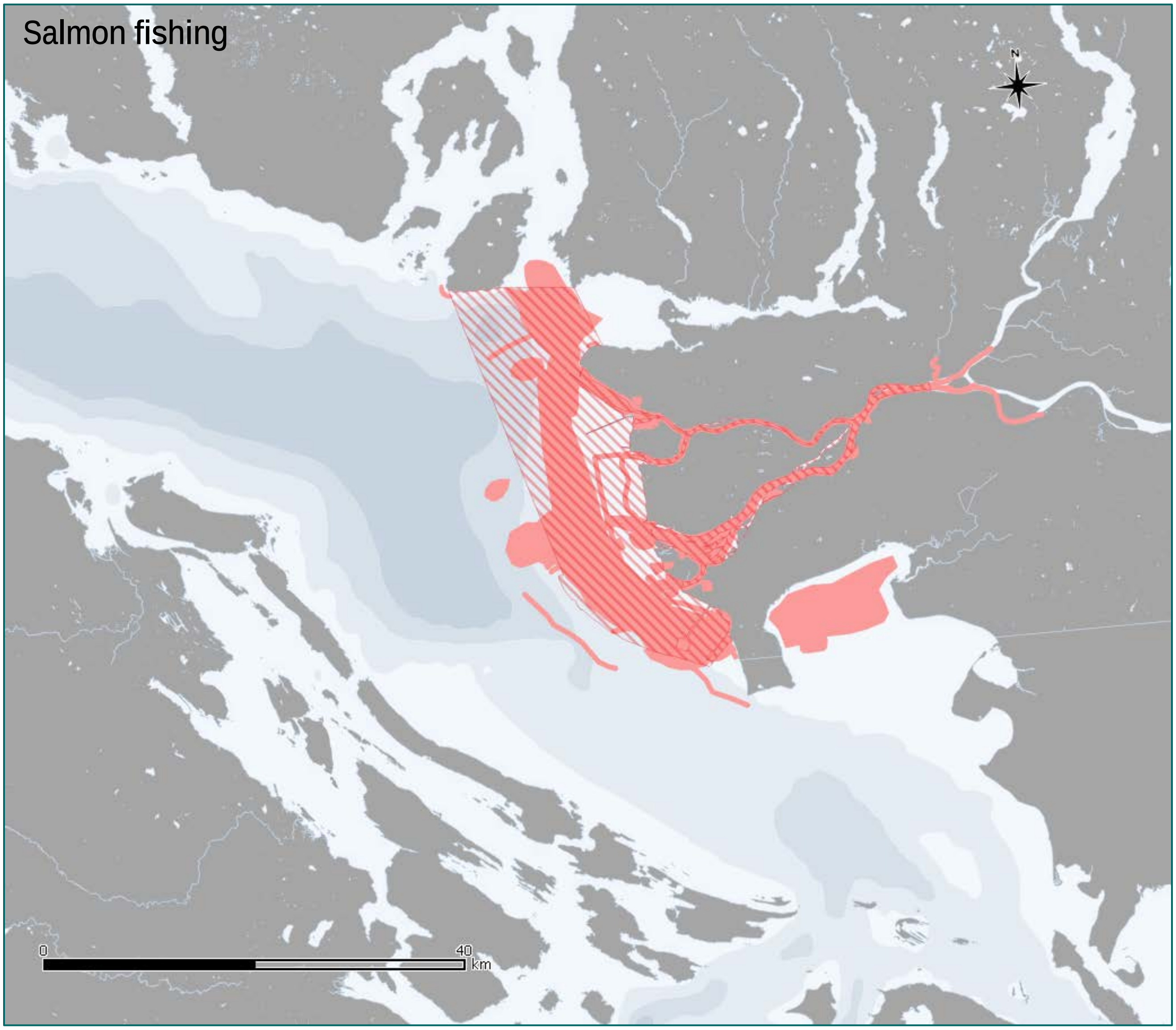

Figure 10. Delineation of the regulated boundaries (thatched shading) and current use areas (darker shading) for salmon fishing by the Musqueam.

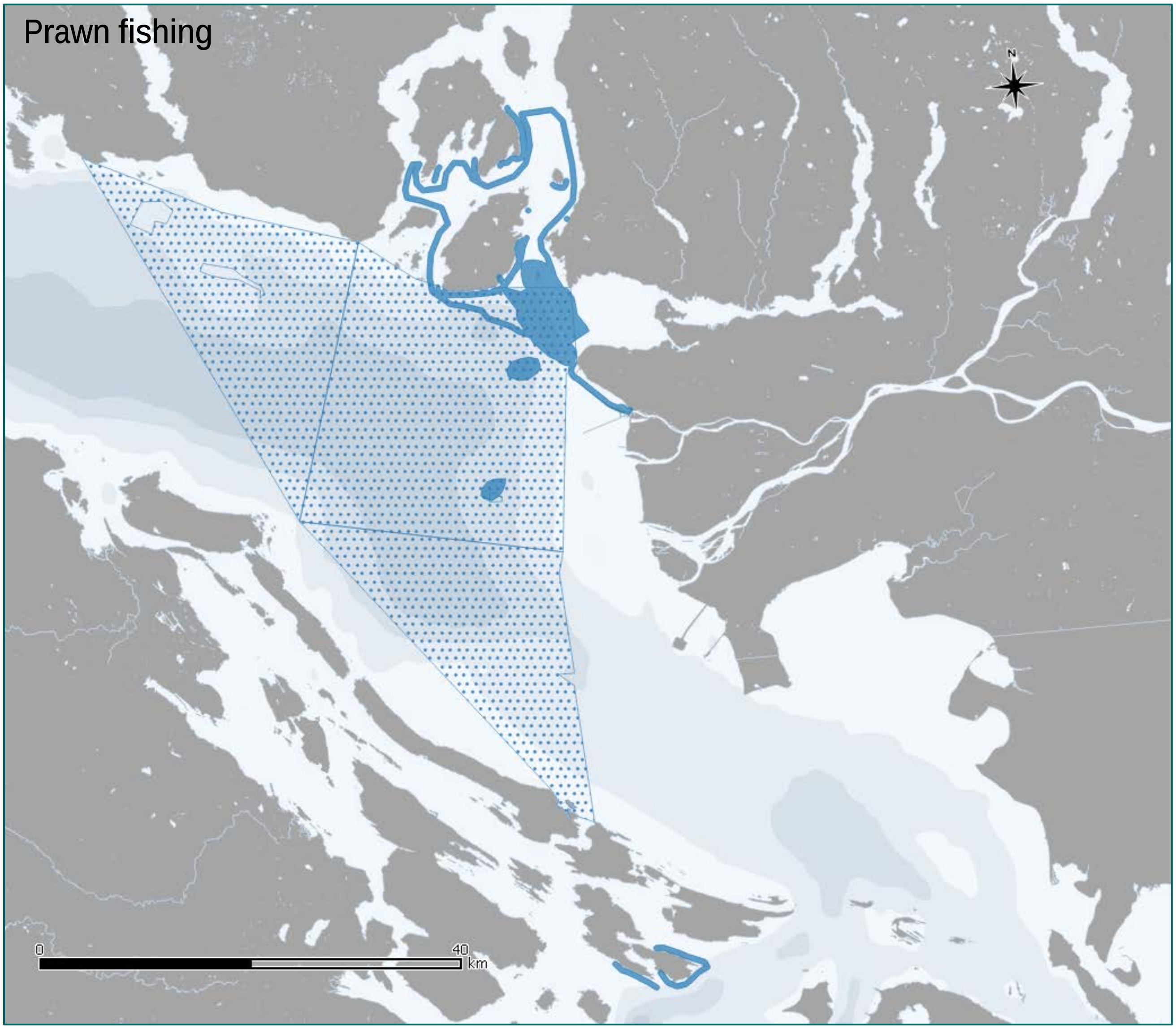

Figure 11. Delineation of the regulated boundaries (dotted shading) and current use areas (darker shading) for prawn fishing by the Musqueam.

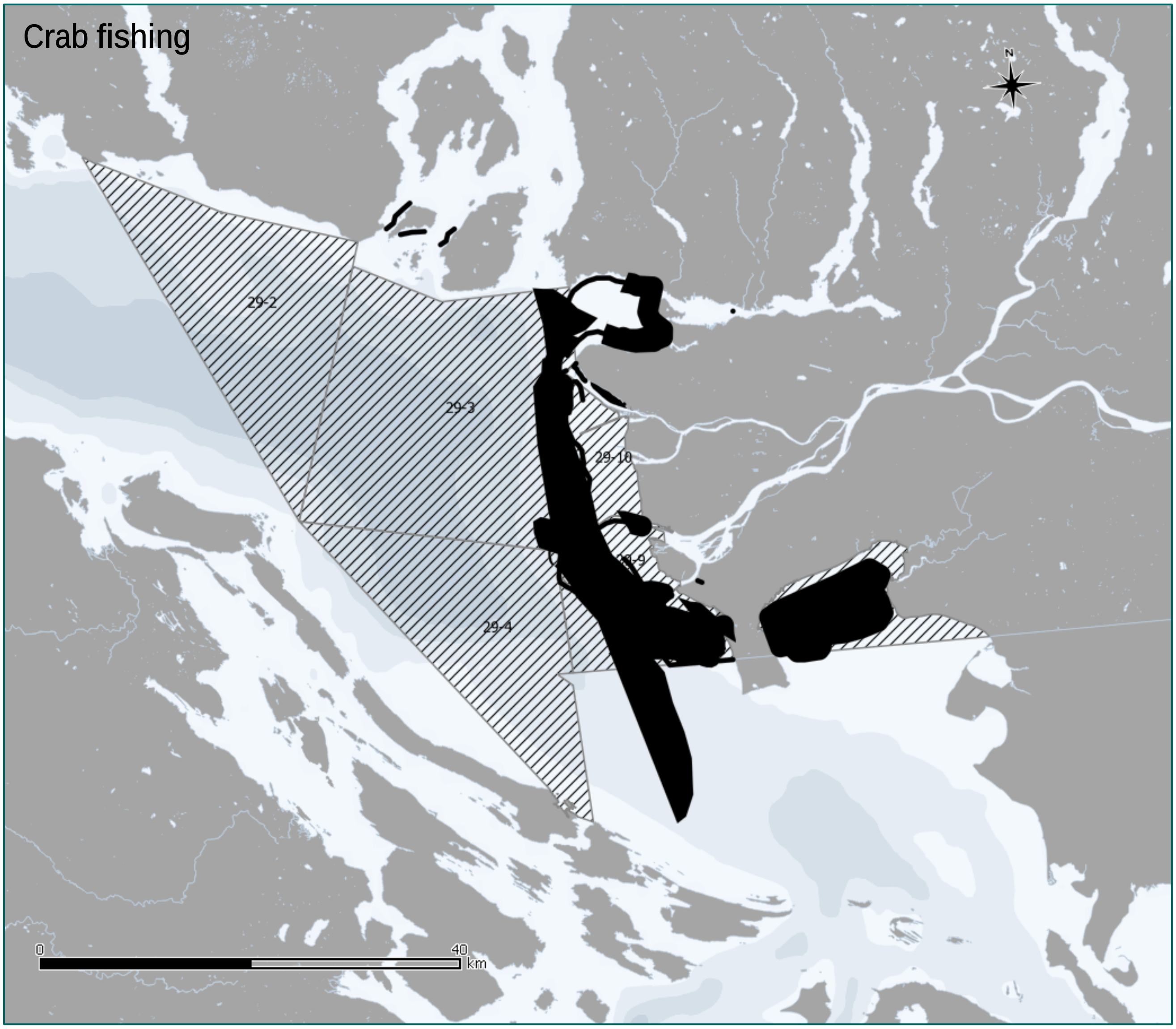

Figure 12. Delineation of the regulated boundaries (thatched shading) and current use areas (darker shading) for crab fishing by the Musqueam.

Figure 13 and Figure 14 below depict the prawn, crab, and salmon fishery openings for Musqueam fishers for the years 2004-2017. The vertical bars in Figure 13 indicate the number of days, in each month (x-axis), for which the respective fishery was open. The vertical black line in the salmon fishery graphs shows the point at which the median day of fishery openings occurred over the course of a year. Years in which no fishery openings are shown may either be the result of a lack of data or that no fishing opportunities were available.

Salmon fishery openings are variable but follow a general seasonal trend of openings in spring to late fall, with closures consistently throughout the months of December, January, and February. Prior to 2010, peak openings generally occurred in mid to late spring, and again in the late summer and early fall, coinciding with run times typical of certain salmon species, like sockeye, which today migrate during late summer (Labelle 2009). Since 2010, openings have become slightly more constrained to the summer and fall months. The median fishery opening time (black line in Figure 13) has gradually shifted from June in 2004 to August in 2017. This trend towards a later median date of openings is consistent between the years 2004 and 2010, but becomes increasingly variable from 2011 to 2017. Musqueam fishers emphasized that preferred access to salmon is during the peak of each run, which does not always occur within the fishery openings provided. Despite this limitation, some sport fishers are still fishing for salmon during times that are unavailable to Musqueam (interview with Musqueam members, March 2, 2018).

Prawn and crab fisheries are typically open most days of the month from spring to fall and are frequently open nearly all month, for the entire year (see years 2011-2012 and 2014-2016 in Figure 13 and Figure 14). Musqueam fishers have identified the extensive period of commercial crab fisheries openings as significantly affecting crab available for subsistence and ceremonial harvesting opportunities. Further, fishing opportunities for crab are influenced by fishery opening times, since nearby areas with earlier crab fishing opening times influence the availability of crabs, and, therefore, the economic incentive to fish crab. As such, the combined effect of the lengthy commercial opening periods and the order of openings for the different First Nations can lead to a reduction in the amount of crab available to the Musqueam.

Figure 15 provides the total hours that Musqueam fished for salmon, prawn, and crab, respectively, from 2004 to 2017. Time available for salmon fishing was highest in 2007, but has since undergone a decline. While prawn fishing is highly variable from year to year, within the years that fishing does take place, there is consistency in the number of hours spent. 2007 was a year in which a large amount of time was dedicated to prawn fishing, while 2008 and 2010 contained the fewest hours fished. With the exception of 2007 and 2008, time available for crab fishing has remained stable over the years.

Musqueam salmon catch for the 2011 to 2017 period is provided in Figure 16. Catch in 2011 and 2014 was markedly higher than in subsequent years, primarily driven by pink and sockeye harvest. Chum harvest makes up the third largest proportion of catch over this period, followed by chinook, and then coho which makes up approximately 0.16% of the total catch between 2011 and 2017.

Musqueam salmon-fishing effort (represented as vessel-hours or the number of vessels multiplied by the opening length of the fishery) is depicted in Figure 17. While variable, effort has generally decreased since 2011. The vast majority of fishing effort takes place during the months of July and August, coinciding with peak fisheries opening times for salmon (Figure 13). October is also a month with substantial fishing effort.

