Ship Congestion at the Port of Vancouver and Southern Gulf Islands

Green Solutions for Better Management of Vessel Arrivals and Anchorage Demand

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EXECUTIVE SUMMARY

THE PROBLEM

Canada takes pride in its commitment to making major ports among the cleanest and most efficient in the world. The declared objective by the Port of Vancouver is to be the world's most sustainable port.

Unfortunately, the current performance is falling short of these commitments in some areas and has started to taint the desired reputation.

In recent years, a growing problem of ship congestion has emerged, and the industry is running out of anchoring space for ships. At the same time, the wasteful practice of long lineups of ship numbers and long waiting times of ships at anchor has serious environmental consequences.

Most anchoring of ships using the Port of Vancouver is by bulk carriers, also referred to as freighters. They wait empty at anchor until they can proceed to load bulk commodities such as coal, grain, fertilizers, or wood products.

Bulk carriers at anchor run loud engines, have bright lights, pollute and bring other negative effects to the environment. One anchored bulk carrier produces approximately 10 tonnes of greenhouse gases every day.

These unnecessary emissions aggravate the climate crisis, impact public health of citizens, threaten the survival of endangered species such as Orcas, and impair the integrity of rare and special marine ecosystems such as those in the Southern Gulf Islands.

Inflated ship movements and avoidable exposure to accidents unnecessarily increase risks of fuel and oil spills in highly sensitive areas close to shore.

During this decade, there has been a very visible expansion of anchoring activity from the Port of Vancouver into the nearby Southern Gulf Islands, which are an area of arguably international importance with high ecological and recreational values. For almost 50 years, these islands have been legally protected by a provincial mandate to limit development and preserve the natural character of these islands.

Considerable conflict has arisen about this expansion of anchoring activity caused by exports from the Port of Vancouver.

The current system is also not satisfactory for the industry because there is an increasing shortage of anchoring space, and no sustainable solution has been found. Inefficiencies and waiting times are creating economic costs. One anchored bulk carrier costs the Canadian economy up to $13,000 in demurrage fees for every late day past the contracted loading schedule. Uncertainties in the delivery of commodity exports and waiting times could be harmful for the market place of Vancouver.

Approach Towards Solutions

The problem of ship congestion is in need of practical solutions. For the Port of Vancouver, little information and analysis has been available on anchoring activity, the extent of ship congestion, and possible key factors for solutions.

In this report, we first look at the characteristics of how the use of anchorages developed over the past decade, the relationship to growth at port, and the expansion into overflow anchorages. Second, we explore some of the mechanics of port congestion and identify important key elements that cause the problem. Third, we explore the extent of the problem and suggest practical solutions.

The objective of this report is to explore the underlying processes in a quantitative manner, and to analyze the problem and possible solutions in a constructive way that is based on evidence.

The purpose of this report is to bring problems and solutions into sharper focus for raising public awareness and for assisting decision makers in industry, institutions, organizations, government, and First Nations with facts and constructive solutions with positive outcomes.

Summary of Key Results

Bulk carrier anchorage use of the Southern Gulf Islands outside the Port of Vancouver has exploded in less than a decade. This growth pattern followed an exponential curve and is not sustainable.

Increasing demand for anchorages at the Port of Vancouver by far exceeded the growth in vessel traffic and in export volumes. Ship congestion and burning fuel at anchor are a problem because of significant environmental damage and millions of dollars lost for the Canadian economy.

Coal is the primary commodity exported by volume, but grain was responsible for the highest use of anchorages, particularly during the winter months.

The Southern Gulf Islands have been used primarily for overflow anchorages when port anchorages were full. Now an increasing number of arriving ships are sent to the islands directly instead of port anchorages first. Coal bulkers have a disproportionately high demand for anchorages in the Southern Gulf Islands, and appear to use them regularly and not only in overflow conditions.

Declining efficiency at port is indicated by a pattern emerging during the last decade: Bulk carriers spend more time at berth, more time at anchor, and make more movements from and to anchorages. More arriving ships first anchor and wait, rather than arrive at berths directly.

The rate of ship arrivals showed discrepancies compared to the rate of loading capacity at port. Consequences are growing vessel lineups and port congestion. Analysis showed a lack of feedback mechanisms that would respond to growing vessel lineups with a reduction of future vessel arrivals.

Simulations of data revealed that ship congestion can be avoided. If the maritime component of the supply chain was better integrated, and feedback information flowed back to decision makers, more efficient scenarios could be achieved with fewer ships unproductively waiting at anchor.

Elsewhere, port congestion similar to the situation in Vancouver has been resolved by implementing a Vessel Arrival System (VAS) that synchronizes ship arrivals with current performance of supply chains. If such a system in Vancouver was only 75% as effective as elsewhere, only half of the port anchorages would be in use on average.

At the port of Vancouver, a Vessel Arrival System of similar efficiency as achieved elsewhere could:

(a) Cut greenhouse gas emissions by approximately 60,000 tonnes per year (more than 100,000 tonnes/yr with shore-to-ship power at bulk terminals);

(b) Save tens of millions of dollars per year in late loading fees paid by Canadian grain farmers;

(c) Reduce average anchorage demand to less than half of existing port anchorages.

Ecologically sensitive areas of unique value such as the Southern Gulf Islands could be protected effectively, by avoiding placement of anchorages for overflow traffic from port into such areas. An average reduction of 2 days in anchoring stays per vessel would eliminate the average current use of about 3,000 anchorage days per year in the Southern Gulf Islands.

Ship movements from and to remote anchorages could be minimized: Lower traffic volumes would enhance marine safety by reducing risks of collision with oil tankers, and would contribute to reduction of noise and pollution in Haro Strait and other critical habitat for the endangered Southern Resident Killer Whale population.

A full list of summarized quantitative results is given in Appendix 2.

CONCLUSIONS

- Current growth in anchorage demand is not sustainable;
- Lacking coordination of ship arrivals is a key factor leading to ship congestion;
- Overflow anchoring of ships in the Southern Gulf Islands is not only a local problem but affects the entire region of the Salish Sea because of (a) Massive amounts of avoidable emissions and pollution; (b) Large and unnecessary traffic volume of empty ships through Haro Strait that only serves the purpose of moving between port and overflow anchorages; (c) Risk of losing the integrity of the protected area of the Southern Gulf Islands with their unique characteristics and ecological value.
- Computer simulations reveal that opportunities exist to reduce waiting times for vessels, ship congestion, and anchorage demand by better integrating the maritime component into the supply chains of bulk exports through implementation of modern Vessel Arrival Systems (VAS). Efficiency comparisons show that the need for anchorages in sensitive and protected areas could be eliminated.

RECOMMENDATIONS

(1) Current policies regarding growing anchorage demand are not sustainable and need to be revised. There are no positive long-term outcomes, also not for the industry that is already reaching anchorage capacity without solutions in sight.

(2) Divisive policies that are not inclusive, such as expanding industrial activity into special areas with high conservation and recreational values like the Southern Gulf Islands, will bring significant environmental damage and social conflict, without providing sustainable solutions for industry and the economy, and should be replaced by a better approach and greener solutions.

(3) The maritime component needs better integration into the supply chains of exported commodities, for example by applying a Vessel Arrival Systems (VAS). Positive outcomes are: Increased efficiency and more reliable business conditions, benefits for the economy and the environment, benefits regarding public health, climate change, marine safety for prevention of oil spills, conservation of endangered Southern Resident Killer Whales, and inclusive solutions for multiple segments of Canadian society.

(4) Vessel Arrival systems should be implemented for all commodities exported from Vancouver, not only grain. Optimized arrivals for coal would greatly reduce the need for overflow anchorages, and including other commodities will help reducing the problem of cumulative ship congestion.

(5) Information transfer specific to each commodity supply chain will be essential for the success of Vessel Arrival Systems. Some centralized services for guiding ships including virtual arrivals and just-in-time arrivals could be provided by the port authority. Marine Traffic Systems for the Port of Vancouver should include Vessel Arrival Systems, or at least provide compatibility for such expansion in the near future.

(6) Positive leadership for solutions should be assumed by industry and the port authority to ensure the highest degree of efficiency. The federal government, especially through Transport Canada, should support these efforts and should consider funding of required components where better outcomes for public interests are involved.

INTRODUCTION

Canada takes pride in its commitment to making major ports among the cleanest and most efficient in the world. The declared objective by the Port of Vancouver is to be the world's most sustainable port.

Unfortunately, the current reality is falling short of these commitments and has started to taint the desired reputation.

In recent years, a growing problem of ship congestion has emerged, and the industry is running out of anchoring space for waiting ships. The wasteful practice of long lineups of ship numbers and long waiting times of ships at anchor has serious environmental consequences. Unnecessary emissions aggravate the climate crisis, impact public health of citizens, threaten the survival of endangered species such as Orcas, and impair the integrity of rare and special marine ecosystems such as those in the Southern Gulf Islands. Inflated ship movements and avoidable exposure to accidents unnecessarily increase risks of fuel and oil spills in highly sensitive areas close to shore.

What is happening, and what can industry, government, and resident s do to solve this massive problem?

Most anchoring of ships using the Port of Vancouver is by bulk carriers, also referred to as freighters. They wait empty at anchor until they can proceed to load bulk commodities such as coal, grain, fertilizers, or wood products.

During this decade, there has been a very visible expansion of anchoring activity from the Port of Vancouver into the nearby Southern Gulf Islands, which are an area of arguably international importance with high ecological and recreational values. For almost 50 years, these islands have been legally protected by a provincial mandate to limit development and preserve the natural character of these islands.