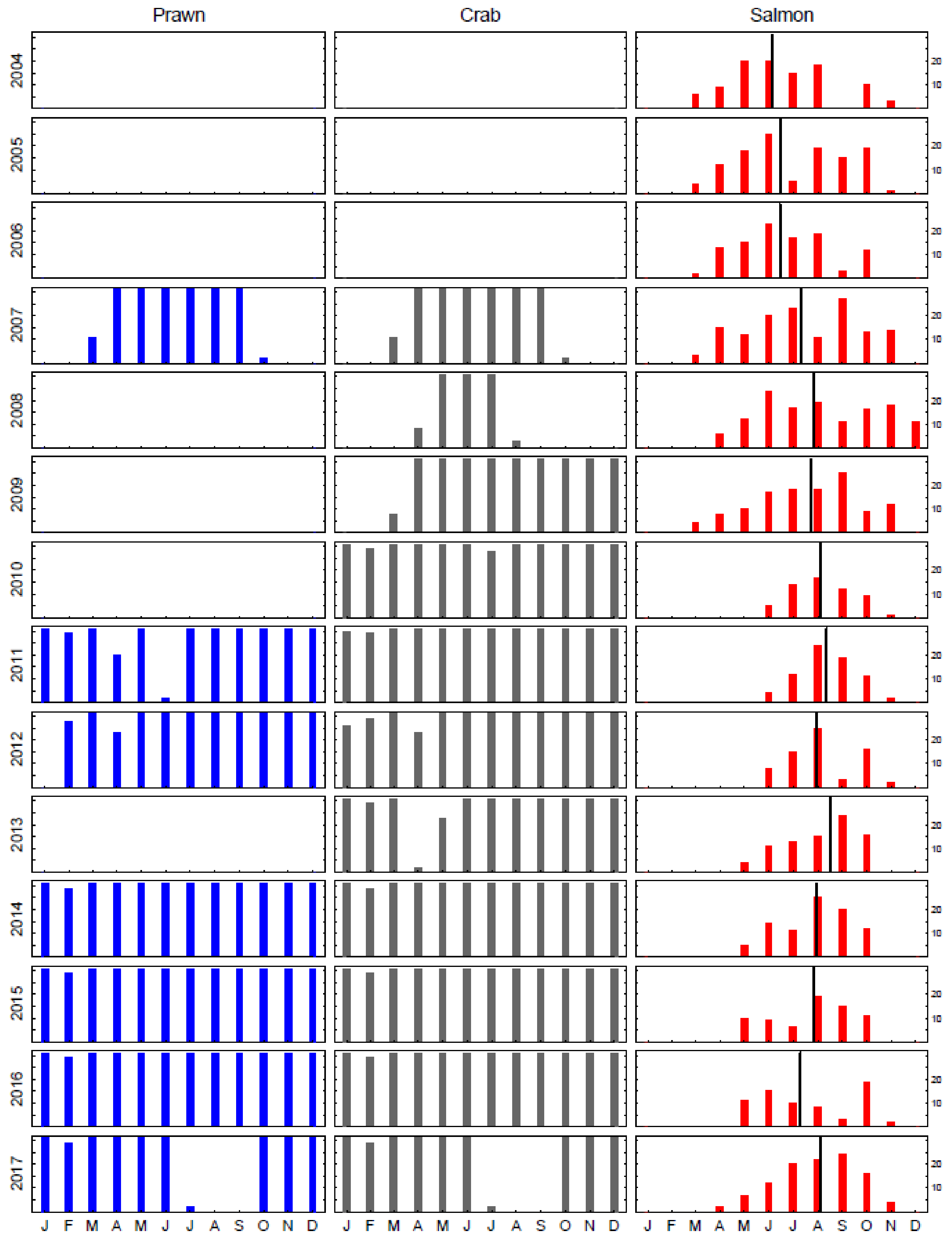

Figure 13. Number of days each month that prawn (blue), crab (grey), and salmon (red) fisheries are open from 2004 to 2017. Data from Fisheries and Oceans Canada (see Appendix A). Note that data from 2004 to 2006 for prawn and crab are lacking.

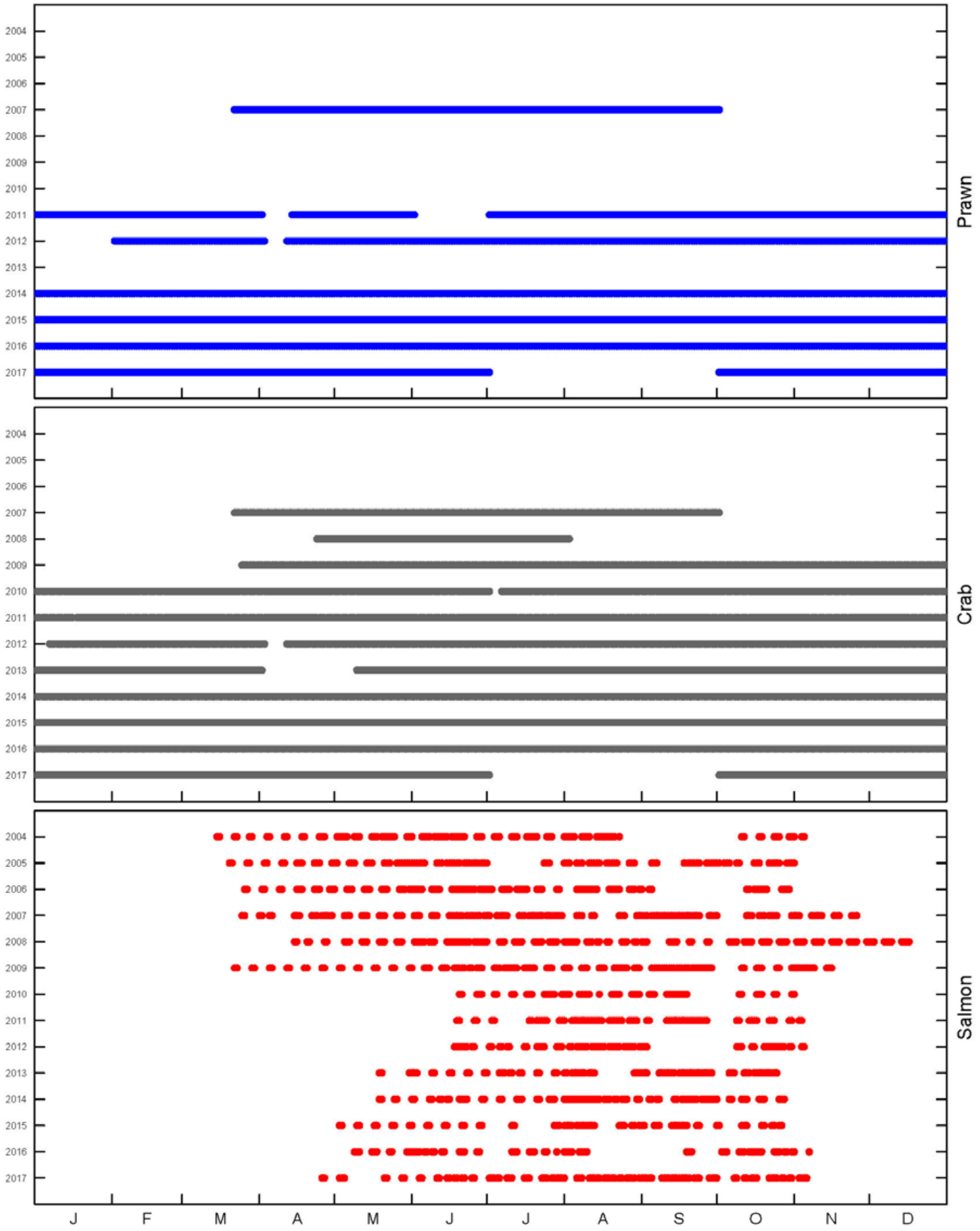

Figure 14. Timing of openings each month for prawn (blue), crab (grey), and salmon (red) fisheries from 2004 to 2017. Dots indicate discrete days the fishery was open, while stretched horizontal lines indicate that the fisheries remain open for the duration shown. Data from Fisheries and Oceans Canada (see Appendix A). Note that data from 2004 to 2006 for prawn and crab are lacking.

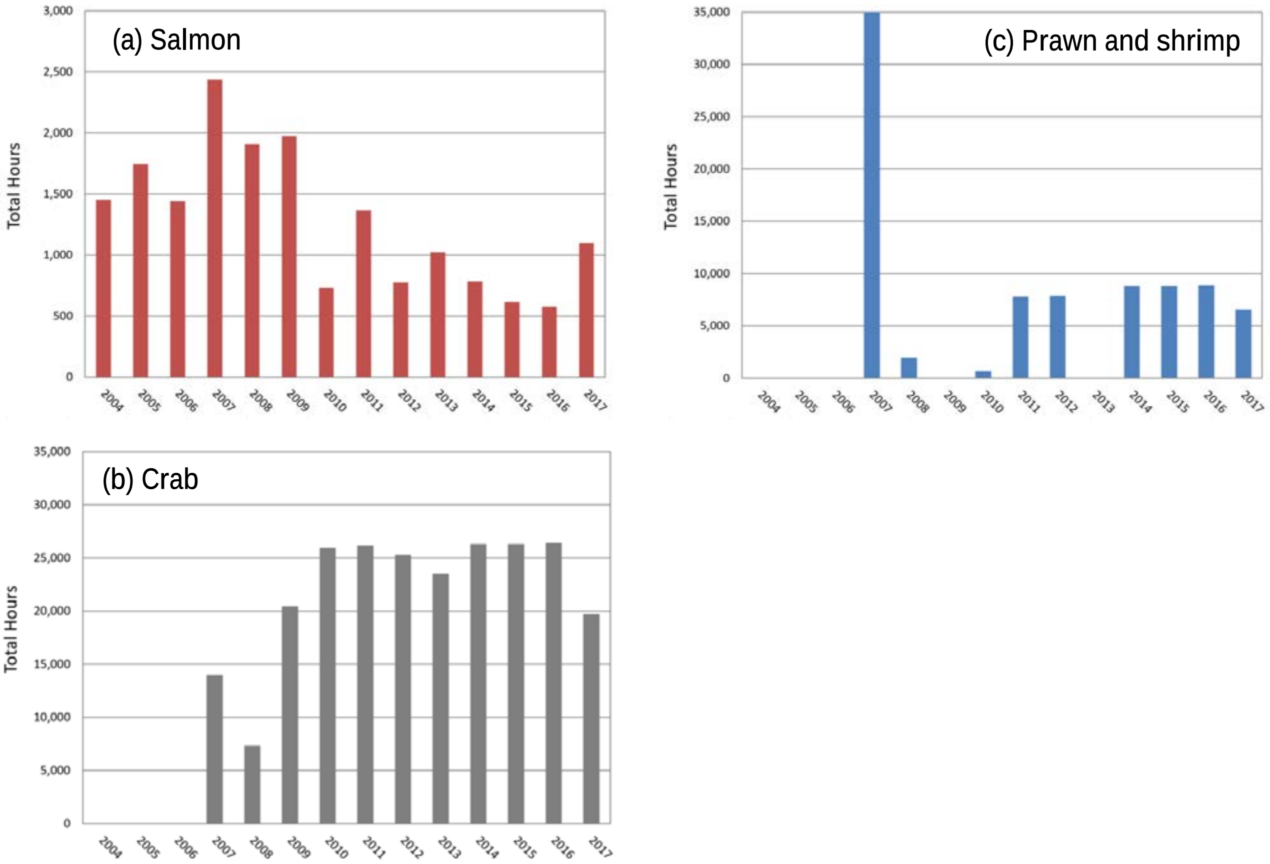

Figure 15. Total hours of fishery openings for Musqueam fishers from 2004-2017 for salmon (pink), prawn and shrimp (blue), and crab (grey). Data from Fisheries and Oceans Canada. See Appendix A. Note that data from 2004 to 2006 for prawn, shrimp, and crab are lacking.

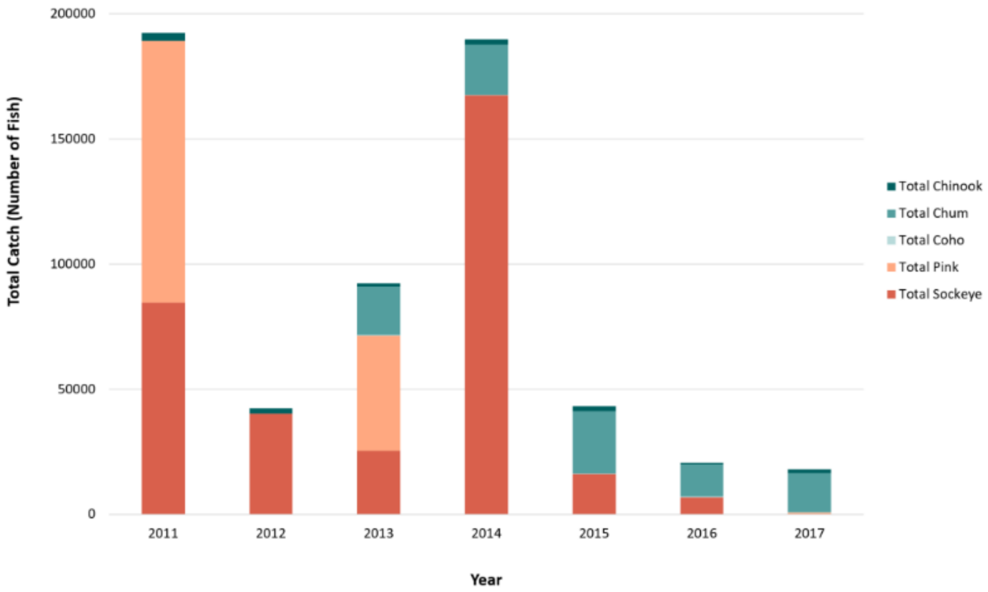

Figure 16. Summary of annual Musqueam salmon catch from 2011 to 2017. Totals catch is separated by salmon species (chinook, chum, coho, pink, and sockeye). Data provided by Musqueam Indian Band. See Appendix A.

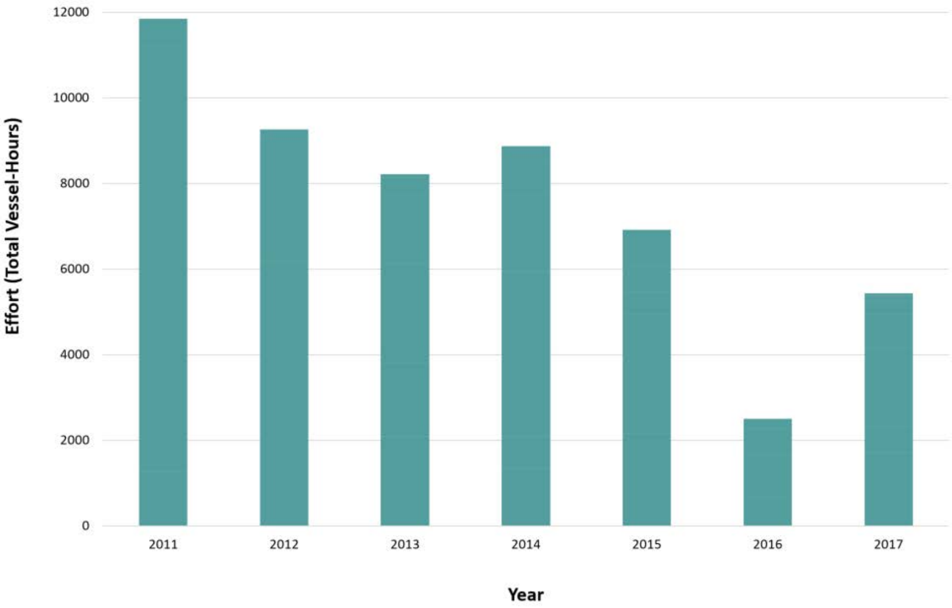

Figure 17. Musqueam salmon fishing effort, calculated as the number of vessels multiplied by the fishery opening length in hours from 2011 to 2017. Data provided by Musqueam Indian Band. See Appendix A.

Within each annual salmon fishery opening for Musqueam fishers, variable numbers of vessels contribute to catch and effort. Figure 18 provides annual median, minimum, and maximum vessel numbers from 2011 to 2017, accompanied by the number of salmon fishery openings within each year. The year 2014 had the greatest number of salmon fishery openings (39), and the most vessels because it corresponded with a high sockeye return year. The year with the fewest Musqueam fishing vessels was 2017, despite having the second highest number of fishery openings (35). Catch in this year was low, however, which suggests that Musqueam vessels did not participate because abundance was low making it difficult to offset the high cost of fishing. In contrast, effort and catch were high in 2011 and 2014, with large participation of Musqueam boats in the fishery to take advantage of the abundance of salmon resources. Hence, there is a relationship between total salmon abundance, the type of salmon available (some species are more desirable for food stocks than others), the number of participating Musqueam vessels, and catch which means that there is and will continue to be year-to-year variation in the potential for interactions between Musqueam fishing vessels and other marine traffic.

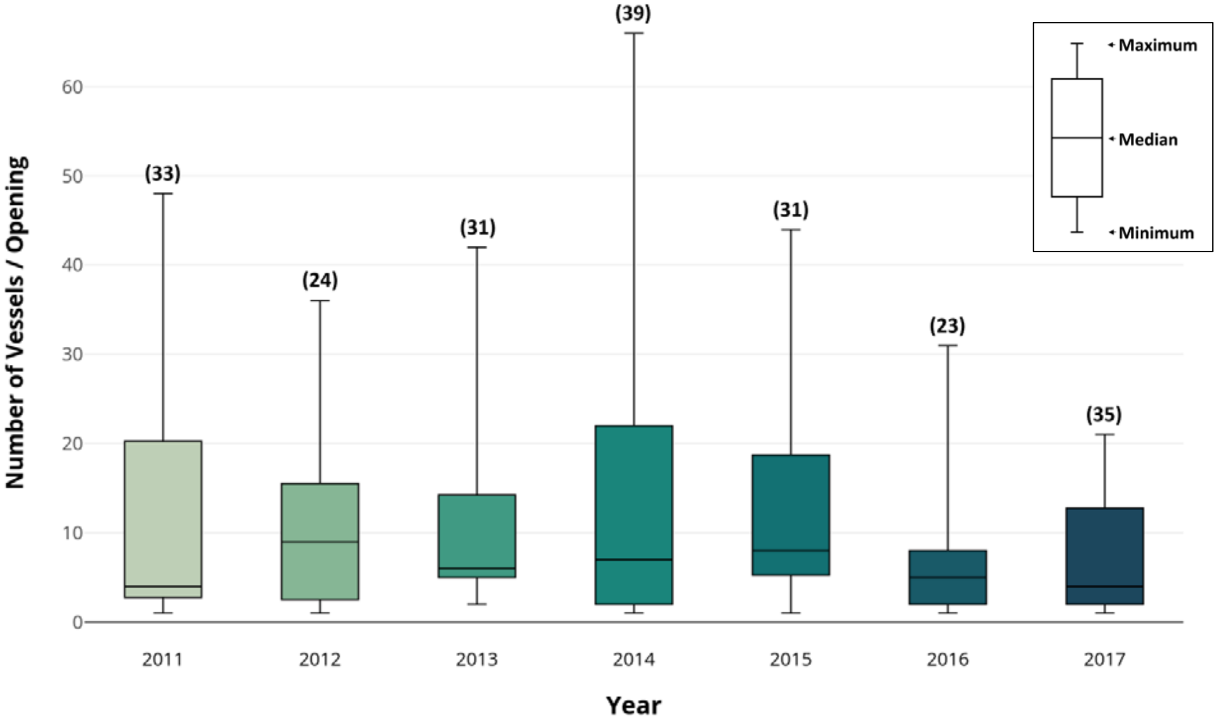

Figure 18. Boxplot of the number of vessels per (salmon) fishery opening from 2011 to 2017. The horizontal line within the box shows the median number of vessels fishing per opening, while the upper and lower whiskers show the maximum and minimum number of vessels per opening. The numbers in parentheses represent the number of (salmon) fisheries openings in each year.

3.1.4 Changes in the pattern of development in the region

The British Columbian population has grown to over 4.5 million people in 2016, approximately 3.2 million of which inhabit the eight regional districts concentrated along the Lower Fraser River and the Strait of Georgia (Labelle 2009, Johannes et al. 2011, Statistics Canada 2016). Based on a 2009 analysis, the population in the areas adjacent to the Strait of Georgia, Juan de Fuca Strait, and

Johnstone Strait is projected to increase by about 40% by 2025 (see Figure 19) (Labelle 2009). The population in most regional districts along the Lower Fraser River has increased by about 150% between 1990 and 2011 (Johannes et al. 2011) compared to a 53% change in Musqueam band membership from 1990 to 2011 (Musqueam Indian Band, band membership data). Although, the current Musqueam population is smaller than the thousands to tens of thousands of people in the territory before smallpox hit in the 1700s (Harris 1994).

The growing population has been accompanied by sustained land and resource development over the past century, including the construction of housing, industry, forestry, agriculture, mining, and other infrastructure projects, all of which potentially contribute to interactions with and influences on salmon habitats (Johannes et al. 2011, Marmorek et al. 2011). The Lower Fraser River represents a valuable resource for commercial and recreational opportunities, a water-supply and irrigation source, and a transportation corridor for human activities. There exist several inlets along this area utilized by a large proportion of salmon produced through artificial rearing and enhancement operations (Labelle 2009, Johannes et al. 2011). Human development activities along the Lower Fraser River have implications for water quality, aquatic and riparian ecosystems, and the salmon species that utilize the area (Labelle 2009). Historic losses of creeks and streams, land and watercourse alterations, such as draining of Sumas Lake, and the use of the river to store and move log booms can have impacts on the river bed and salmon habitats. Sockeye salmon, for example, spend less residence time in habitats contiguous with areas of human development projects. As well, flood gates along the Lower Fraser River have been noted to reduce native fish species richness and dissolved oxygen concentrations (Seifert and Moore 2018). While more recent conservation efforts have reduced the impact of development projects in or along the river on salmon, crab, and prawn productivity through regulation, older projects have negatively impacted these species (Johannes et al. 2011).

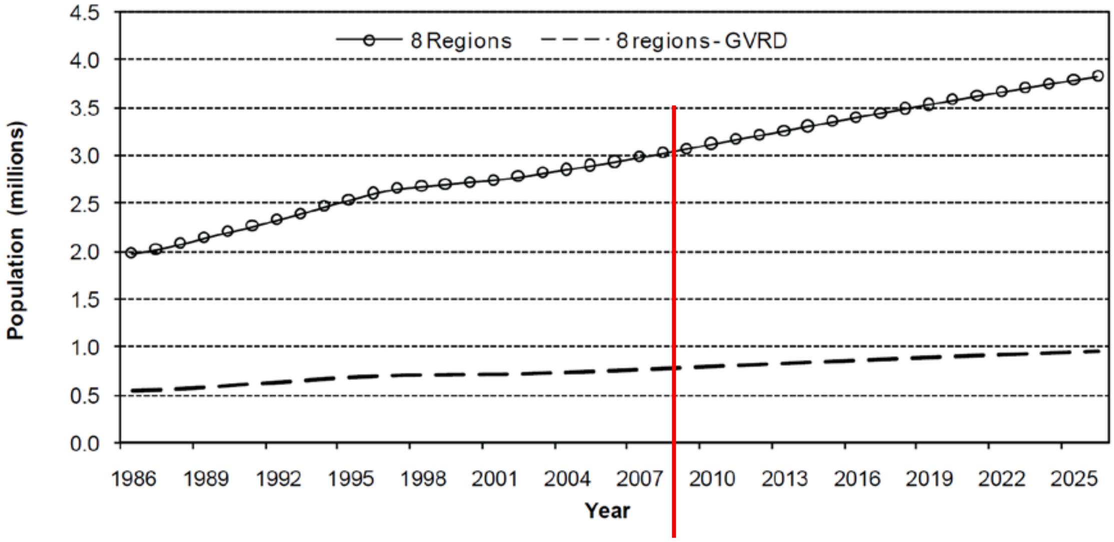

Figure 19. Historic and projected human population size in the regional districts adjacent to the Strait of Georgia. The red line indicates the year in which this graph was created (2009), hence the data to the right of this line represent projected growth. Graph taken from Labelle (2009).

Over 300 industrial sites and infrastructure development projects, including the construction of ferry terminals, airports, waste treatments plants, hydroelectric facilities, and pulp and paper mills, have been constructed along the Fraser River in the last century (Johannes et al. 2011). Figure 20 and Figure 21 provide a visual cue to the enormity of industrial and anthropogenic development that occurred between the years 1919 and 1956, and even before 1919 the region was extensively altered due to farming, forest harvesting, and watercourse alterations. Several transportation infrastructure projects along the Fraser River, or crossing it, have been undertaken over the past decade, including the construction of the Golden Ears Bridge, the Port Mann Bridge project, and the South Fraser Perimeter Road (GVWD 2017). Potential future and in-progress developments include the replacement of the George Massey Tunnel and the Pattullo Bridge, the establishment of a fuel delivery facility for the Vancouver airport, the WesPac LNG Marine Jetty project, the Fraser Grain Export Facility, BHP Potash Terminal, and Roberts Bank Terminal 2 (GVWD 2017).

Figure 20. Photo looking East, up the Lower Fraser River between South Vancouver (Marpole) and Richmond. Photo taken by Stuart Thomson, May 27, 1919. Photo taken from the City of Vancouver Archives website: http://searcharchives.vancouver.ca/bridges-over-fraser-river-at-eburne.

Figure 21. Aerial view of the Lower Fraser River, showing Sea Bird Island (left-most-land form), South Vancouver (Marpole) in the North, and Richmond in the South. Photo taken in May 1956. Donated to the City of Vancouver Archives by Harold G. Prenter in 1974. Taken from the City of Vancouver Archives website: http://searcharchives.vancouver.ca/aerial-photo-vertical-marpole-and-junction-of-fraser-river-bridgeport.

Dredging operations in the Lower Fraser River date back to 1885. Dredging operations have contributed to the removal of approximately 140 million m^3 of material since the 1950’s, primarily isolated downstream of the Port Mann bridge, and with increased material removal between the years 1946 and 1956 for the purpose of enhanced vessel navigation (McLean et al. 2006). A significant spike in operations between 1976 and 1990 occurred due to the need for industrial construction materials (McLean et al. 2006). Dredging in the South Arm of the Fraser River has lowered the channel bed elevation by 3 meters in 30 years, increasing the velocity of the water, making fishing in some areas challenging (Johannes et al. 2011, Tam et al. 2017a). Moreover, Musqueam nets no longer reach the bottom of the river because it is dredged deeper than net allowances. Previously shallow areas where fishing was good have disappeared. Such impacts to fishing have corresponding effects on Musqueam cultural continuity, and sense of place and identify (Tam et al. 2016a). The establishment of new, major shipping routes has also resulted in the dredging of some channels along the Fraser for navigational purposes, whereby channels are regularly widened and deepened to a depth of 11.5 m, allowing for passage of vessels closer to the shorelines and increased traffic (GVWD 2017). Dredging directly impacts crab fisheries, as dredged materials are occasionally dumped in areas where crab traps are present, burying them and preventing fishers from finding and accessing their crab traps. Further, deeper channels lead to increased flow velocity, which poses a challenge to crabbing for Musqueam fishers (interview with Musqueam members, March 2, 2018).

Diking along the Lower Fraser began in the early 1900s and trailed off in the 1950s. During this period, diking projects effectively removed many gravel reach areas along the river and partially sealed-off sloughs (Seifert and Moore 2018). While the construction of new dikes has drastically declined in the past 30 years, projects aimed at upgrading or replacing existing dikes have continued to occur (Johannes et al. 2011).

Musqueam fishers have identified a number of development patterns that have occurred over the years in the Lower Fraser River. Between the 1970s and 1980s, many of the natural sandbars were replaced with cement. The development of docks that extend into the channels has created barriers and challenges to navigation, as the docks narrow the area available for safe passage of Musqueam fishing vessels. The establishment of log booms along the river, and tugs towing booms of logs up and down the river, has also escalated over the last few decades, representing additional obstacles and debris for navigation (interview with Musqueam members, March 2, 2018). For this reason, most fishers avoid fishing in the north arm since there is a high chance of gear loss. Access restrictions imposed by the Port Authority, include off-limits areas, anchored tankers in English Bay impede Musqueam from fishing for crab in the area, and tethered pilot tug vessels may also act as barriers preventing fishers from accessing some fishing sites. Marine vessel traffic has also increased significantly since the 1920s, with a notable drop in the number of vessels in the early 1940s, and highest recorded numbers occurring in the late 1980s and late 1990s (Figure 22). The decrease in the number of vessels following a peak in the 1990s is due to: increasing vessel size,[5] and changes in global economic conditions (i.e., 2007–2008 financial crisis) (Pacific Pilotage Authority 2018).

Musqueam fishers have explicitly highlighted significant increases in vessel traffic over recent years; recreational users represent a substantial source of traffic and serious impediment to Musqueam fishing opportunities. Sawdust and gravel barges, pilot tugs, and dredgers are a few of the vessels that more frequently occur along the Fraser River and marine areas (interview with Musqueam members, March 2, 2018).

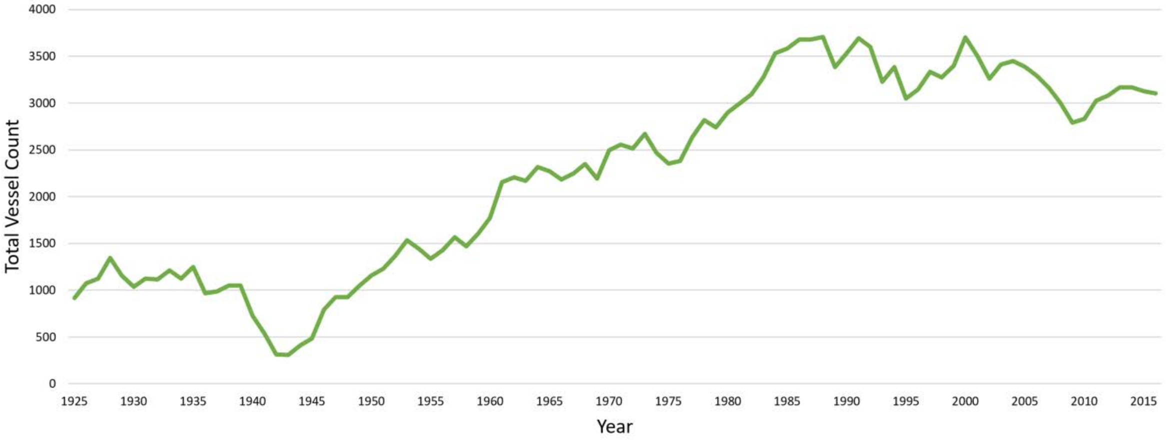

Figure 22. Port of Vancouver vessel traffic counts from 1925 to 2016.

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[5] The largest vessels serving Vancouver's Ports used to be no more than 295 m in length, whereas they are now 350 m to 400 m in length, with corresponding increases in beam width.