Bulk carriers at anchor run loud engines, have bright lights, pollute and bring other negative effects to the environment. One anchored bulk carrier produces approximately 10 tonnes of greenhouse gases every day. One anchored bulk carrier costs the Canadian economy up to $13,000 in demurrage fees for every late day past the contracted loading schedule. Considerable conflict has arisen about this expansion of anchoring activity caused by exports from the Port of Vancouver.

Little information has been available about this expansion of anchoring activity through the Port of Vancouver. For this study, we compiled a database from public sources of data of about 150,000 records on movements of oceangoing ships using the Port of Vancouver during 2008-2019, provided by the Pacific Pilotage Authority (PPA). Further analysis was based on public monitoring data of the Canadian grain supply chain by Quorum Corporation.

In this report, we first look at the characteristics of how the use of anchorages developed over the past decade, the relation ship to growth at port, and the expansion into overflow anchorages. Second, we explore some of the mechanics of port congestion and identify important key elements that cause the problem. Third, we explore the extent of the problem and suggest practical solutions.

The objective of this report is to explore the underlying processes in a quantitative manner, and to analyze the problem and possible solutions in a constructive way that is based on evidence.

The purpose of this report is to bring problems and solutions into sharper focus for raising public awareness and for assisting decision makers in industry, institutions, organizations, government, and First Nations with facts and constructive solutions with positive outcomes.

METHODS

This study is based on the analysis of data primarily reported by the Pacific Pilotage Authority[1] (PPA). Unless noted otherwise, this is the source for data in Figures 1-15. The use of pilot services is mandatory for bulk carriers that enter the inland waters of British Columbia, such as the marine area between Vancouver Island and the Mainland, also referred to as the Pacific Gateway. Therefore, the records of these pilot services describe the movement of vessels in the study area.

The major challenge was assembling a consistent database with some 150,000 individual records from a decade of reporting by PPA, and correctly grouping together all documented movements that occurred during each visit to port by each vessel. Each visit contains arrival, movements between anchorages and berths, and departure.

For calculating durations from PPA data, our focus was on events when vessels were stationary rather than shorter events when vessels were moving (for analyzing movements, AIS data would be more suitable). Several time records are available in PPA data. For estimation of event durations, we conservatively selected time records that provided minimum estimates. For example, when a vessel moved to an anchorage, the beginning time would be marked by the time the pilot debarked, and the end time would be marked by the time a pilot was ordered to move the vessel away from the anchorage. Thus the calculation of days follows the format: [Duration (days) = Pilot Ordered(t+1) – Pilot Embarked(t)]. The associated errors are usually only fractions of a single day.

For estimating the type of cargo, publicly available descriptions of bulk terminals at the Port of Vancouver were used to associate vessels with their cargo. Only vessels with unambiguous association with terminals were used for analysis of different cargo types. Cargo types other than the three main categories grain, coal, and fertilizer were not included for analysis involving cargo types. Only vessels that were categorized as 'Bulk Carriers' in PPA records were used. This leads to some underestimates, because vessels classified as 'General Cargo' were not included, although some may have transported bulk exports. Anchorage locations at the Port of Nanaimo were included in the 'Port Region' (see Appendix 1) for all analyses that compare specific commodities and for analyses of port congestion (considered part of regular operations within port limits and not overflow).

Some records appeared to have some data errors or multiple entries. For the calculation of durations such as 'Days in Port', we excluded about 5% of visits that did not originate and end with Brotchie (Sea) as the correct start and end point.

Additional data for Vancouver bulk exports was obtained from annual statistics reports by VFPA[2] and include only cargo volumes that were reported as both "outbound" and "foreign". Data for Figs. 16-24 primarily originated from monitoring the characteristics of the Canadian grain supply chain and was obtained from weekly, monthly, and annual reports by Quorum Corporation[3]. All statistical tests are two-tailed unless noted otherwise.

We thank the teams at all of the above sources for their patience and help in providing us with digital files and explanations about variables and data structure. We thank Prof. Trevor Heaver, UBC Sauder School of Business, for sharing his profound knowledge, for comments, and for constructive debates.

RESULTS

Implications of Growth: Bulk Exports and Anchorage Demand

A surprising development was observed during recent years in the Southern Gulf Islands, which are located near Vancouver but on the opposite side of the Salish Sea and outside the limits of the Port of Vancouver. The number of bulk carriers using the narrow waterways between these islands as anchorage space increased exponentially (Fig. 1) over the course of less than a decade.

It is often assumed that increased anchorage demand is simply an expression of growth in vessel traffic and exports at the Port of Vancouver. This assumption, however, is not confirmed in Fig. 1 when the number of bulk carrier arrivals at port is examined during the same time period. Growth in vessel traffic is not exponential but nearly linear and very moderate compared to the explosive expansion in anchorage demand.

What are the underlying causes of this surprising development, and how can this paradox be explained?

First, we explore the growth and annual growth rates of different characteristics of the export trades at the Port of Vancouver in Table 1.

By 2018, almost half of the bulk exports from Vancouver were coal (47.5%). Grain is next in importance, with about a third of bulk exports (29.1%). Potash, potassium, and sulphur were counted together as fertilizers (14.5%). Wood products consisted of 9% of the export volume.

Grain was the commodity with the strongest growth, with an average annual growth rate of 6.2%, followed by coal with an annual growth rate of 3.7%. Fertilizers and wood products grew at less than 3% per year. Annual growth is not a constant value but varied considerably between years, as illustrated in Fig. 2.

The overall growth rate of bulk exports was 3.86% per year, with a resulting growth of 46.1% from 2008-2018. This was closely reflected in the vessel GRT that describes cargo tonnage with an annual growth rate of 3.74% and a resulting growth of 44.4% during the same time period.

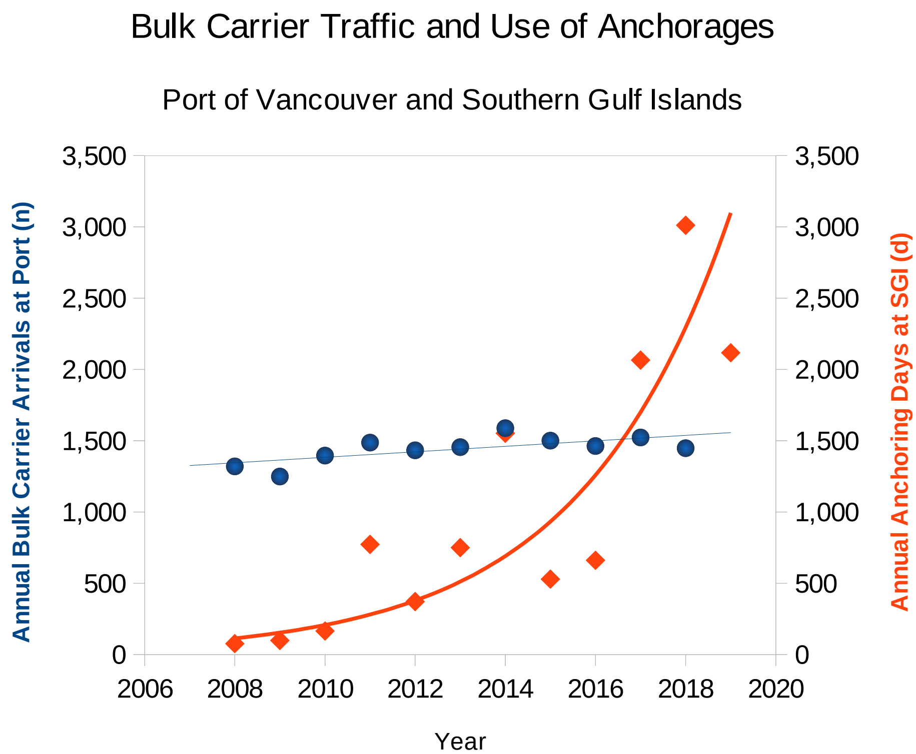

Fig. 1: Comparison of growth in annual arrivals of bulk carriers at the Port of Vancouver (blue) with the growth of the sum of annual days at anchor of bulk carriers at the Southern Gulf Islands (SGI, orange). Vessel arrivals at port increased only moderately by about 10% from 2008 to 2018, but the increase in use of SGI anchorages was exponential (about 10 fold). This indicates that the use of anchorages is not optimized and the growth in demand for anchorages is not sustainable.

Table 1: Growth numbers related to bulk exports at the Port of Vancouver, 2008-2018. Annual growth rates were based on curve fitting of ln(y)=a*x+b. Goodness of Fit are described with R^2 and F-statistic (* = p<0.05, ** = p<0.01, *** = p<0.001).