3.1.5 Summary of the interaction among factors

The decrease in sockeye, coho, and to a lesser extent, chinook over the past decade has limited Musqueam harvest of these species and has led many Musqueam fishers to shift to crab and prawn fishing for subsistence, ceremonial purposes, and economic opportunity. Increased vessel traffic since the 1940s, human population growth, and the associated increase in aquatic and terrestrial developments have similarly affected access to fish resources and has impacted fishing quality. Analysis of Musqueam fishing effort and catch data show generally declining trends between 2011 and 2017. Dredging operations that widen and deepen channels along the Fraser River allow more than one shipping vessel to pass at a given point and allow vessels to pass closer to shore. Such changes in geomorphology increase the width of the river and increase the potential for interact between Musqueam fishers and deep-sea vessels. Dredging operations also impact crab fishing, as the dumping of dredged materials buries crab traps, and the resulting increased depth of the channel increases the flow velocity, making crab fishing even more difficult.

Fishing represents a critically important aspect of Musqueam culture and identity. It provides physical nourishment and a source of income, and it establishes spiritual and emotional wellbeing and a sense of place. Other knowledge and use studies describe Musqueam's valued components, such as cultural continuity, sense of place and identify, and describe how culture is the central point from which resource based rights extend (Tam et al. 2017a; 2018). The compounding effects of lower salmon abundance, constrained fishing openings, increased vessel traffic, and intensified developments along the Fraser River and adjacent marine areas are related to decreased fishing effort, reduced use of traditional fishing areas, and impacts on the quality and access to fishing opportunities for Musqueam fishers. While it is not always possible to attribute impacts on Musqueam fishers to specific incidents (e.g., near-collisions with other vessels), acknowledgement of these simultaneously occurring trends helps to shed light on the complexity of the issue.

3.2 Impact of recent marine vessel traffic on access

As noted above, estimates of shipping induced exclusion (or inaccessible fraction) of Musqueam from fishing opportunities were aggregated in different ways to explore how impacts vary based on a consideration of the following factors:

- Marine resource effect – salmon, crab, and prawn
- Fishing area effect (for salmon only) – regulatory boundaries, regularly accessed areas (Lower Fraser River), and high conflict zones, specifically Tilbury Island and Fraser Surrey Docks
- Tidal effect – slack tide (+/- 1-hr buffer) vs. non-slack tide
- Time effect – across years and within a year

The following insights emerged based on the analyses and data summaries that follow:

- Differences in the temporal resolution of AIS data collection from 1-hour intervals (2009-2011) to 5-minute intervals (2012-2017) and exploration of the results indicate that the AIS data coverage in the earlier years are consistently biased low and there is a step-wise difference in results between time periods that is consistent with the timing of the change in resolution of data collection. As such, the early years of results are not directly comparable to AIS data from the later years. These data were collected by others and differences in the methodology of data collection are not fully understood to explain differences between time periods (i.e., whether due to differences in tracking technology, different levels of coverage of vessel types). As such, only data from 2012-2017 are presented in the analyses that follow.

- Table 6 summarizes the variation in vessel traffic per day for different vessel types across different fisheries and locations of interest to Musqueam across years from 20122017. Between 5-34 cargo-tanker vessels, 1-31 tug-towing vessels, and 4-51 other vessels interact each day with Musqueam prawn fishing opportunities. For crabbing opportunities, 8-40 cargo-tanker vessels, 2-33 tug-towing vessels, and 8-61 other vessels interact with access to Musqueam fishing. In regularly accessed areas for salmon across the Lower Fraser River, 2-12 cargo-tanker vessels, 10-30 tug-towing vessels, and 3-23 other vessels affect Musqueam's access to fishing. In high conflict zones in the Lower Fraser River, specifically at Tilbury Island, 2-10 cargo-tanker vessels, 1-15 tug-towing vessels, and 0-4 other vessels interact with access to salmon fishing, while at Fraser Surrey Docks 0-9 cargo-tanker vessels, 1-18 tug-towing vessels, and 0-4 other vessels interact with salmon fishing.
- Within the regulatory boundaries for the three fisheries from 2012-2017, this level of vessel traffic led to exclusions from access to fishing for prawn (22% to 25%), crab (18% to 21%), and salmon (7% to 11%); see Figure 23. Note that these fisheries each have different regulatory boundaries, as illustrated in Figure 10, Figure 11, and Figure 12, and different timings of access, as illustrated in Figure 13 and Figure 14.
- Across years, there appears to be a qualitatively modest seasonal effect on exclusion with slightly higher exclusions from June to Sept for prawn and crab, and a slightly higher exclusion for salmon in Sept (see Figure 24).
- The exclusion of Musqueam fishing opportunities for salmon in the Lower Fraser River was slightly higher during slack tide (+/- a 1-hour buffer on either side) when compared to non-slack tide windows from 2012-2017 (2-6% higher average exclusion during slack tides, see Figure 25). An exception was 2015 when average exclusion during non-slack tide windows was 2% higher than slack tide windows. Similar effects were noted when comparing exclusion between rising tide and non-rising tide periods.
- Across years the exclusion of Musqueam salmon fishing opportunities due to shipping vessel traffic was highest in the high conflict zone of Fraser Surry Docks (62% to 78%) and Tilbury Island (39% to 55%), followed by the regularly accessed areas in the Lower Fraser River (39% to 45%), and areas defined by the regulatory boundaries (7% to 11%); see Figure 26.

Table 6. Summary statistics representing the quantiles and average number of vessels per day for the different fisheries and locations of interest to Musqueam using marine vessel traffic data from 2012-2017. Note that values for traffic represented by the 25th and 75th percentiles were used to represent low and high baseline marine traffic scenarios in Table 5.

	0%	25%	50%	75%	100%	Average
Prawn Regulatory Area						
vessels_cargo_tanker	5	14	17	20	34	17.59
vessels_tug_towing	1	12	15	17	31	14.66
vessels_other	4	8	12	21	51	14.99
Crab Regulatory Area						
vessels_cargo_tanker	8	19	22	25	40	22.35
vessels_tug_towing	2	15	18	20	33	17.64
vessels_other	8	13	18	28	61	21.02
Salmon Regularly Accessed Areas, Lower Fraser River						
vessels_cargo_tanker	2	5	6	8	12	6.34
vessels_tug_towing	10	19	21	24	30	21.20
vessels_other	3	8	10	12	23	10.28
Salmon High Conflict Zone, Tilbury Island						
vessels_cargo_tanker	2	3	4	5	10	4.23
vessels_tug_towing	1	5	7	9	15	6.93
vessels_other	0	0	1	1	4	0.92
Salmon High Conflict Zone, Fraser Surrey Docks						
vessels_cargo_tanker	0	3	4	5	9	3.65
vessels_tug_towing	1	8	10	11	18	9.66
vessels_other	0	0	1	2	4	0.97

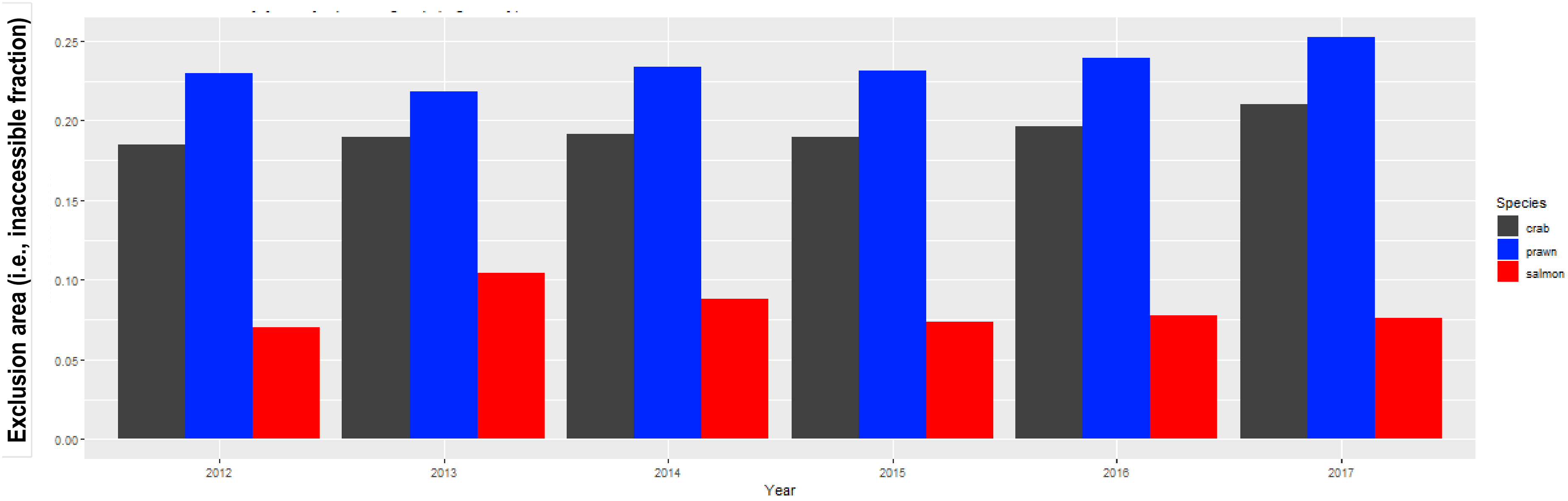

Figure 23. Summary of the average annual level of exclusion (i.e., inaccessible fraction) of Musqueam from salmon (red), prawn (blue), and crab (grey) fishing in the regulatory boundary areas during available fishery openings from 2012 to 2017.

Figure 24. Summary of the daily level of exclusion (i.e., inaccessible fraction) of Musqueam from salmon (A), prawn (B), and crab (C) fishing in the regulatory boundary areas during available fishery openings from 2009 to 2017.

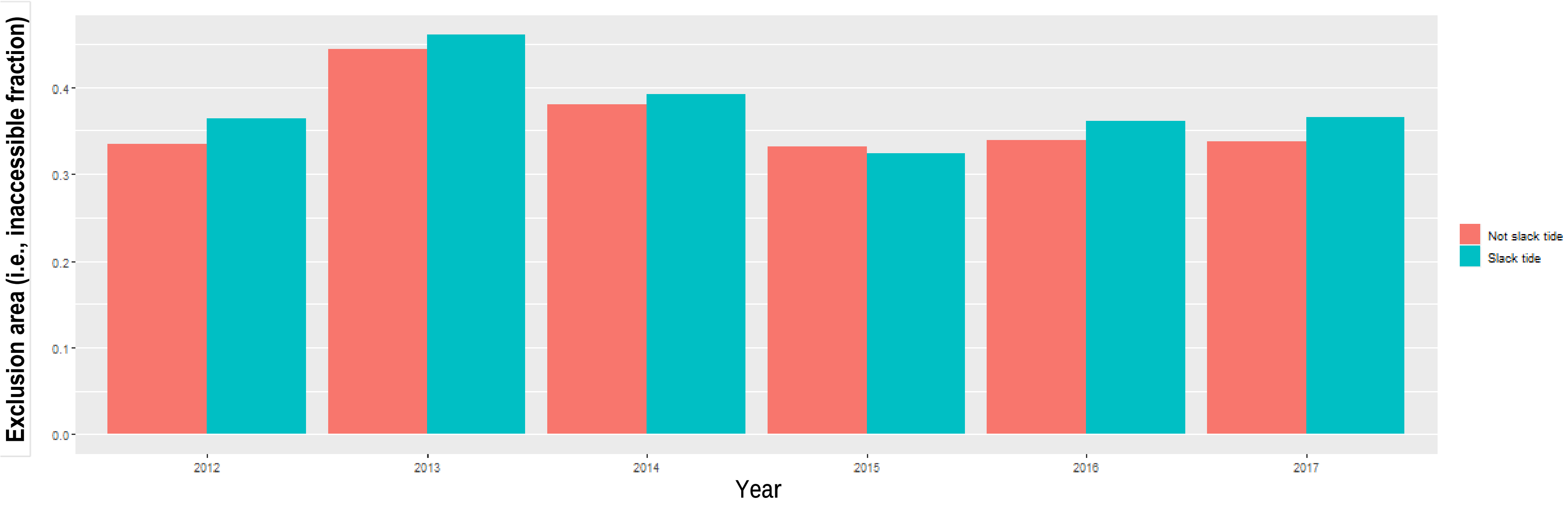

Figure 25. Comparison of the average annual level of exclusion (i.e., inaccessible fraction) of Musqueam from salmon fishing opportunities in the regularly accessed areas in the Lower Fraser River during available fishery openings from 2012 to 2017 for slack tide (including a +/- 1-hour buffer around peak) and non-slack tide windows.

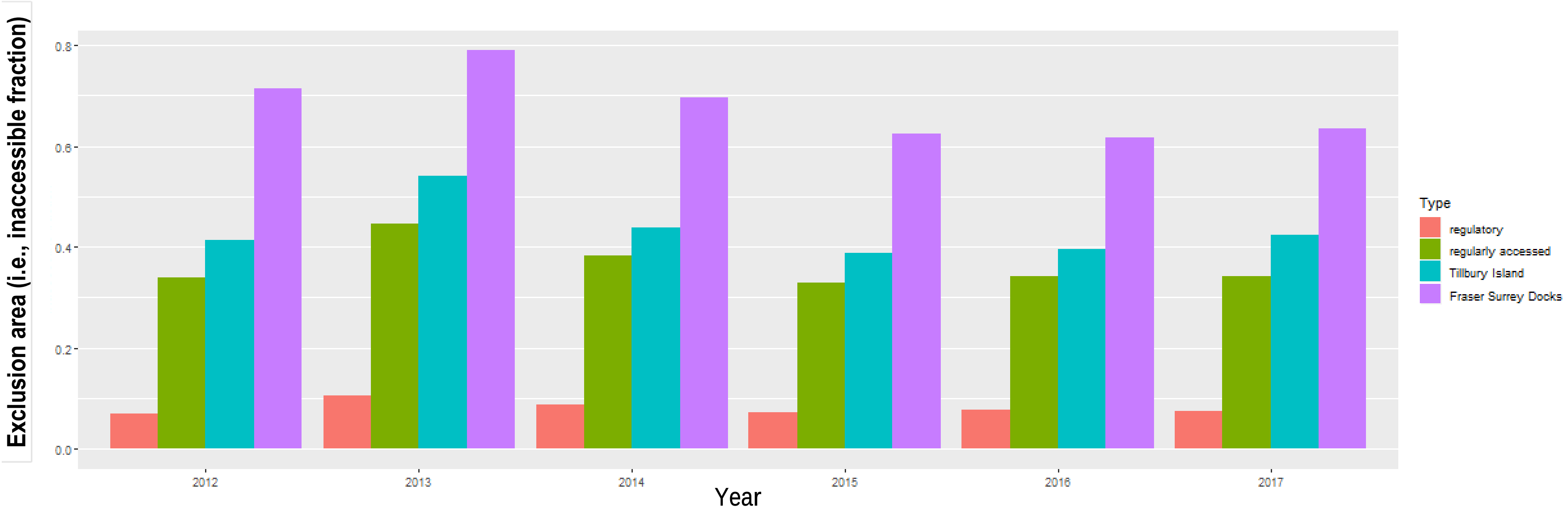

Figure 26. Summary of the average annual level of exclusion (i.e., inaccessible fraction) of Musqueam salmon fishing opportunities from 2012 to 2017 with a comparison between regulatory, regularly accessed, and two high conflict zones on the Lower Fraser River, specifically Tilbury Island and Fraser Surrey Docks.

3.3 Impact of future marine vessel traffic on access

As described in Section 2.3, the effect of additional future projects on access to fishing opportunities can be extrapolated using a regression model developed from an analysis of the historic relationship between varying levels of marine vessel traffic from 2012-2017 and exclusion of Musqueam from accessing their fishing opportunities.