Annual Exports In Bulk Commodities	Growth since 2008	Annual Growth Rate	Curve Fit R^2, p	Exports in 2018 (tonnes)	% of Bulk Exports 2018
Coal	43.8%	3.70%	0.64***	37,301,280	47.4%
Grain	83.2%	6.24%	0.86***	22,891,980	29.1%
Fertilizers (Potash, Sulfur)	26.3%	2.36%	0.21	11,447,572	14.5%
Wood Products	14.2%	1.34%	0.16	7,087,789	9.0%
Total Bulk Exports	**46.1%**	**3.86%**	**0.83*****	**78,728,622**	**100.0%**

Annual Bulk Carrier Data	Growth since 2008	Annual Growth Rate	Curve Fit R^2, p	Data in 2018
Vessel Arrivals (n)	14.8%	1.39%	0.47*	1,448
Vessel GRT (tonnes)	44.4%	3.74%	0.79***	58,653,692
Trips per Visit (n)	39.8%	3.41%	0.95***	4.25
Days at Anchor, Port (d)	199.7%	11.60%	0.66***	6,026
Days at Anchor, SGI (d)	1374.6%	30.88%	0.70**	3,011

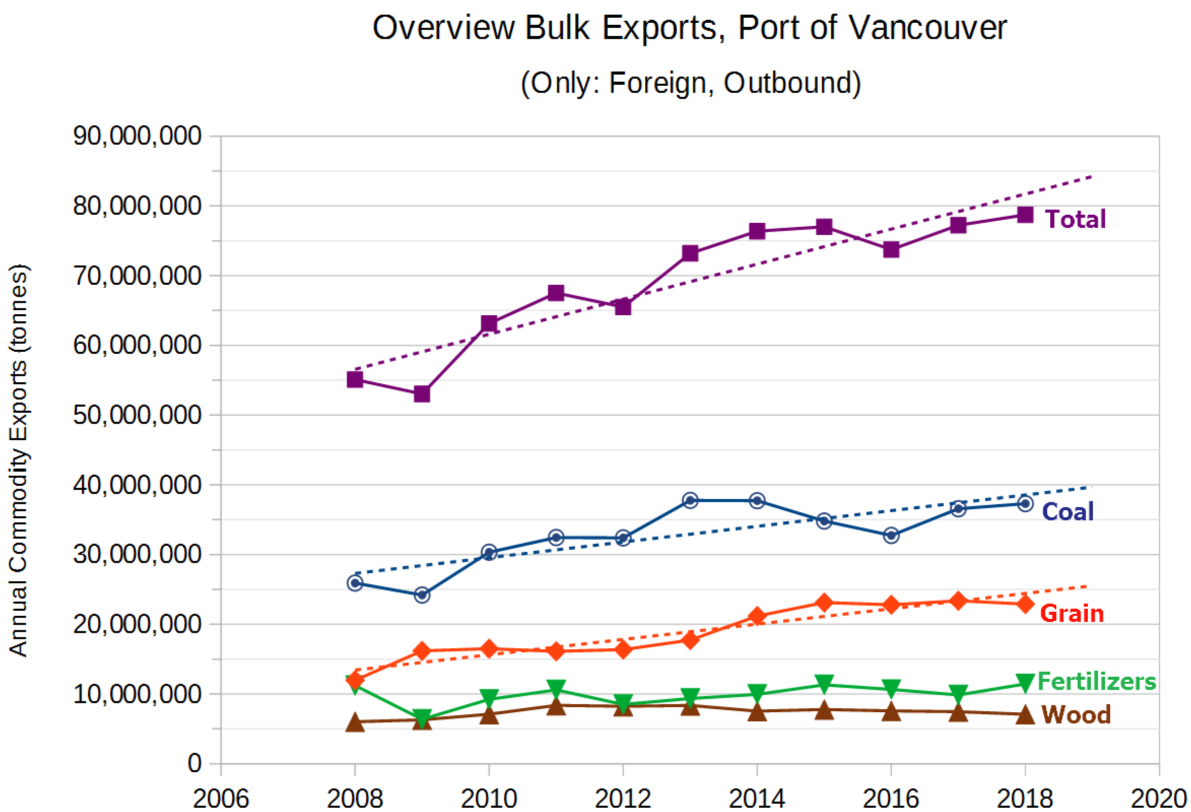

Fig. 2: Annual Bulk Exports at Port of Vancouver, 2008-2018.

In contrast, growth in anchorage use by bulk carriers was much higher. The days at anchor inside port limits grew 11.6% per year, resulting in a two-fold increase of 199.7% during 2008-2018. In the Southern Gulf Islands (SGI), the annual growth rate of days at anchor was 30.9%, with an over 10-fold increase (1,375%) during the same time period.

To further illustrate the disparity in growth rates, we calculated the expected anchorage use if growth rates for anchorage demand were assumed to be the same as for total bulk exports. Figures 3(a) and 3(b) show how anchorage demand would increase if growth was proportional to the growth in bulk exports (the value used was 6.2% and conservatively reflected the highest annual growth found in any commodity, see Table 1). The observed data showed much higher growth than expected in anchorage demand, and is an indication that this growth is not sustainable and in need of better management.

A comparison of annual anchorage days at the Port of Vancouver with overflow anchorages in the SGI reveals a distinctive pattern in Fig. 4. As vessel traffic builds up to port congestion, the resulting overflow into the SGI is not linear but exponential. This means that at lower levels of vessel arrivals,

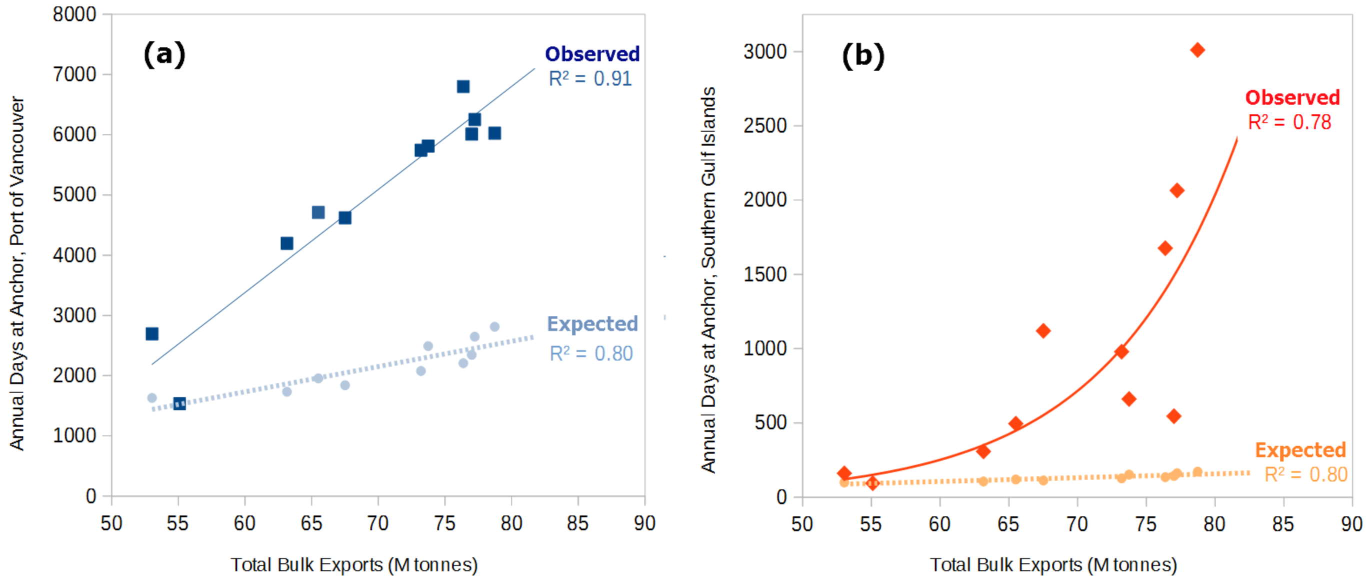

Fig. 3: Increase in anchorage use at **(a)** Port of Vancouver, **(b)** Southern Gulf Islands (SGI). Growth of anchorage demand is not proportional to growth in bulk exports, but much higher. Expected points were calculated assuming the same annual growth as bulk exports, but observed data showed much higher growth in anchorage demand that is likely not sustainable and in need of better management.

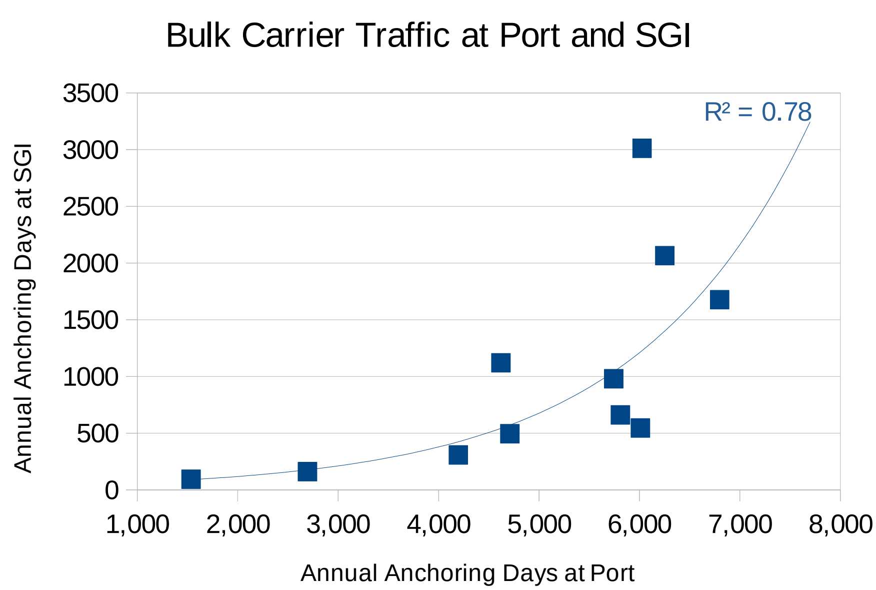

Fig. 4: Correlation of annual anchorage days at the Port of Vancouver and overflow anchorages at the Southern Gulf Islands (SGI). As vessel traffic builds up to port congestion, the resulting overflow into the SGI is not linear but exponential. When port anchorages are full, the spillover into neighbouring areas becomes massive.

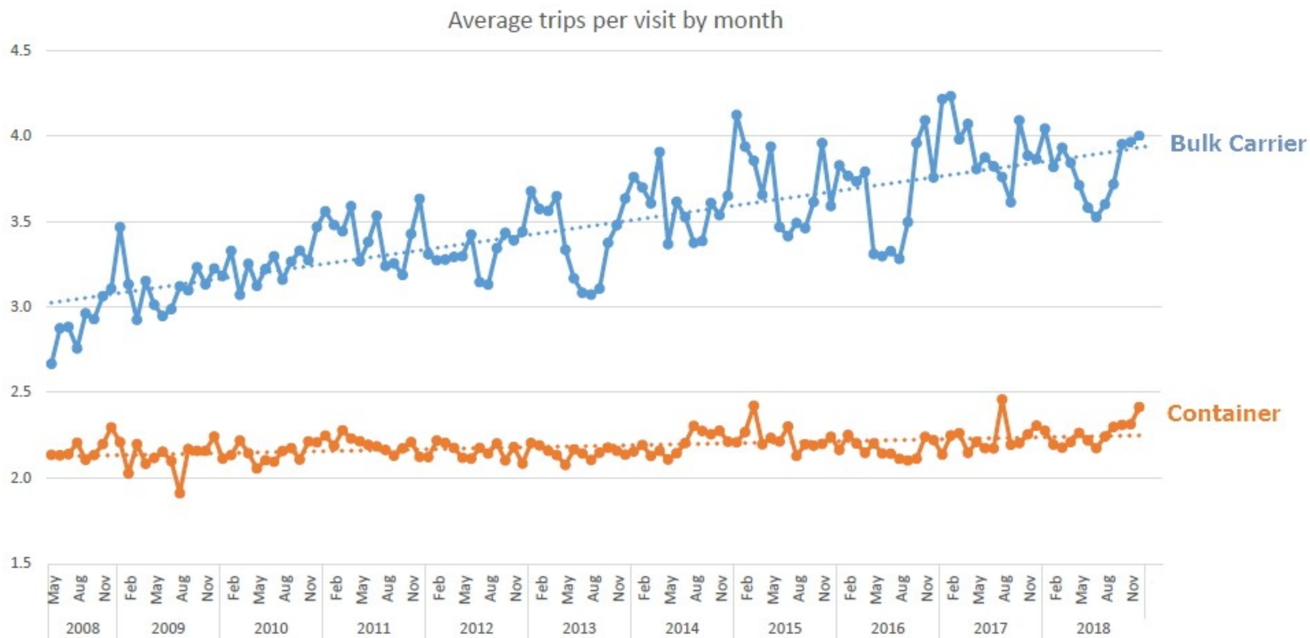

Fig. 5: Average number of trips made by different types of cargo ships within the Port Region of Vancouver for each arrival, displayed for each month over time. Line shipping for containers is efficient and constant with tight scheduling, and mostly requires only one trip for arrival and one for departure. Bulk carriers are making more trips involving anchorages. Over time there is a trend showing a substantial increase in average movements before vessels are loaded and depart.

the port anchorages are sufficient, but once these are filled, the spillover into overflow areas suddenly becomes massive.

The number of trips that vessels are making during a visit to the Port Region is another indicator of throughput efficiency, aside from the duration at anchorage. Containers are transported by liner shipping with tight scheduling. Visits to multiple terminals occur but anchoring is rarely needed. As illustrated in Fig. 5, the movements of a majority of container ships are limited to one trip for arrival plus another trip for departure. There is barely an increase in the number of trips over years, despite substantial growth in container trades over the same time period[2].

In contrast, the number of trips made by bulk carriers during each visit of the Port Region has increased by 39.8% over the time period studied (Fig. 5, Table1). Instead of arriving directly to a terminal and departing from there, the average movements of a bulk carrier rose to 4.25 separate trips from and to anchorages and berths in 2018. There also appears to be a seasonal difference in Fig. 5, with bulk carriers making more trips during winter than in summer (seasonal effects will be explored in later sections).

These movements of bulk carriers within the Port Region were dominated by trips involving anchorages. During 2018-2019, anchorages were involved in 77.8% of trips for grain, 70.3% for

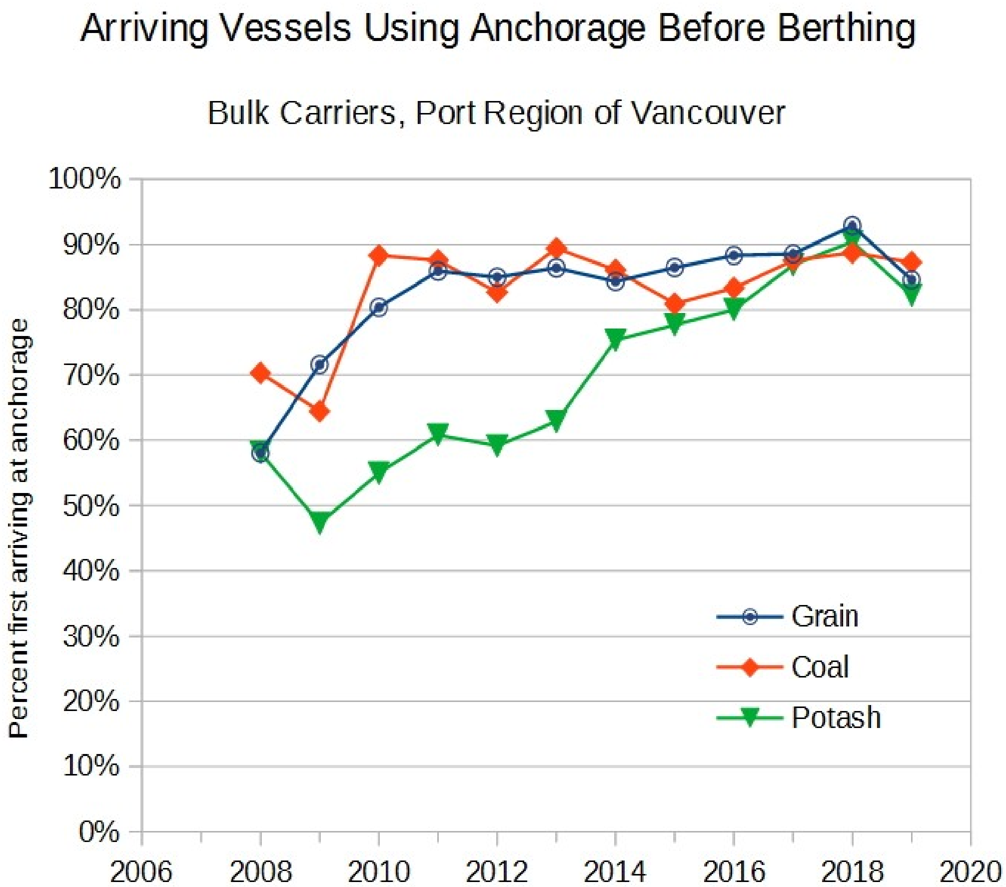

Fig. 6: Percentage of bulk carriers arriving at an anchorage before they move to a berth for loading, shown for the Port Region of Vancouver, for grain, coal, and potash (including other fertilizers). There is an increase of bulk carriers that are first arriving at anchor rather than at berth, and using anchorages before loading has become the norm for the vast majority of arriving bulk carriers.

coal, and 70.8% for fertilizers. Movements from berth to berth accounted for only 6.4% of trips for grain, 1% for coal, and 2% for fertilizers.

The mode of arriving at terminals has also changed drastically for bulk carriers during the study period. In the first two years a decade ago (2008-09), an estimated 38.4% of bulk carriers that entered the Port Region proceeded efficiently and arrived directly at their terminal for loading. Now, only 12.3% are estimated to arrive directly at berth. It has become the norm that the vast majority of bulk carriers are first directed to anchorages. These results are displayed in Fig. 6 and show the increase in the percentage of bulk carriers that are first arriving at anchor rather than at berth.

Reporting all of these changes over years and giving insights into correlations between different measurements cannot give direct answers about the causes of these changes. Some have suspected that the increase in average size of bulk carriers is involved in causing some of the changes observed[4,5], although larger vessels also decrease traffic and appear not to fully explain why anchorage demand has risen much more than export volume. Others see a main cause for the observed changes in the privatization of the Canadian Wheat Board (CWB) in 2012, primarily by fragmenting terminal resources and the previous central-desk system of logistics into multiple separate systems that are operated by competing grain companies, which form separate lineups of vessels without coordination[6].

FACTORS AFFECTING OVERFLOW ANCHORAGE: COMMODITIES AND SEASONALITY

Demand for anchorages is not equal for the main commodities exported through the Port of Vancouver, and anchorage use is not determined by export volume alone. While coal made up 47.5% of exports of the main commodities in 2018, grain accounted only for 29.2% (Table 1). These proportions were not reflected in anchorage use. The growth in annual anchoring days is compared for the different commodities in Fig. 7. Grain shows the highest overall use of anchorages with 60.6%, followed by coal with 30.7%, and fertilizers with 8.8%.

There are a number of causes that can make grain trades less predictable for delivery at port and result in uncertainties with waiting time for ships at anchor. Some of the complexities are the diversity in inventory of different grain types and specialty grains, a long supply chain from the Canadian prairie provinces, the time scale for export contracts being finalized weeks or months before delivery at port, difficulties of loading ships during winter rains, and multiple ownership of supply chain components and terminals[5].

Unexpectedly, the overall anchorage demands by different commodities are not reflected the same way in the use of overflow anchorages in the SGI (Fig. 8). Grain bulkers were not the leading users of anchorages in the SGI but only represented 39.9% during 2008-2019, while coal accounted for 55.2%, with fertilizers being present at only 4.9%.

First, this aspect has to be put in perspective of the strong expansion in anchorage use that has occurred in recent years, particularly in the SGI. Grain bulkers have shown a much steeper growth in anchorage demand than coal bulkers, and it appears that by 2018-19 grain is close to overtaking coal in demand for overflow anchorages in the SGI. The anchorage use by grain ships increased from 26.5% in 2008-10 to 43.4% in 2018-19.