Bivariate scatterplots between cargo-tanker vessels, tug-towing vessels, and other vessels for the fisheries and locations of interest to Musqueam reveal positive relationships between inaccessible fraction (or exclusion) and the number of vessels for all fisheries and locations (see Figure 27, Figure 28, Figure 29, Figure 30, and Figure 31). In other words, higher numbers of vessels per day tended to be associated with higher exclusion of access to fishing regardless of the vessel type, harvestable species, or locations of interest.

A regression analysis of these data revealed statistically significant effects of cargo-tanker vessels, tug-towing vessels, and other vessels on the magnitude of inaccessible fraction across salmon, crab, and prawn fisheries. Hence, these models are useful tools for estimating the effect of increases in future vessel traffic on access to fishing. Table 7 summarizes the best fit generalized linear models (GLM) for prawn, crab, and salmon in regularly accessed areas in the Lower Fraser River and high conflict zones, specifically Tilbury Island and Fraser Surrey Docks. The effect of cargo-tanker vessels and tug-towing vessels was statistically significant across all models. The effect of other vessels was statistically significant in four of five models; the exception was the salmon model representing regularly accessed areas in the Lower Fraser River in which there was no significant relationship with other vessels (illustrated in part by the lack of relationship in Figure 29, panel (C)). R-squared values in Table 7 represent a measure of the goodness of model fit. Prawn and crab models have high R-squared values (0.618 and 0.625 respectively), meaning that these models explain the majority of the variation in inaccessible fraction. The salmon models have lower values (0.244, 0.212, and 0.198) meaning that the models explain less variation in inaccessible fraction (i.e., other unexplored factors are contributing to variation in inaccessible fraction in addition to the number of vessels).

The magnitude of the coefficient estimates in Table 7 represents the strength of the effect of different vessel types on inaccessible fraction. In the prawn model, the magnitude of effect of tug-towing vessels was greatest, followed by cargo-tanker vessels, and other vessels. In the crab model, the magnitude of effect of tug-towing vessels was also greatest, followed by cargo-tanker vessels, and then other vessels. In the salmon model for regularly accessed areas in the Lower Fraser River, the magnitude of effect of cargo-tanker vessels was greatest followed by tug-towing vessels. In the salmon model representing the high conflict zone at Tilbury Island, the magnitude of effect of tug-towing vessels was greatest followed by other vessels and then cargo-tanker vessels. Lastly, in the salmon model representing the high conflict zone at Fraser Surrey Docks, the magnitude of effect of other vessels was greatest followed by cargo-tanker vessels, and then tug-towing vessels.

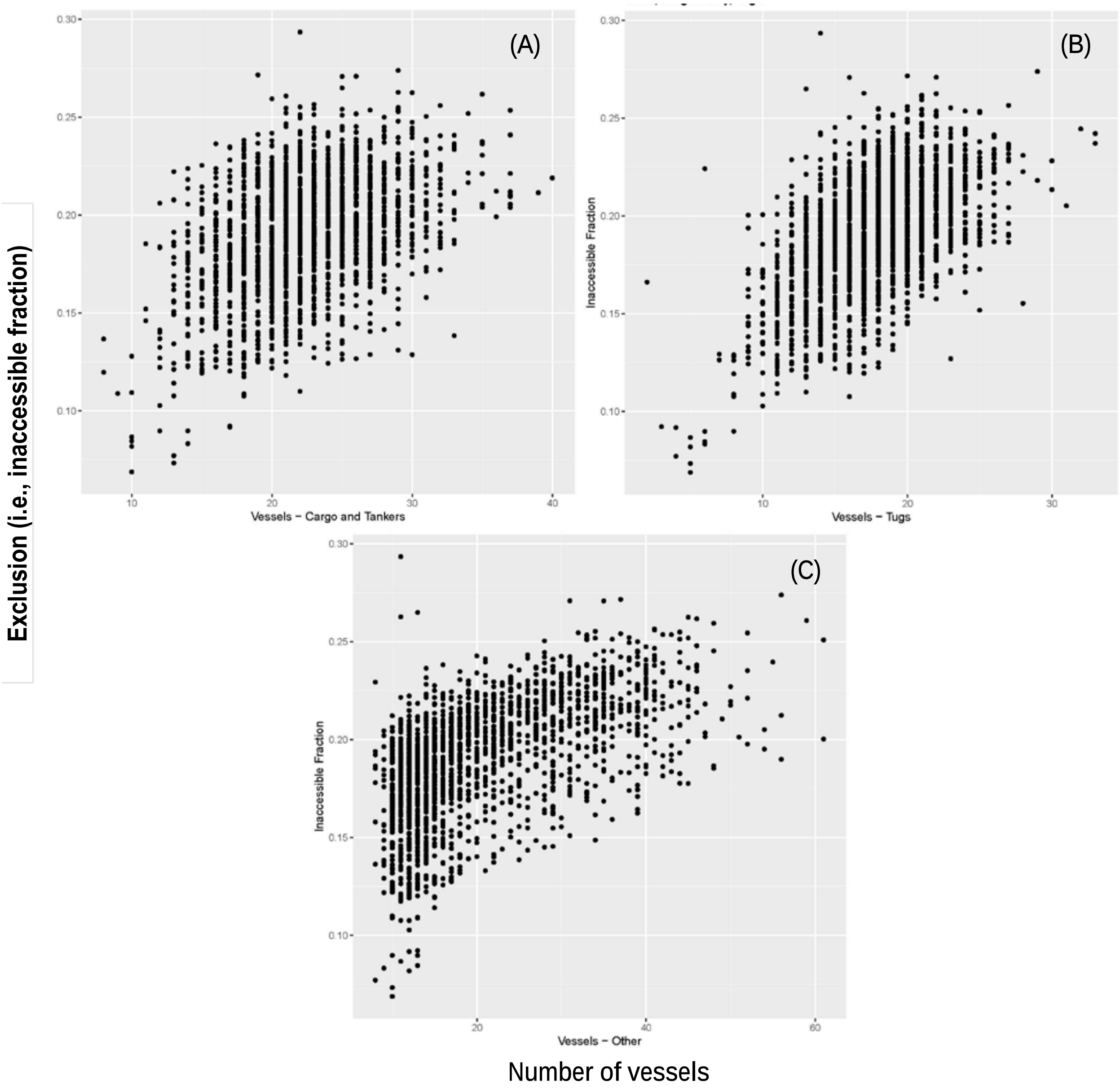

Figure 27. Bivariate scatterplots between inaccessible fraction (or exclusion from access to fishing) and (A) cargo / tanker vessels, (B) tug / towing vessels, and (C) other vessels for **crab fishing in the regulatory area** based on vessel traffic from 2012-2017.

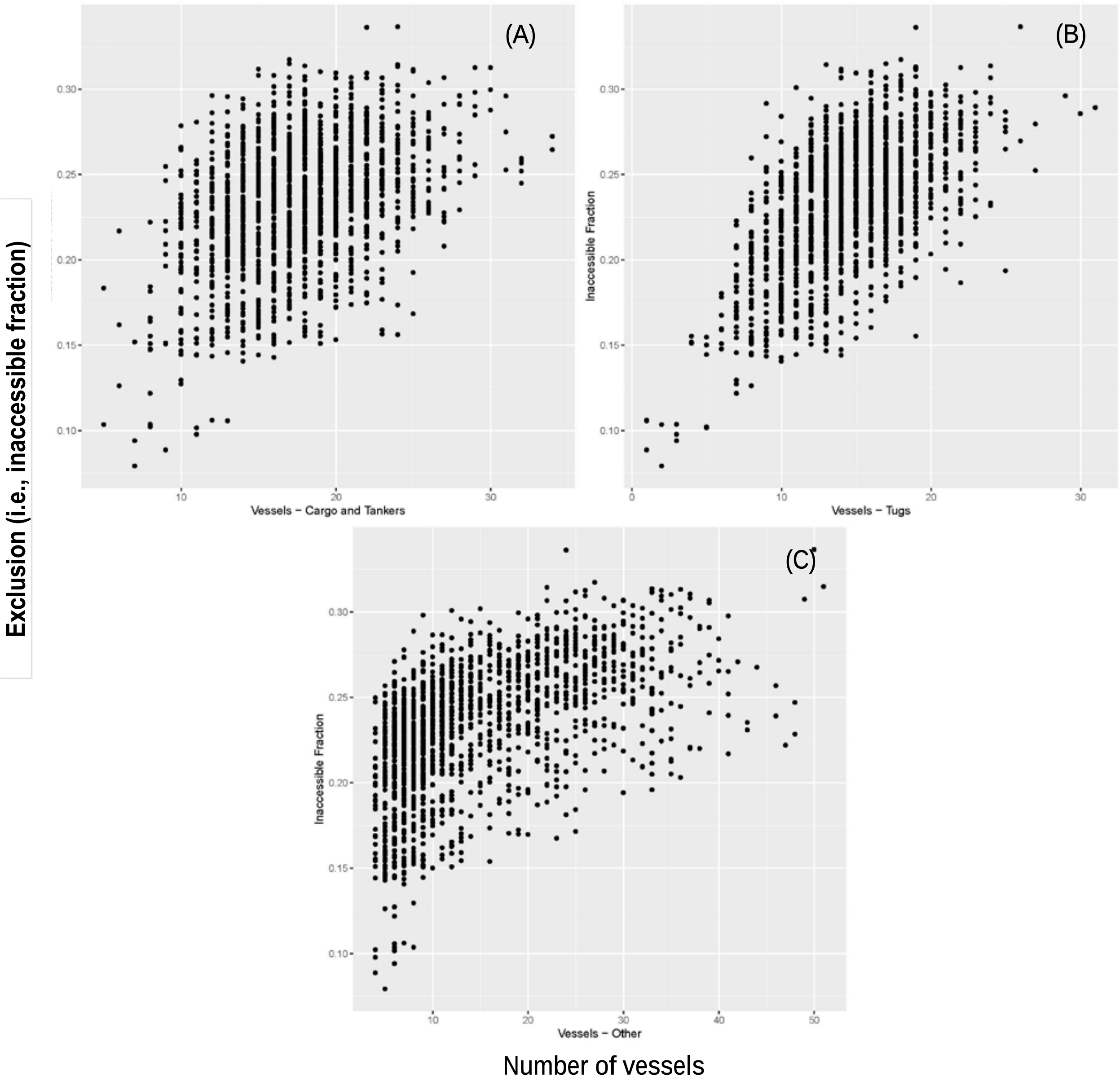

Figure 28. Bivariate scatterplots between inaccessible fraction (or exclusion from access to fishing) and (A) cargo / tanker vessels, (B) tug / towing vessels, and (C) other vessels for **prawn fishing in the regulatory area** based on vessel traffic from 2012-2017.

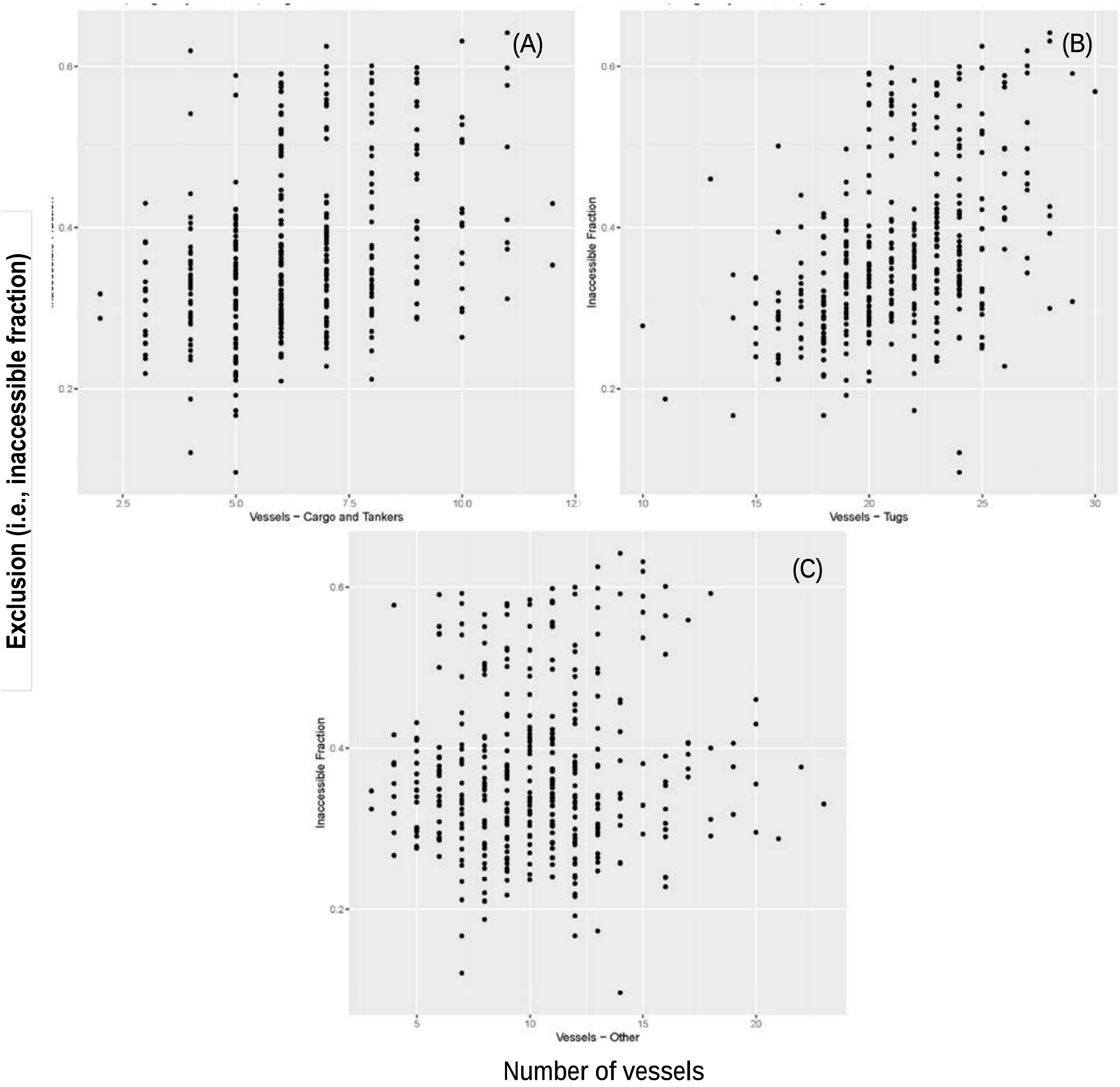

Figure 29. Bivariate scatterplots between inaccessible fraction (or exclusion from access to fishing) and (A) cargo / tanker vessels, (B) tug / towing vessels, and (C) other vessels for **salmon fishing in the regularly accessed areas in the Lower Fraser River** based on vessel traffic from 2012-2017.