Secondly, there is a strong seasonal aspect. Grain will dominate peak anchorage demand both in port and overflow anchorages when the worst cases of port congestion occur during winter months. The seasonal pattern for grain trades is illustrated in Fig. 9. Traffic by grain vessels starts to increase with the beginning of the wheat harvest and the ‘grain year’ in August. Numbers build up over the winter months and peak in late winter and early spring, and fall again to lower levels during summer (Fig. 9). Overall demand on anchorages is fairly constant throughout the year for coal and fertilizers.

The overflow anchorages in the SGI also show a strong seasonal peak for anchoring grain bulkers (Fig. 10). The percentage of anchorages used by coal freighters is much higher in the SGI than overall. It is unclear if there is a winter peak for coal, possibly because of displacement by grain vessels occupying most of the port anchorages during winter congestion, or if there is higher variability throughout the year because of other factors.

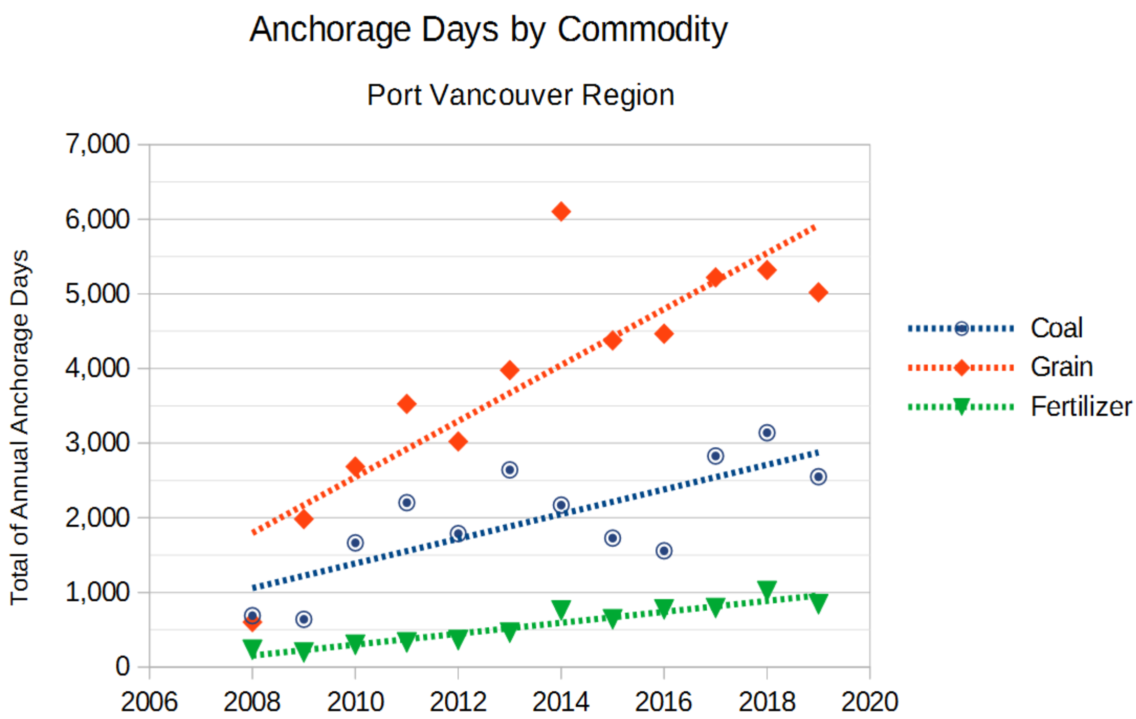

Fig. 7: Annual anchoring days by commodity, for Port of Vancouver Region. Grain shows the highest overall use of anchorages, although it is second to coal in export volumes (see Fig.2).

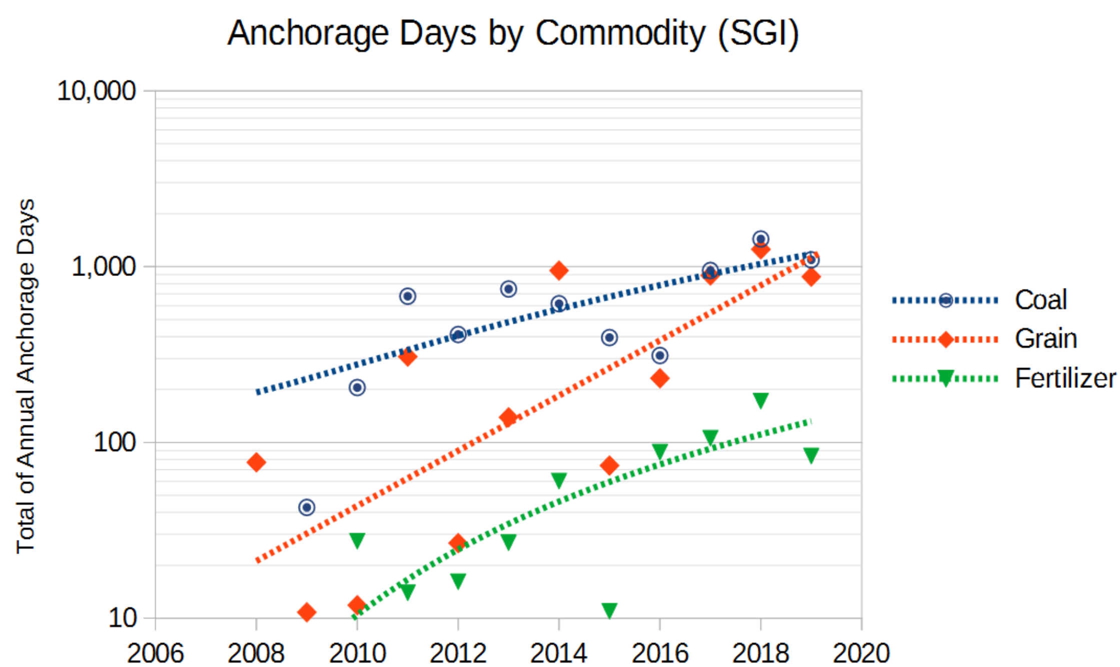

Fig. 8: Annual anchoring days by commodity, for overflow anchorages in SGI. Coal shows higher use of anchorages in the SGI than overall. The use by grain vessels, however, is growing very fast and has now reached comparable levels to those of coal bulkers. The scale of the y-axis is logarithmic because growth was exponential.

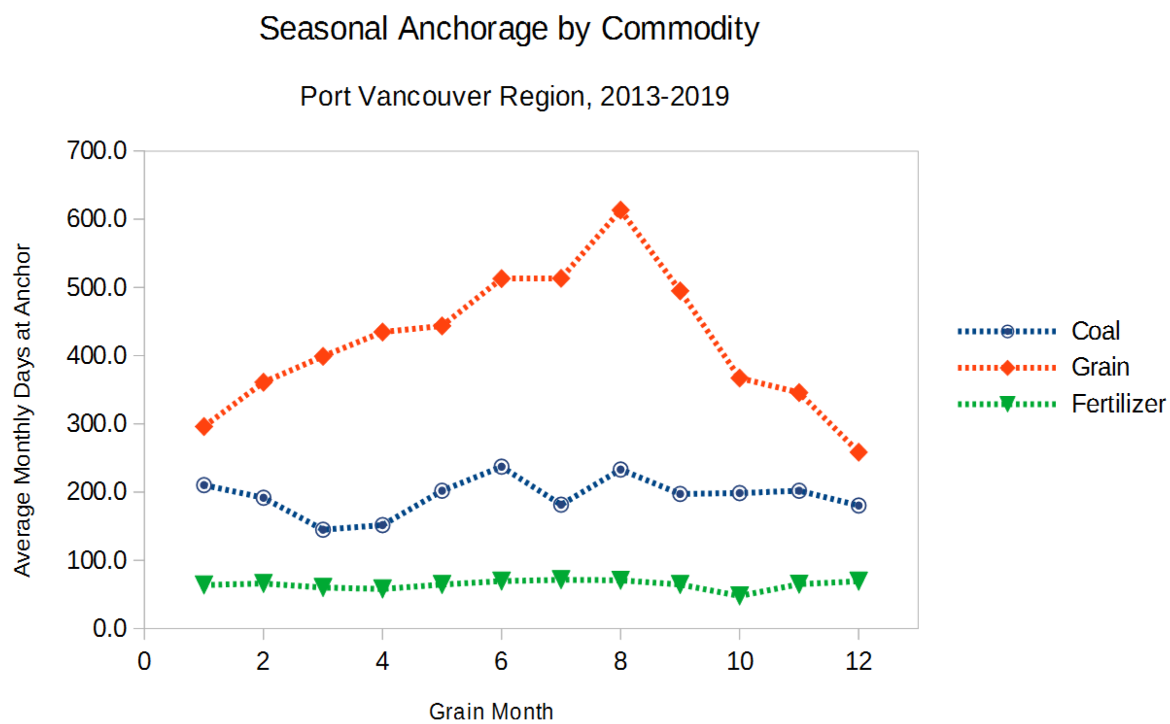

Fig 9: Seasonal variation in anchorage use by commodity for the Port Vancouver Region, 2013-2019 (grain years start with grain month 1 in August). Overall, grain required most anchorage use. Grain is more seasonal and creates bottlenecks of high traffic, on average peaking in late winter.

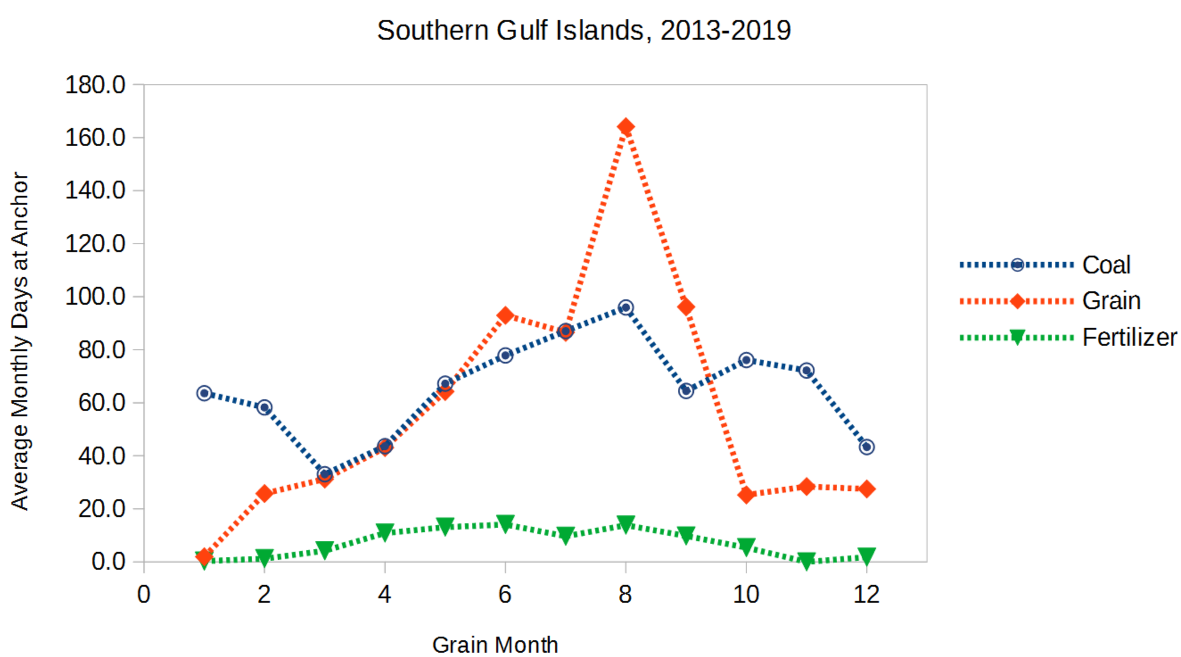

Fig. 10: Seasonal variation in anchorage use by commodity for the Southern Gulf Islands (grain years starts with grain month 1 in August). Grain is the most seasonal commodity but on average only exceeds the high anchorage use by coal in mid-late winter.

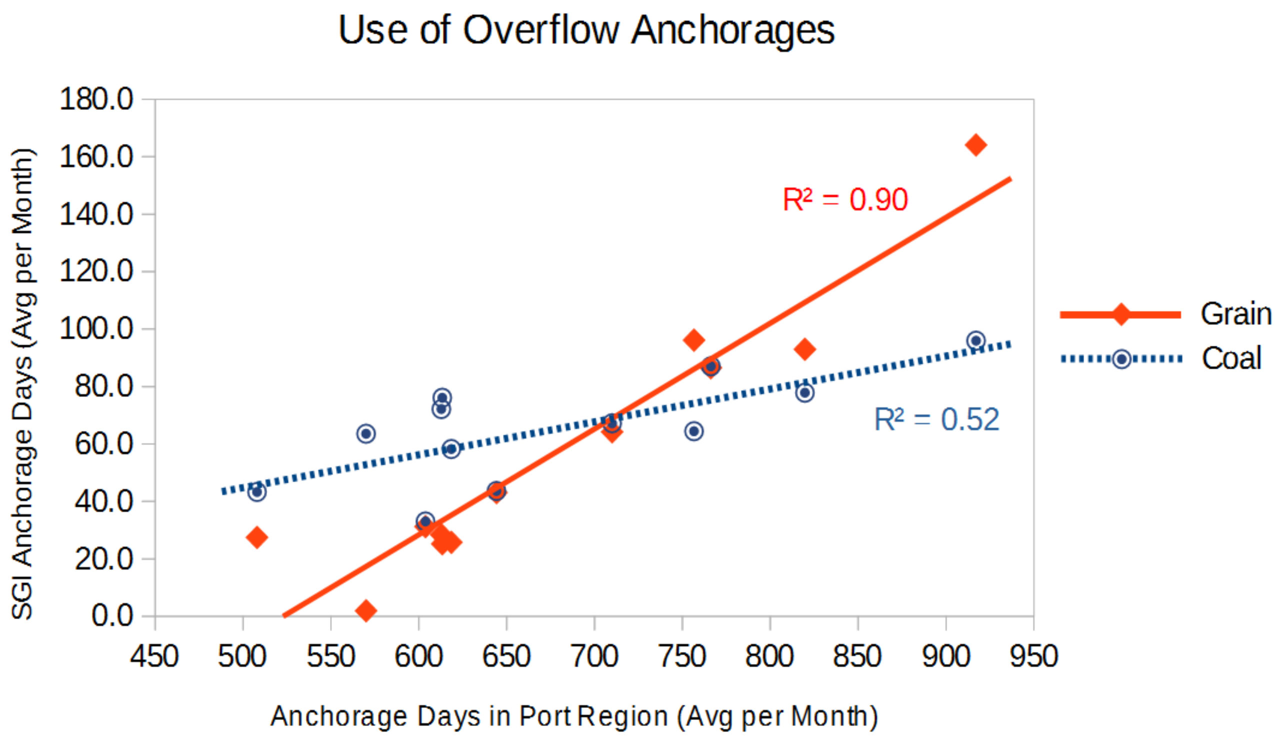

Fig. 11: Comparison of grain and coal bulk carriers in respect to how they use overflow anchorages near the Port of Vancouver. The number of overflow anchorage days increases more steeply for grain carriers as anchorage sites get filled up. Coal vessels have a flatter response, but they exceed grain carriers in the use of SGI anchorages when overall vessel traffic is low, suggesting their use may not be for overflow entirely.

This still leaves the question of why coal vessels are using overflow anchorages in the SGI more than expected. Another way of exploring the seasonal data of 'average anchorage use per month' is plotting the data for the overflow anchorages as a function of the data of the entire Port Region on the x-axis. This is shown in Fig. 11 and illustrates how overflow anchorages are being used while the entire Port Region is filling up more and more.

The resulting difference in Fig. 11 between grain and coal vessels is drastic. Grain bulkers use overflow anchorages only little when traffic is low, and then shift explosively to the SGI as anchorages fill up. In contrast, coal bulkers show a much flatter response in using overflow anchorages as port congestion increases.

Of particular interest is the situation with lower traffic, where the blue line for coal is clearly above the red line for grain, when grain ships have receded in their use of overflow anchorages but coal ships have not done so as much. This raises the question whether SGI anchorages are actually used as overflow by coal vessels, or whether coal terminals have included overflow anchorages into their regular operations even at conditions when other port anchorages are available. Some of the vessels appear to arrive 1-3 weeks early and are then placed directly into overflow anchorages for extended waiting periods.

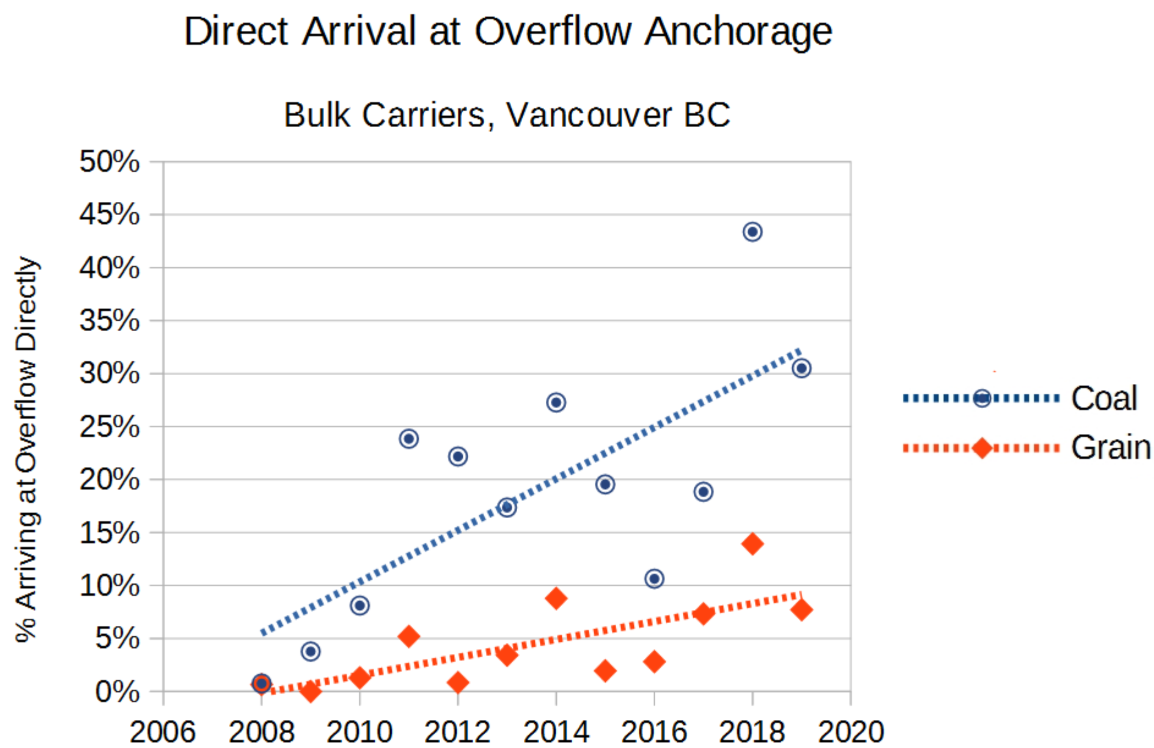

Fig. 12: Bulk Carriers sent directly to an anchorage at arrival: Proportion of vessels that are sent to overflow anchorages directly instead of first to port anchorages. Vessels for potash and other fertilizers had proportions of less than 5% of direct arrival at overflow anchorages and are not shown in this graph.