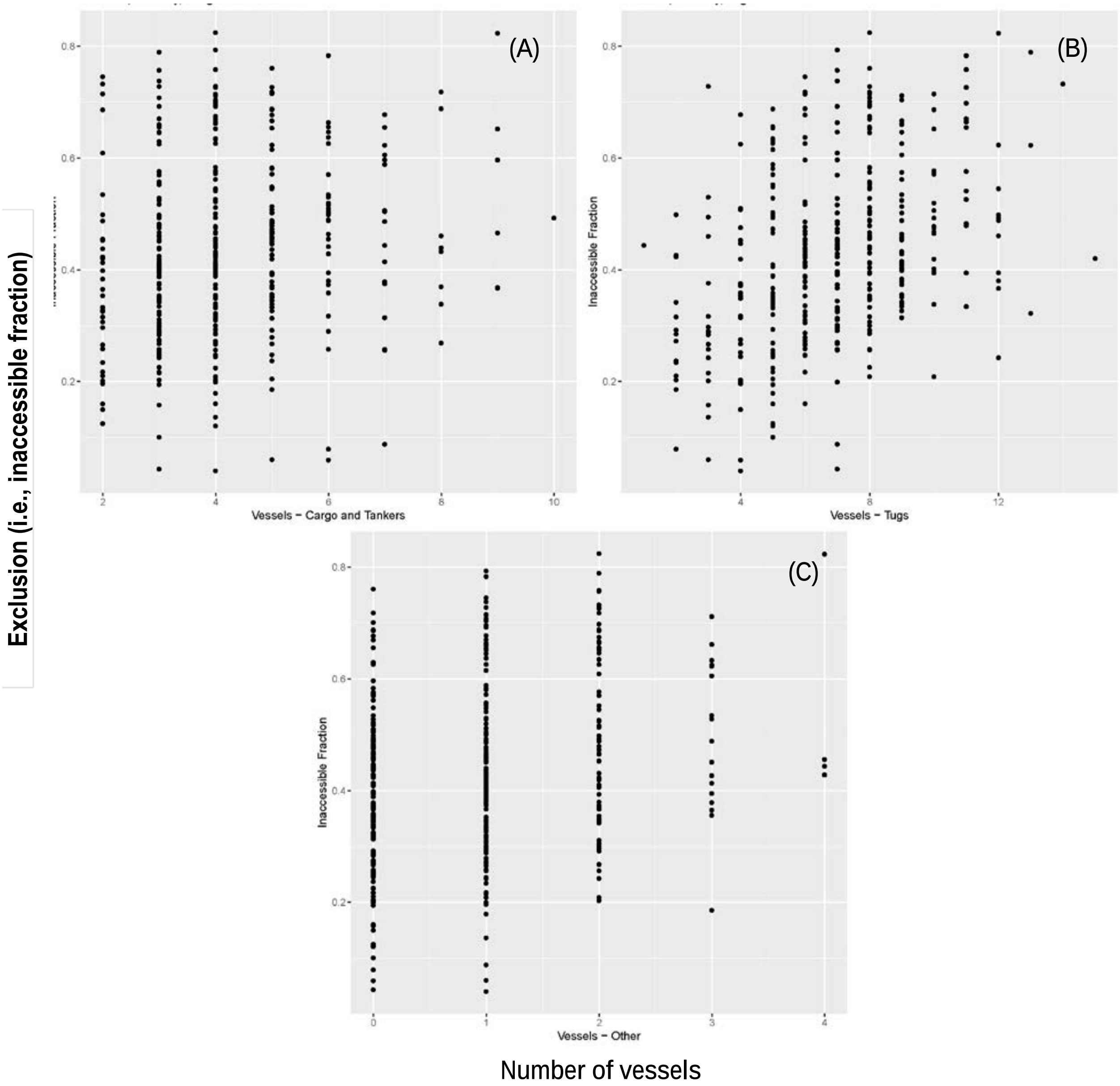

Figure 30. Bivariate scatterplots between inaccessible fraction (or exclusion from access to fishing) and (A) cargo / tanker vessels, (B) tug / towing vessels, and (C) other vessels for **salmon fishing in a high conflict zone at Tilbury Island** based on vessel traffic from 2012-2017.

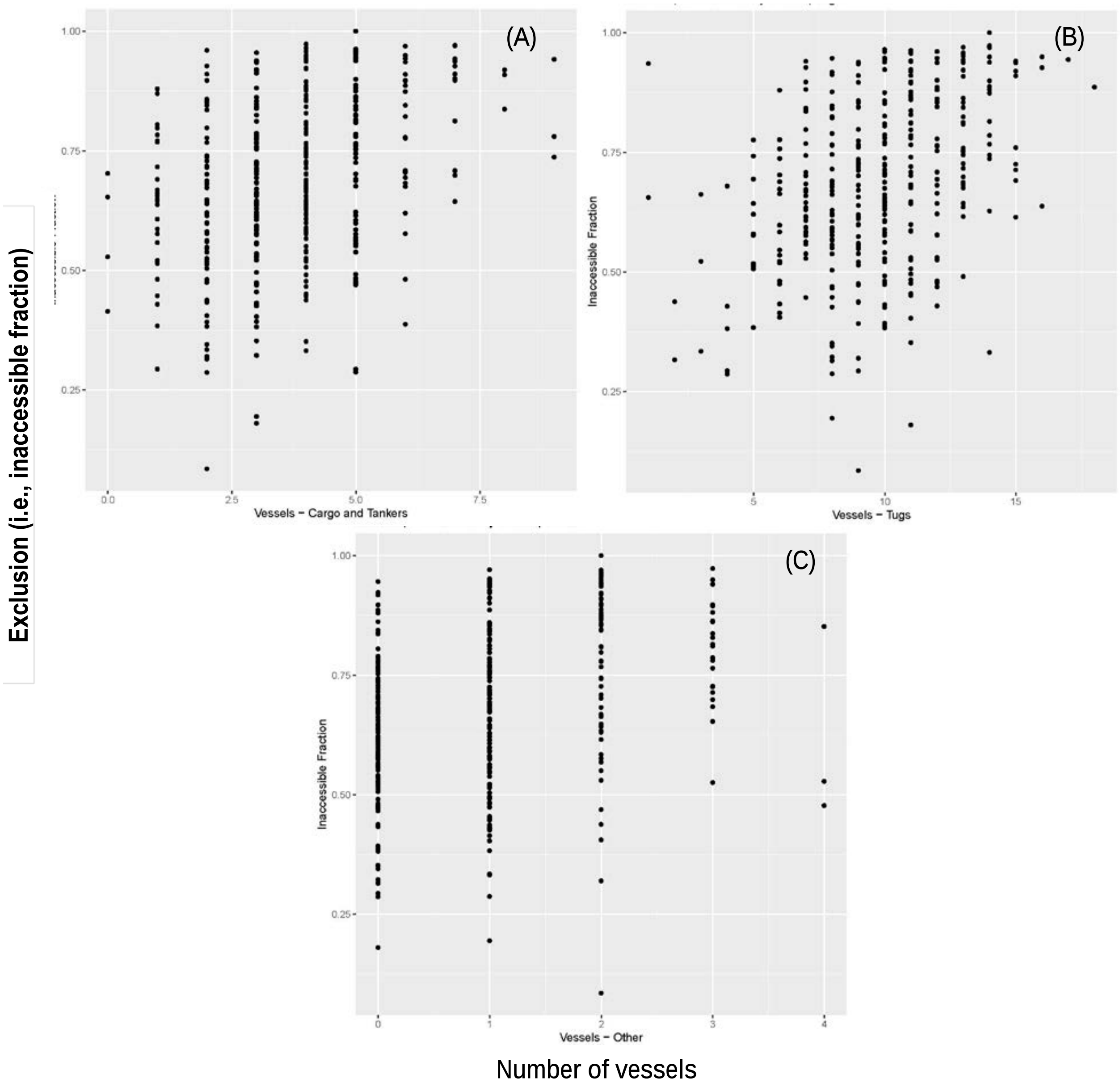

Figure 31. Bivariate scatterplots between inaccessible fraction (or exclusion from access to fishing) and (A) cargo / tanker vessels, (B) tug / towing vessels, and (C) other vessels for **salmon fishing in a high conflict zone at Fraser Surrey Docks** based on vessel traffic from 2012-2017.

Table 7. Summary of model coefficients for the best fit models from a regression analysis used to estimate the effect of number of vessels per day on exclusion (i.e., inaccessible fraction) of Musqueam from accessing fishing opportunities. Note that model coefficients presented below represent values from a model with a logit transformation of inaccessible fraction. All model coefficients were statistically significant at less than a 0.01 level.

	Estimate	Std. Error	t value	Pr(>|t|)
Prawn Model **Multiple R-squared: 0.6183**				
(Intercept)	-2.0220466	0.0180742	-111.88	<2e-16
vessels_cargo_tanker	0.0158078	0.0008128	19.45	<2e-16
vessels_tug_towing	0.0259302	0.0009199	28.19	<2e-16
vessels_other	0.0107488	0.0003872	27.76	<2e-16
Crab Model **Multiple R-squared: 0.625**				
(Intercept)	-2.3757309	0.0178672	-132.97	<2e-16
vessels_cargo_tanker	0.0147611	0.0006423	22.98	<2e-16
vessels_tug_towing	0.0216404	0.0007600	28.47	<2e-16
vessels_other	0.0098426	0.0002968	33.17	<2e-16
Salmon Model 1: Regularly Accessed Areas, Lower Fraser River **Multiple R-squared: 0.2443**				
(Intercept)	-1.994453	0.140992	-14.146	< 2e-16
vessels_cargo_tanker	0.066562	0.010942	6.083	2.94e-09
vessels_tug_towing	0.047613	0.006628	7.183	3.77e-12
Salmon Model 2: High Conflict Zone, Tilbury Island **Multiple R-squared: 0.2124**				
(Intercept)	-1.43037	0.13506	-10.591	< 2e-16
vessels_cargo_tanker	0.06360	0.02214	2.872	0.004315
vessels_tug_towing	0.10302	0.01423	7.240	2.62e-12
vessels_other	0.14681	0.03802	3.861	0.000133
Salmon Model 3: High Conflict Zone, Fraser Surrey Docks **Multiple R-squared: 0.1983**				
(Intercept)	-0.69593	0.19177	-3.629	0.000325
vessels_cargo_tanker	0.14595	0.03477	4.198	3.38e-05
vessels_tug_towing	0.08629	0.02093	4.123	4.62e-05
vessels_other	0.30960	0.05778	5.359	1.48e-07

The effects of future vessel traffic were estimated by calculating the inaccessible fraction of fishing opportunities under different scenarios of baseline and future marine vessel traffic (i.e., scenarios summarized in Table 5). A scenario analysis was used to explore the effect of future marine vessel traffic on inaccessible fraction or exclusion from access to fishing opportunities for several reasons. First, the relationship between inaccessible fraction and marine vessel traffic is modelled as a non-linear relationship, meaning that the effect of additional future traffic will depend on the baseline or background level of vessel traffic interacting with a particular fishery and area of interest. An analysis of future effects requires assumptions about the level of baseline vessel traffic. Second, as illustrated by the list of projects in Table 3, many projects are being proposed across the Musqueam territory that will lead to an increase in traffic. There is uncertainty about which ones and how many may ultimately be developed. As such, it would be an incomplete analysis to consider the isolated effect of one project in the absence other projects. Hence, an analysis of effects also requires assumptions about the level of future vessel traffic.

Figure 32 illustrates the effect of increases in vessel traffic on exclusion under different scenarios of baseline and future traffic for different fisheries at different locations of interest to Musqueam. Increases in marine vessel traffic from a low to a high scenario of development are predicted to increase exclusion of Musqueam from fishing opportunities, regardless of the fisheries or locations of interest. Across scenarios, the largest exclusion effects are on salmon fisheries with the greatest effect on salmon fishing near Tilbury Island (an 8-24% increase). Exclusion effects are already very high at Fraser Surrey Docks so the additional effects and percent change of additional marine vessel traffic are less (a 4-9% increase). Regularly accessed areas for salmon demonstrate a 7-16% increase in exclusion effects, while additional traffic leads to a 3-14% increase in exclusion from crab fishing and a 3-16% increase in exclusion from prawn fishing. Based on the anticipated interactions of a specific project, such as WesPac LNG Terminal, the exclusion effects on salmon can be represented by results under scenarios 1, 3, 5, and 7. The effects on crab and prawn of this project can be represented by scenarios 13 and 16. Based on the anticipated interactions of a specific project, such as the BHP Potash Terminal, the exclusion effects on salmon can be represented by the results under scenarios 1, 3, 5, 7, 9, and 10. The effects on crab and prawn of this project can be represented by scenarios 13 and 16. Variation in results across scenarios for these projects depend on the level of baseline marine traffic, not the number of other projects and induced vessel traffic that may be developed at the same time.

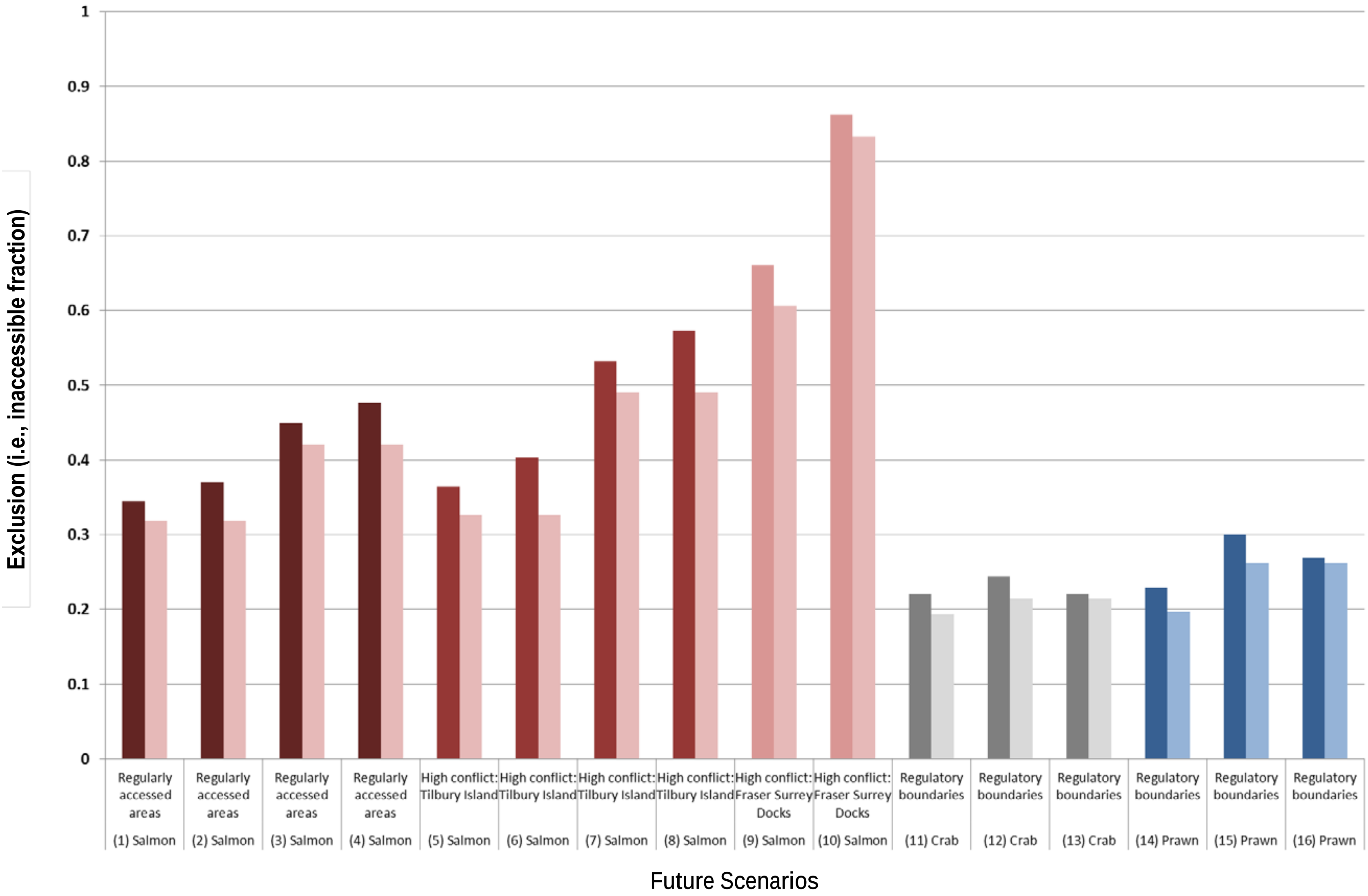

Figure 32. Estimates of exclusion across different scenarios of future marine vessel traffic using the best fit regression models (shown in Table 7) for different fisheries and locations of interest to Musqueam (scenarios are summarized in Table 5). Estimates of exclusion for each scenario with no additional future traffic are shown by the lighter shaded bars on the right.