The importance of such observations was confirmed when testing this hypothesis with traffic data from PPA. Fig. 12 shows what happens to bulk carriers that arrive in the Port Region and are sent to an anchorage before berthing at a terminal. While the Interim Protocol[7] requires that vessels first arrive at port anchorages and are then transferred to overflow anchorages if they were not able to berth at a terminal within 7 days, the data suggests that other practices are in place.

During 2008-2010, only 0.7% of grain vessels and 5.1% of coal bulkers were sent directly to overflow anchorages. This proportion grew drastically over the years, with the highest year in 2018 showing 13.9% for grain, and 43.4% for coal.

It can be argued that all port anchorages were completely full every time when vessels were directly sent to overflow anchorages instead. While the responses to varying level of port congestion deserve further research, this argument fails to answer the question why coal bulkers get assigned 2-3 times more often directly to overflow anchorages compared to grain bulkers, which accounted for the majority of the overall anchorage use.

The data presented in Figs. 7-12 strongly suggest that overflow anchorages in the SGI have been used for regular operations of coal terminals even when traffic volumes at port are not extremely high.

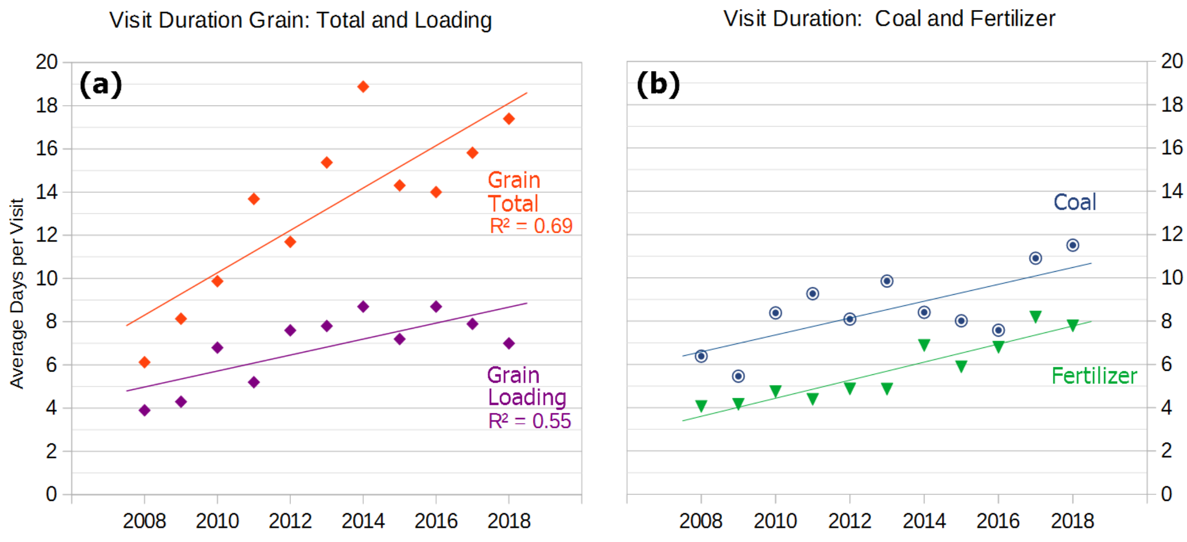

Fig. 13: Average days spent at port by bulk carriers for **(a)** grain and **(b)** coal and fertilizer. The increase of average total time per vessel visit is much steeper for grain than other commodities. Fig. 13(a) also shows the average time that is actually spent loading at terminals, which shows an increase that is more similar to other commodities, and suggests that the time waiting at anchor increased most for grain. (Data for average number of days at port calculated from PPA database, data for loading time of grain by Quorum.)

Measures of Efficiency: Vessel Time spent at Port and at Anchor

The time spent by vessels at port and related factors are critical for understanding the efficiency of commodity export, their supply chains, and the mechanics of port congestion.

The overall time spent at port by grain vessels increased drastically from an average of 6.1 days in 2008 to 17.4 days in 2018 (Fig. 13a). The increase of average visit duration at port was much flatter for vessels transporting coal and fertilizer (Fig. 13b).

This stronger increase in time spent at port for grain vessels appears to be caused by longer waiting times at anchor. When plotting the actual loading time as reported by Quorum in Fig. 13(a), a more moderate increase in average duration becomes apparent, which is similar to the other main commodities in Fig. 13(b).

The seasonal pattern in time spent at port in Fig. 14 confirms the longest durations for grain, with a pronounced peak building up over winter to early spring. This peak is very similar to the seasonal pattern described for anchorage demand in Fig. 9 and emphasizes that not only traffic numbers but also average waiting times before loading determine the amount of anchorage use.

There has been some concern about the extent of delays for vessels because of limited capacity for inspections. To examine this question, Fig. 14 compares two types of monthly data for grain.

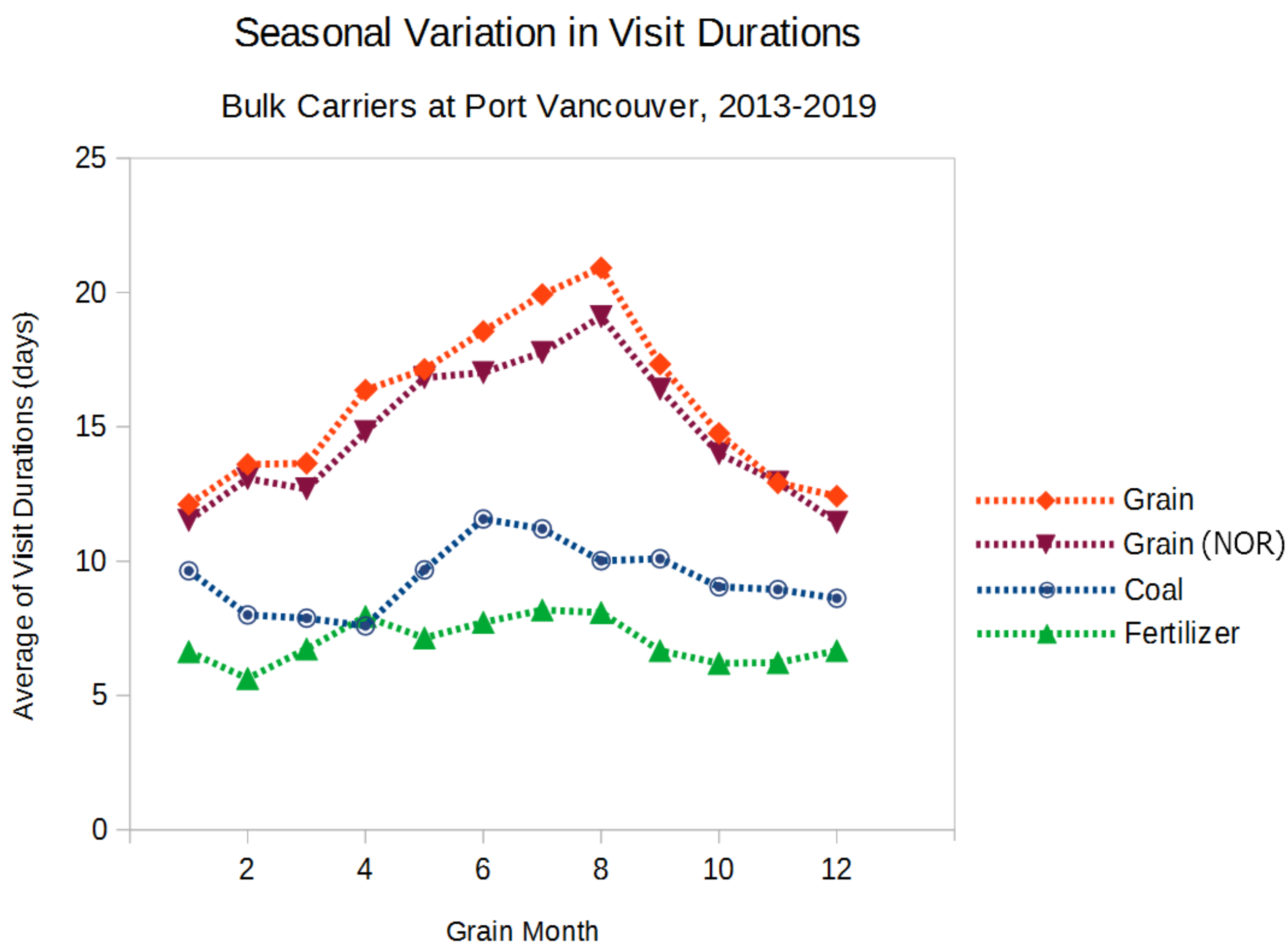

Fig. 14: Seasonal pattern in time spent by bulk carriers at the Port Region of Vancouver. Grain shows the longest durations, with a pronounced peak building up over winter to early spring This peak is very similar to the seasonal pattern described for the volume of anchorage use in Fig. 9 and emphasizes that not only traffic numbers but also average waiting times before loading determine the amount of anchorage demand. Grain data showing 'Total days at port' that start not at arrival but with the Notice Of Readiness to load ('NOR', as reported by Quorum) show a difference of 1-2 days that are needed for inspections.

The average number of days in Figs. 13-14 is based on PPA data and is defined by the time a vessel enters the inside waters of the Salish Sea and the Port Region Vancouver with the help of a pilot, until it departs again through the same gateway at the moment when the assisting pilot debarks.