4.0 Implications of these findings on understanding access to fishing opportunities

The analysis in Section 3 provides insights about factors that have cumulatively contributed to current restrictions on access to fishing by Musqueam (Section 3.1), quantitative evidence about the interaction between marine vessel traffic in recent years and the specific fishing opportunities provided to Musqueam (Section 3.2), and estimates about the effect of increases in future marine vessel traffic on exclusion from fishing (Section 3.3). Collectively, these insights and this evidence provide a greater understanding about the effect of increases in future marine vessel traffic on Musqueam access to fishing opportunities. The results, however, do not account for the significance of restricted fishing access to Musqueam that might result from variation in their desired timing and locations of access. For instance, restrictions in access during months and years with high returns of sockeye salmon when potentially more Musqueam fishing vessels are on the water would be more significant than a year with smaller abundance and fewer fishying boats on the water. These years can be critically important for setting aside stores of fish for future use in lean years.

An examination of the factors contributing to the current situation emphasize that baseline exclusion from fishing is high for a variety of reasons. The region has seen intense growth in human population (Figure 19) and vessel traffic (Figure 22) over the last 100 years, which has led to a marine environment in which there are frequent interactions between Musqueam fishing opportunities and existing marine vessel traffic. Interviews with Musqueam fishers also reveal that the traditional timing and locations of access are already highly constrained. In other words, the fishing windows (Figure 14) and boundaries (Figure 10, Figure 11, Figure 12) prescribed by Fisheries and Oceans Canada and used in this analysis represent restrictions that are not accounted for or represented in the results shown here. These restricted fishing windows and locations are determined by DFO based, in part, on the abundance of marine resources like salmon and eulachon, which are currently in decline due to factors beyond the influence of the Musqueam and marine vessel traffic in the region (Figure 4). Hence, future changes in the status of marine resources may also affect access. If declines in abundance of target species continue, the extent of fishing opportunities used in this analysis, and projected into the future, will be fewer than assumed in the scenario analysis, resulting in even higher levels of exclusion from fishing. Lastly, there is an additional compounding / cascading effect of exclusion. Increasing barriers to access fisheries can lead to a shift in people’s behaviour: they may decide to fish less, invest less in fishing gear, and ultimately spend less time on the water. Musqueam has tried to adapt by shifting their fishing efforts to different target species, but across multiple years the exclusion of harvesters from fishing has ultimately led to changes in the fishing fleet and a decline in total fishing effort across the fleet (Figure 17).

Among other insights, the examination of the baseline situation in Section 3.1 provides clarity around the fishing windows provided by DFO (Figure 14) and some locations of interest to Musqueam (i.e., regulatory boundaries for prawn and crab, regularly accessed areas in the Lower Fraser River, and high conflict zones at Tilbury Island and Fraser Surrey Docks for salmon). This information is necessary to perform the quantitative analysis of the interaction between marine vessel traffic and access to Musqueam fishing opportunities in Section 3.2.

A summary of the number of vessel per day from 2012-2017 demonstrates high variation in the number of cargo-tanker vessels, tug-towing vessels, and other vessels interacting with the different fisheries and locations of interest (Table 6). Up to a maximum of 40 cargo-tanker vessels, 33 tug-towing vessels, and 61 other vessels are noted as interacting with fisheries on a given day (not necessarily all on the same day). The number of vessels also varies depending on the locations of interest to the different fisheries. The highest number of vessels was noted in the regulatory areas for salmon, crab, and prawn given the large spatial boundaries of the analysis in these areas. However, there were greater concentrations of traffic in the Lower Fraser River (i.e., number of vessels per unit area) with the greatest number being tug-towing vessels, followed by cargo-tanker vessels, and other vessels. Due to an observed bias in AIS data from the 2009-2011 period compared to the 2012-2017 period, these earlier years were not included in the exclusion analysis since they are known to have a different temporal resolution of reporting. This constraint in the data means that years with Musqueam fishing opportunities associated with strong sockeye salmon returns are not represented in the results (e.g., 2010 and 2011).

Based on an analysis of AIS data, this level of vessel traffic resulted in exclusion effects across all years for all fisheries - salmon, crab, and prawn - when examined across the broad regulatory boundaries for these fisheries (Figure 23). As noted during interviews with Musqueam fishers, however, these boundaries and fishing windows already represent restrictions in traditional access. For instance, large areas of the Lower Fraser River are unavailable for salmon fishing due to other development activities (e.g., inaccessibility of the north arm of Lower Fraser River due to log booms). The analysis did not include all vessel types moving throughout the region (Table 1). While AIS data captures the majority of interactions from cargo vessels, large tug, and barge combinations, not all vessels are required to carry AIS. Other recreational and commercial harvesters, as well as pleasure craft (vessels not required to carry AIS), can sometimes run over nets and therefore impact Musqueam fishing access. These interactions are not represented in the above summary of traffic. As well, the analysis required crude approximations of the spatial and temporal buffers between Musqueam fishing gear / vessels and other marine vessel traffic (Table 2), which did not provide the granularity to represent individual behaviour and interactions among different vessels on the water. Furthermore, these assumptions around set and haul times do not consider how the acoustics of other marine vessels affect fish movement and may lead to further adjustments in fishing gear. These limitations imply that the exclusion effects reported here underestimate restrictions on access to fishing.

For salmon fishing, Musqueam have a traditional interest and particular concerns about restrictions to access in the Lower Fraser River. An examination of exclusion effects at different locations shows increasing exclusion when comparing the broad regulatory boundaries for salmon to regularly accessed areas in the Lower Fraser River to high conflict zones in Lower Fraser River, specifically Tilbury Island and Fraser Surrey Docks (Figure 26). The reason for higher exclusion at more localized areas is due to the increasing spatial concentration of the analysis and higher density of vessel traffic in the Lower Fraser River. In other words, exclusion effects are lower when averaged over a larger spatial area that may not be as meaningful to Musqueam. Exclusion effects are particularly high at Fraser Surrey Docks with an average annual exclusion of approximately 80% in 2013 with some days exceeding 90% exclusion.

Musqueam knowledge holders note that these high conflict zones are important fishing locations due to their unique environmental characteristics, which create favourable habitat for salmon and eulachon as a holding area. These areas are also frequent fishing locations especially when fishing efficiencies are reduced and competition for fish is high from marine mammals, such as seals and sea lions. Increased traffic in these areas will intensify exclusion from fishing in addition to the already high level of exclusion in these areas.

Interviews with Musqueam harvesters highlighted that there are increasing conflicts between fishing vessels and other traffic during tides and currents on the Lower Fraser River that favour salmon migration, fishing opportunities, and movement of vessel traffic. An examination of the effect of tides on exclusion generally showed an increase in exclusion during slack tide windows across most years (Figure 25). However, the analysis is unable to directly consider the effect of currents (a better measure of the timing of conflicts) so the estimates reported here are useful as a proxy, but do not likely provide an accurate estimate of tide-current effects on exclusion.

The analysis of vessel interactions in Section 3.2 provided the data necessary for developing relationships between number of vessels of different types and the level of exclusion from fishing (see Figure 27, Figure 28, Figure 29, Figure 30, and Figure 31). The limitations discussed above imply an unavoidable crudeness around understanding the relationship between vessel traffic and exclusion from fishing (e.g., determination of exclusion across broad spatial areas and broad timing windows, limitations in considering the influence of tides-currents, coarse rules for representing interactions among fishing vessels, gear types, and marine vessel traffic). Despite these limitations, a regression analysis revealed significant relationships between the number of vessels of varying types (cargo-tanker, tug-towing, and other vessels) and exclusion from fishing at different locations (Table 7). Hence, the best fit models serve as a useful tool for estimating the effect of future vessel traffic and understanding the relative influence of varying vessel types on access to fishing. The strength of the relationships and contributions from different vessel types vary depending on the fisheries and locations of interest. In addition, the relationships are non-linear, which means that the exclusion effect will vary depending on the level of baseline traffic (i.e., exclusion effects are different on days with low versus high baseline traffic).

Given uncertainties in precisely predicting the baseline and future levels of marine vessel traffic under different patterns of development (Figure 1), a scenario analysis is used to explore the effect of different traffic conditions on exclusion of Musqueam from different fisheries opportunities at different locations (Table 5). Scenarios of baseline vessel traffic are defined based on an analysis of historic levels of traffic (Table 6). Scenarios of future vessel traffic are defined based on the anticipated interaction between proposed projects and different fisheries (Table 4), and the level of traffic of different vessel types across projects (see Table 3 and Appendix C). Low scenarios are based on only one project being developed, resulting in an increase of 1 cargo-tanker and 1 tug-towing vessel per day. High scenarios are based on the average number of boats per day anticipated if all projects are developed, though at most increasing traffic by 4 cargo-tankers and 5 tug-towing vessels per day in the marine environment, and increasing traffic by 2 cargo-tankers and 2 tug-towing vessels in the Lower Fraser River.

Based on an application of the regression models under different traffic scenarios, increases in future vessel traffic are shown to increase the exclusion of Musqueam from all fisheries and locations (Figure 32). The greatest increase in exclusion is at Tilbury Island, though there are also heightened effects at Fraser Surrey Docks due to the high exclusion associated with existing levels of marine vessel traffic (Figure 26). There is also an indication of increases in exclusion during slack tide windows (Figure 25), which is not accounted for in these estimates of future exclusion. As such, the additional vessel traffic associated with the BHP Potash Terminal and WestPac LNG

Terminal, for instance, are anticipated to add significantly to the existing and already elevated exclusion from salmon fishing around Fraser Surrey Docks and Tilbury Island. These effects may be even greater if increased traffic occurs during high conflict tide-current windows.

Moreover, there are other types of projects not accounted for in this analysis that can affect fisheries within Musqueam territory today and into the future. For example, the construction of additional piers into the Fraser River associated with infrastructure projects, such as the Pattullo Bridge Replacement Project, will impact Musqueam access to fishing by changing river hydraulics and making important fishing areas difficult or unsafe to fish (Tam et al. 2017b). Other projects that require in-river work, such as localized dredging, building of piers and piles, can also result in localized exclusions in the Fraser River that may be temporary or permanent (interview with Musqueam members, March 2, 2018).

Regarding the scenario analysis of future vessel traffic, there are limitations with this analysis that need to be considered when interpreting results. Estimates of future effects are based on three assumptions: (1) that Musqueam fishing opportunities from 2012-2017 will represent future fishing opportunities (e.g., number, duration, time of year, species, and gear types); (2) that baseline levels of traffic in the future will be similar to the same period (2012-2017); and (3) that the levels of future marine vessel traffic in the scenario analysis are appropriate. Changing future conditions and different assumptions would suggest a need to interpret results differently. For instance, estimates of exclusion would be higher if decreases in abundance of marine resources lead to further restrictions in the spatial and temporal availability of fishing opportunities for Musqueam. Estimates of effects on future exclusion are also highly dependent on the assumptions about future levels of traffic (particularly traffic levels around Fraser Surrey Docks and Tilbury Island). It is possible that fewer projects could lead to a greater increase in traffic per day and a greater exclusion effect than indicated by the high future traffic scenarios described above. Lastly, the regression models and analysis of future effects of increases in vessel traffic are unable to consider differences in the design and operation of individual projects, even though the number and types of vessels, trips per day, vessel loading times, and exclusion areas around vessels while being loaded are expected to vary (i.e., all projects are treated the same in the regression models). Hence, these models may not fully account for the effect of an individual project on exclusion from fishing, and as such the models are not appropriate for identifying specific project mitigation measures and understanding the effectiveness of these measures at reducing the exclusion of Musqueam from their fishing opportunities.

5.0 Conclusions and next steps

Findings in Section 3 reveal that there are substantial baseline effects of marine vessel traffic on Musqueam fishing opportunities across different fisheries as measured by the inaccessible fraction or exclusion in space and time from available openings. Moreover, an analysis of the historic relationship between the number of vessels (especially cargo-tanker and tug-towing vessels) and inaccessible fraction of fishing opportunities revealed that their influence is statistically significant. These relationships can be used to estimate the effect of marine vessel traffic imposed by future projects on different fisheries at different locations.

Given these findings, this study is useful for understanding the implications of marine vessel traffic on access to current and future fishing opportunities by Musqueam fishers. There is, however, some unavoidable crudeness to the data and available methods for estimating effects. Our understanding about the effects of vessel traffic on access to fishing can be improved by addressing known data gaps and advancing methods for estimating effects today and into the future. In particular, this study implies a need for the following next steps:

- Address the gap in tide-current data so as to better quantify the interaction among tides-currents, salmon migration, vessel traffic, and exclusion from fishing;
- Improve the resolution of information / prediction at a project scale by building on the modeling techniques developed here so results can better account for and reflect project-specific interactions between marine vessel traffic and Musqueam fishing vessels;
- Improve the confidence in the cumulative level of future marine vessel traffic given the significant influence of this information on estimating future effects on exclusion;
- Explore improvements to the regression models that predict exclusion from salmon fishing in the Lower Fraser River since these models have relatively low R-Squared values (i.e., there are other unexplored factors and potentially greater complexity in the Lower Fraser that contributes to unexplained variation in exclusion), though the values are comparable with R-Squared values in other ecological studies;
- Be mindful of other factors that may further restrict the timing and location of access to fishing opportunities since these factors may indirectly lead to other exclusion effects that are not accounted for in this analysis (e.g., declines in abundance of target species that lead to further restrictions in the timing and locations of openings for the Musqueam or physical barriers in the river, such as piles, which can block fishing in specific locations and alter the hydraulics of the river to make it unfavourable and/or unsafe for fishing); and
- Explore exclusion effects at other focal areas of interest to Musqueam for salmon, crab, and prawn fisheries, for other salmon return years with higher abundance and more fishing opportunities (e.g., 2018), and develop methods to evaluate effects on other species around which there is a desire for harvesting, but which are currently inaccessible (e.g., eulachon and sturgeon).

Despite some limitations, this study provides the following useful and broad insights about the drivers that affect exclusion:

- The current baseline level of exclusion in space and time from fishing opportunities across Musqueam territory is elevated and due to a variety of cumulative factors, including the level of existing marine vessel traffic and current constraints on traditional access in space and time;
- The number and types of marine vessels (e.g., cargo-tanker vs. tug-towing) are important determinants of exclusion; a greater number of vessels leads to greater exclusion and the influence of different types of vessels depends on the fishery and location of interaction;
- The spatial scale (e.g., entire Lower Fraser River vs. a high conflict zone in the Lower Fraser River) and locations of interest (e.g., Tilbury Island vs. Fraser Surrey Docks) have an important influence on the analysis and accurately understanding the effect of vessel traffic on exclusion;
- The timing of potential interactions between marine vessel traffic and fishing has an important influence on exclusion (e.g., the influence of tide-current windows, duration, and seasonality to fishery openings); and
- The level of exclusion depends on the target species (crab, prawn, and salmon), fishing vessel type, and type of fishing gear being used by Musqueam fishers.

Given the effect of these factors, the following broad strategies could help minimize the magnitude of exclusion and chance of interactions between Musqueam fishing boats and other vessel traffic:

- Reduce the number of vessels interacting with Musqueam fishery openings;
- Monitor incidents of interaction between Musqueam fishing vessels and other vessel traffic;
- Encourage marine vessels to minimize and/or avoid locations of interaction during fishery openings (e.g., high conflict zones in the Lower Fraser River, such as Tilbury Island and Fraser Surrey Docks);
- Encourage marine vessels to minimize interactions during fisheries with gear types that require more time to deploy (e.g., crab and prawn fisheries, salmon seine fisheries);
- Engage with project proponents to design projects and adopt mitigation strategies that will minimize interactions with Musqueam fishing opportunities; and
- Promote communication with marine vessels operators to encourage the implementation and adherence to measures that will minimize interference with Musqueam fishing opportunities.

The intent of this study has been to develop a better understanding about the historic, recent, and future effects of marine vessel traffic on Musqueam’s access to fishing opportunities in their territory. The results in this report complement the knowledge of Musqueam fishers who indicate significant effects of marine vessel traffic on their access to fishing as well as published use studies which provide more information on the significance of specific project impacts (Tam et al. 2016a; 2016b, 2017a; 2017b; 2018). Insights from this study can be used to inform and facilitate more detailed discussions about strategies for reducing impacts as development pressures continue into the future.

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Appendix A: Data Sources

Data label	Data description	Source	Data provider
AIS data	Data representing the position and timing of vessel movement within the study area.	Data between Jan 1, 2009, and June 30, 2017 were purchased from Astra Paging LTD. VAT ID: BG 119063656	Astra Paging LTD. Business centre, H. Dimitar sqr Sliven 8800, Bulgaria
Fishery opening data	Specifications of the day, duration, gear type for different fishery openings provided to the Musqueam by DFO.	https://www-ops2.pac.dfo-mpo.gc.ca/fns-sap/index-eng.cfm	Brian Matts, Fisheries & Oceans Canada
Catch and effort data	Summary of catch and number vessels participating in a fishery during a particular fishing opportunity.	http://www.pac.dfo-mpo.gc.ca/fm-gp/fraser/archives-a-eng.html	Lawrence V. Guerin,Musqueam First Nation
Future development projects and vessel traffic	Summary of future / proposed development project, location, induced traffic and vessel type.	Various. See references in Table 3.	Various. See references in Table 3.
Tide data	Tidal elevation data on the Lower Fraser River at New Westminster.	http://www.isdm-gdsi.gc.ca/isdm-gdsi/twl-mne/inventory-inventaire/sd-ds-eng.asp?no=7654&user=isdm-gdsi&region=PAC&ref=maps-cartes	Fisheries & Oceans Canada
Regulatory fishing boundaries	Fishing boundaries as delineated by DFO for the different fisheries provided to Musqueam.	For salmon, primary boundary from the Sparrow case supplemented with PFMA Subarea 29, areas 3, 4, 6, 7 and 9. Regulated boundaries for crab and prawn also used PFMA subareas from DFO: https://catalogue.data.gov.bc.ca/dataset/dfo-fisheries-management-sub-areas	Fisheries & Oceans Canada
Regularly accessed areas and high conflict zones for salmon fishing	Focal fishing areas of particular interest to Musqueam due to potential for high conflict with vessels or for providing regular access to fisheries resources.	Interviews with Musqueam fishers	Musqueam Indian Band

Appendix B: Data Analysis

Task 1: Acquisition of non-spatial and spatial data

AIS and fishery opening data

Musqueam acquired AIS data for a section of the Georgia Strait and Howe Sound for tow time periods:

- January 2009 to December 2011 – 1 hour time resolution
- January 2012 to June 2017 – 5 minute time resolution

We acquired historical data on Musqueam fisheries openings from DFO, including:

- opening and closing date
- target species
- gear
- fishery type
- area

Regulatory boundaries

We developed boundaries corresponding to the areas identified in the historical fishery openings data.

Prawn – DFO PFMA area 29 subareas 2, 3, 4. Clipped to the area for which we have AIS data.

Crab – Musqueam crab license area, supplied by Musqueam, clipped to area for which we have AIS data

Salmon – Primary boundary produced using the definitions from the Sparrow case. Additional boundary produced from PFMA Subarea 29, areas 3, 4, 6, 7 and 9, clipped to the area for which we have AIS data and with land areas clipped out.

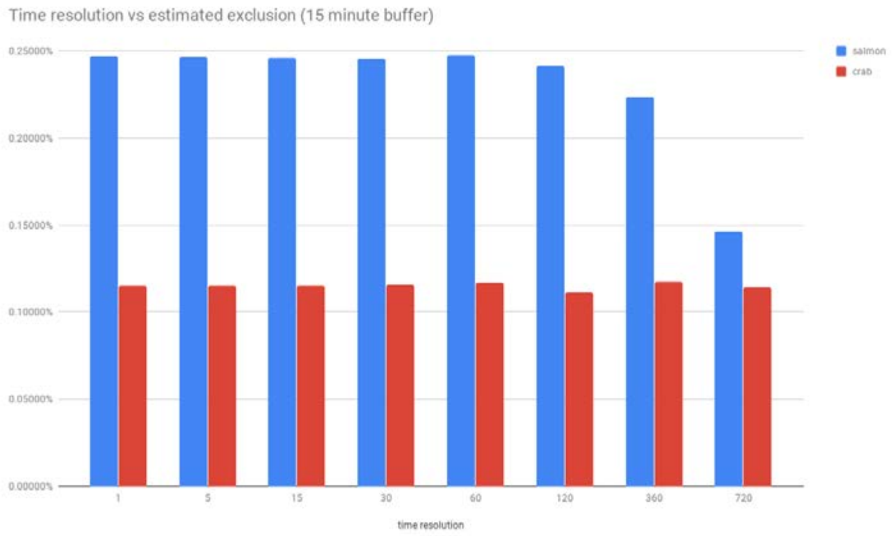
Regularly accessed area boundaries

In addition to the boundaries defined by regulation, we generated a set of boundaries to represent the current, regularly accessed fishing areas of the Musqueam for salmon. A Musqueam Aboriginal Fisheries Officer delineated a series of polygons representing areas that could not be fished in (in the south arm of the Fraser River) and areas which could be fished in (in the north arm), due to extensive existing barriers to fishing in the areas identified in the south arm and in the majority of the north arm. These were combined to create a set of regularly accessed areas in the Lower Fraser, and extended to include the channel as it flows out of the Fraser to the shelf boundary.

Task 2: Pilot analysis to determine appropriate time-step

An initial pilot analysis was used, focusing on a single month and then a single year of data, to assess the effect of choosing a higher or lower resolution time-step on the results of the analysis.

We performed a slightly simplified version of the analysis (using exclusion buffers which were fixed rather than varying by species/gear type) repeatedly on the same data subset. The summarized results of the analysis were compared, and we observed that those results were extremely similar when produced using a 1-minute, 5-minute, 15-minute, 30-minute or 1-hour time resolution. Slightly different results were obtained when run at a 2-hour resolution, and 6- and 12-hour resolutions produced notably different results, at least for some species. This suggested that the distribution of vessels and their areas of estimated effect tends to vary over something more than a one hour scale within our study area. We chose one hour as a balance between computational efficiency and apparent accuracy.



Task 3: Data processing

LOADING DATA AND ENUMERATING ENTITIES

AIS

All AIS data were imported into a spatially enabled relational database management system (RDBMS). Vessels present in the AIS data were enumerated, and their per-vessel characteristics (call sign, width and length, identified type, etc.) were summarized by choosing the either the average or most common reported values for each vessel, as appropriate. Standard data reported by the AIS system is summarized here: http://catb.org/gpsd/AIVDM.html#_type_5_static_and_voyage_related_data

The standard AIS type groups (listed in the document above) were further condensed into metagroups, and each was identified by the Musqueam as either excluding fishing in their vicinity or not (see Time/area analysis, below).

AIS points were processed into per-vessel “timeline” linestrings, retaining both the coordinates and the time information associated with each AIS-derived vertex in the line. The linestrings were generated for daily subsets of the AIS point data.

We used daily subsets, rather than generating vessel timelines which spanned the entire length of the available data, to speed subsequent processing steps and to reduce spurious “ghost” trips between reported locations separated by large gaps in time. These per-vessel timeline subsets were centered on a given day but extended by six hours into the previous and subsequent day to allow for additional projection of the vessel's path as required by the analysis.

Fishery openings

A script was used to parse the provided historical fisheries opening, to enumerate each

- opening time period
- fishery type (Communal, Ceremonial, Economic Opportunity)
- species and species group (Eulachon, Chinook, Dungeness Crab, etc.)
- gear type
- opening area

present in the data and establish the appropriate relationships among them in the RDBMS.

Fishery boundaries

For each area associated with a fishery opening (identified above), the GIS boundaries acquired and processed were loaded into the RDBMS, so that they could be used to bound the analysis.

TIME/AREA EXCLUSION ANALYSIS

For every hour, every fishery opening which was active during that hour was identified. For every such fishery opening, we enumerated all the vessels which either were present in the boundaries of the fishery, or which were approaching the fishery boundary, and which were of a type identified to prevent fishing activities.

AIS type group	Included in exclusion analysis
Cargo	Y
Tug	Y
Pleasure Craft	Y
Towing	Y
Passenger	Y
Towing: length exceeds 200m or breadth exceeds 25m	Y
Tanker	Y
Dredging or underwater ops	Y
Military ops	Y
High speed craft (HSC)	Y
Wing in ground (WIG)	Y
Reserved for future use	N
Diving ops	N
Law Enforcement	N
Noncombatant ship according to RR Resolution No. 18	N
Medical Transport	N

AIS type group	Included in exclusion analysis
Fishing	N
Not available (default)	N
Other Type	N
Sailing	N
Search and Rescue vessel	N
Port Tender	N
Pilot Vessel	N
Spare - Local Vessel	N
Reserved	N
Anti-pollution equipment	N

The identified vessels were enumerated by extracting a segment of each of the per-day vessel "timelines" (see AIS above) from an interpolated point on that timeline corresponding to the start of the analysis hour, to a point further down the timeline, the length in time of which was determined by the approximate haul-out time of the gear of that fishery. A table was supplied by Musqueam indicating the time required to haul in each gear type.

Resource	Gear type	Approximate setup time	Approximate haul in time	Value used in analysis (minutes)
crab	trap	4 hrs	5 hrs	300
prawn	shrimp & prawn	n/a	n/a	300
prawn	trap	4 hrs	5 hrs	300
salmon	beach seine	30 min	45 min	45
salmon	drift net	5-10 minutes	10min - 1 hr	35
salmon	purse	30 min	2 hrs	120
salmon	salmon	n/a	n/a	35
salmon	seine	30 min	2 hrs	120
salmon	tangletooth	5-10 minutes	10min - 1 hr	35
shrimp	shrimp trawl	8 hrs		30

A distance of 250m to the port and starboard of the vessel was used as a spatial buffer to represent a zone of safety for fishing vessels and their lines and gear.

The buffered timeline extracts were then clipped to the edges of the boundary for that fishery opening.

Finally, all the buffered and clipped extracts for that time-step/fishery combination were dissolved together into a single polygon. The area of that dissolved polygon was calculated, as was the total area of the fishery opening boundary. Both areas were multiplied by the time available in the time-step (60 minutes) to produce an estimate of the total available and precluded area and time for fishing. The inaccessible area/time was divided by the available area/time to produce an estimate of inaccessible fraction for that time-step and opening.

Regulatory and regularly accessed boundaries

After performing the analysis identified above using the regulated boundaries of the fisheries, the analysis was run again using a modified version of the boundaries. These were subset to represent the regularly accessed areas of fishing, which were most likely to provide significant value to fishers. These areas were identified at a workshop, a focus session, and a group meeting, attended by Musqueam Band fishers and fishing officers.

Task 4: Validation of methods and results

At each significant step in the development of the analysis workflow, a sample of processed data was loaded into a GIS for visual inspection, to ensure that it corresponded with expectations. In some cases, values produced by the spatial SQL methods were reproduced using conventional desktop GIS tools applied to the same underlying data, and the results compared.

Appendix C: Summary of Future Traffic

Project name	Year of operation	Crab / Prawn / Salmon Regulatory				Salmon regularly accessed				Salmon high conflict: Tilbury Island				Salmon high conflict: Fraser Surrey Docks			
		Cargo / Tanker		Tug / Towing		Cargo / Tanker		Tug / Towing		Cargo / Tanker		Tug / Towing		Cargo / Tanker		Tug / Towing	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
Kinder-Morgan Westridge Transfer Facility	2020	120	480	240	960												
VAFFC Marine Transfer Station	2020?	60	60	50	76	60	60	50	76	60	60	50	76				
Woodfibre LNG Marine Terminal	2020 or later	36	48	108	144												
Fraser Grain Terminal	2020 or later	63	80	126	160	63	80	126	160	63	80	126	160	63	80	126	160
WesPac LNG Terminal	2021	137	137	273	342	137	137	273	342	137	137	273	342				
BHP Potash Terminal	2021 or later	187	187	374	374	187	187	374	374	187	187	374	374	187	187	374	374
Lehigh Phase 1	2021	100	100			100	100			100	100						
Lehigh Phase 2	2022 or later	35	45			35	45			35	45						
Roberts Bank Terminal 2	2024	260	260	520	780												
Centerm	?	52	52														
Burnco Mine	?	182	182	182	182												
Fibre Co.	?	9	9	9	9												
G3 Terminal	?	112	112														
Derwent	?	52	52	52	104												

Project name	Year of operation	Crab / Prawn / Salmon Regulatory				Salmon regularly accessed				Salmon high conflict: Tilbury Island				Salmon high conflict: Fraser Surrey Docks			
		Cargo / Tanker		Tug / Towing		Cargo / Tanker		Tug / Towing		Cargo / Tanker		Tug / Towing		Cargo / Tanker		Tug / Towing	
		Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max	Min	Max
FSD Direct Coal Transfer Facility	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?
Total number of vessels per year across projects		1405	1804	1934	3131	582	609	823	952	582	609	823	952	250	267	500	534
Average number of vessels per day across projects		3.84	4.94	5.29	8.57	1.59	1.66	2.25	2.60	1.59	1.66	2.25	2.60	0.68	0.73	1.36	1.46
Total number of projects interacting with a fishing location		13	13	13	13	5	5	5	5	5	5	5	5	2	2	2	2
Low future traffic scenario (additional vessels per day)		1*	1	1*	1	1*	1	1*	1	1*	1	1*	1	1*	1	1*	1
High future traffic scenario (additional vessels per day)		4*	5	5*	9	2*	2	2*	3	2*	2	2*	3	1*	1	1*	1

Asterisks (*) denote values used as the vessel traffic per day for the high and low future traffic scenarios for different fisheries and locations in the scenario analysis described in Section 2.3. Low traffic scenarios are based on additional cargo / tanker and tug / towing vessel traffic if a single project was in operation. High traffic scenarios are based on the average number of vessels per day across all project rounded to the nearest whole number.