In Fig. 14 the waiting times for grain vessels before loading was added. Quorum labels this data 'Total Days at Port', but it refers only to the time that starts after a vessel passed inspections, is issued a certificate of readiness to load, and then reports a Notice of Readiness (NOR). This is the start for the accounting of laytime with fees for early loading (dispatch) or late loading (demurrage).

Inspections are taking place between the time of arrival until a certificate of readiness is issued. Therefore, the difference between the two grain estimates after arrival and after 'NOR' in Fig. 14 reveals information amount the time that is required for inspections.

On average throughout a season, a minimum estimate for inspections was 1.0 days. February was the month with the longest delay of 2.2 days. This data suggests that ships are on average not arriving excessively early before planned schedules, because they fear a line up to get inspections done in time, or because they are anchoring for other purposes before requesting inspections.

The data confirms the pattern observed elsewhere, that vessels "rush to wait"[8], because a timely reporting of certificate of readiness is critical for vessels for receiving demurrage fees when terminals are not ready and loading is delayed.

There are two important aspects to consider. First, this described time between arrival and notice of readiness to load is a minimum estimate, because of the conservative way how it was measured (see Methods). Other factors may also have an influence on the accuracy of the estimate.

A second aspect is that the delay may appear small and can be discarded. All delays, however, are cumulative over time and need to be considered for optimizations where every hour of delay can count for maximizing throughput rates at terminals[9]. Also, consider that if the time at anchor can be reduced by only one day for the about 1,500 vessel arrivals in recent years, this will provide a reduction of 1,500 anchoring days per year or half of the entire annual overflow demand seen in recent years.

Waiting times at anchor show similar patterns to the average visit time, suggesting that time at anchor accounts for much of the total days necessary at port. Average days at anchor per vessel increased at the Port of Vancouver, and by the years 2018-19 reached 11.0 for grain, 8.0 for coal, and 3.9 for fertilizers.

These estimates were obtained for bulk carriers loading at Vancouver terminals and using anchorages in the entire region in the port vicinity. Because there is a 7-day time limit for anchorages at port[7], vessels with longer waiting periods are directed to overflow anchorages such as in the SGI. Anchorage durations measured within port limits only will underestimate the extent of the real situation.

Fig. 15(a) shows the time at anchor for bulk carriers that spent their entire visit within port limits. Using the same scale, this is compared to Fig. 15(b) that displays the total waiting time at anchor for vessels that were directed to overflow anchorages in the SGI at least once during their visit before they were loaded and could depart.

The difference is striking, with vessels that used overflow anchorages spending 2-3 times longer at anchor than vessels that were processed within port limits only. During the years 2018-19, the total average of days at anchor for vessels including trips to overflow sites were 20.5 days for grain, 9.5 days for coal, and 12.3 days for fertilizer. In contrast, ships processed within port limits showed much shorter waiting times at anchor of 9.5 days for grain, 5.0 days for coal, and 3.9 days for fertilizer.

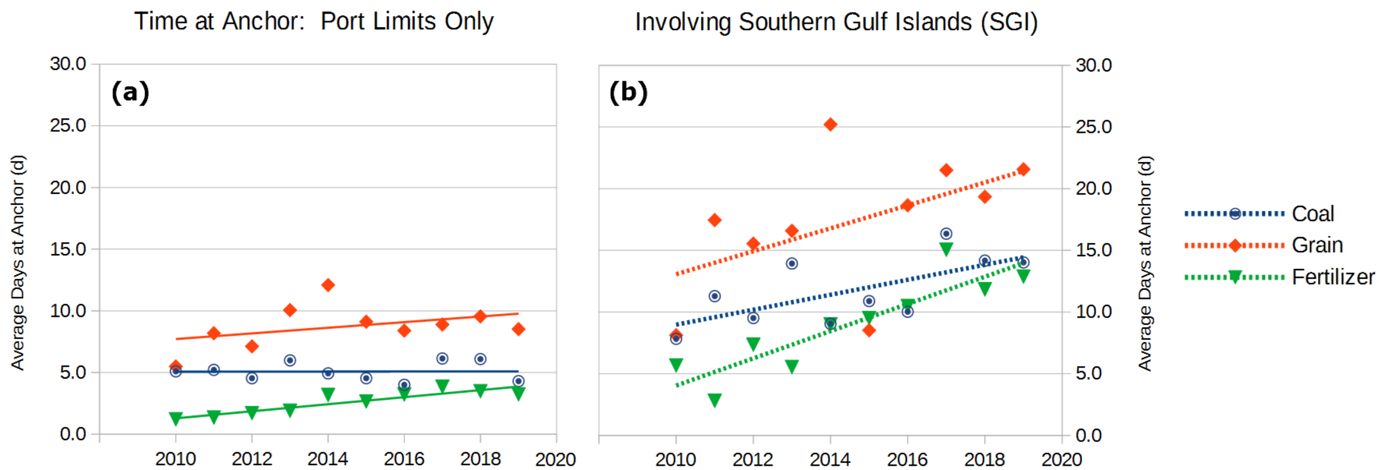

Fig. 15: Waiting time at anchor spent by bulk carriers at the Port of Vancouver: **(a)** Vessels that were processed within port limits only; **(b)** Vessels loading at Vancouver terminals that were directed to overflow anchorages outside port limits in the SGI at least once during their visit. Vessels that used overflow anchorages spent 2-3 times longer at anchor than vessels that were processed within port limits only. Growth in anchoring durations over years was steeper for vessels using overflow anchorages. (All average days per vessel at anchor included the entire visit until departed. 2008-2009 were not included because of sparse sample sizes for SGI.)

It is interesting to note that coal vessels did not increase their anchorage duration within port limits over the years. Their entire increase in anchorage time occurred in the SGI. This is consistent with observations made in Figs. 11-12, which suggest that even at lower traffic volumes a portion of coal vessels arrive earlier than average and are not being sent to port anchorages but directly into the SGI.

Mechanics of Port Congestion: The Importance of Vessel Arrival

A more mechanistic approach to understanding ship congestion at port is to explore how vessel numbers build up over a smaller time scale. For the supply chain of grain, some newer data is available at a weekly basis and includes information about numbers of vessels at port[3].

Overall, arriving vessels must be in balance with vessels that have been loaded and are departing. At certain times, imbalances can occur. Arriving vessels will accumulate when processing at terminals is slower. A cumulative number of arrivals can be calculated and carried over to the next week after adjusting for ships that were loaded and are cleared to depart.

Fig. 16 illustrates the relationship between such a calculation and the actual number of grain bulkers anchored in the Southern Gulf Islands. The figure demonstrates that the cumulative number of

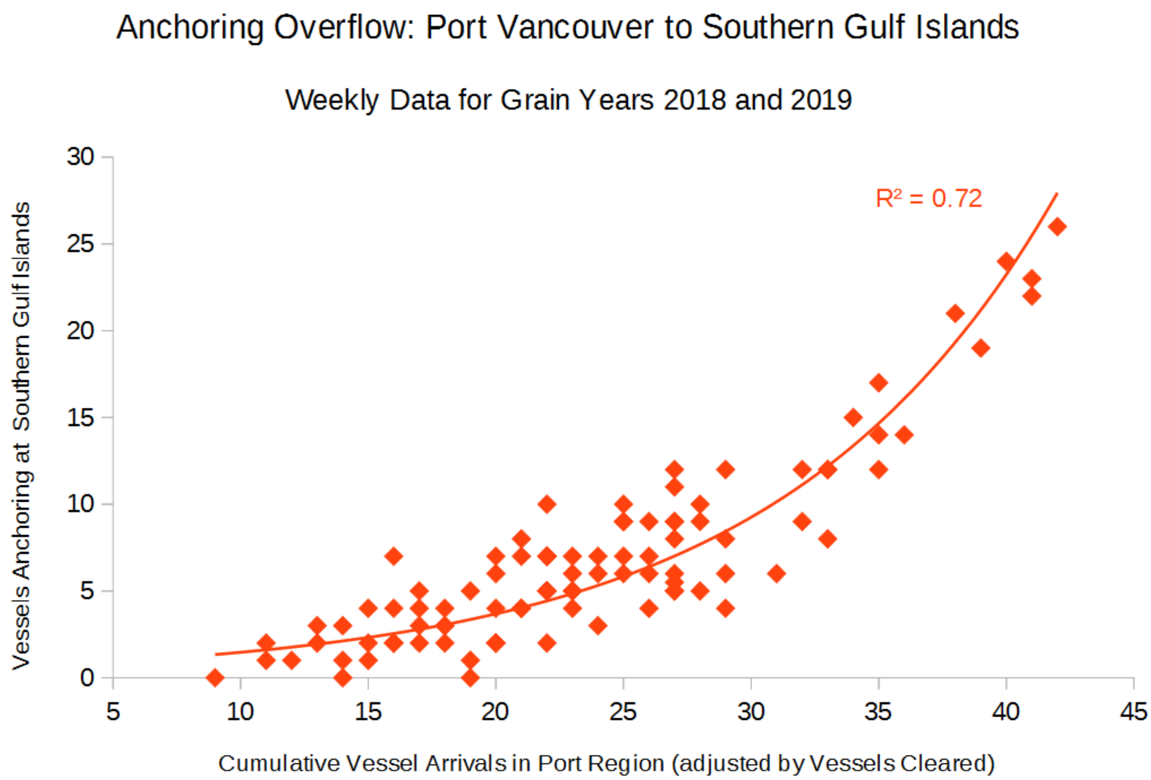

Fig. 16: Anchoring overflow from Port of Vancouver to Southern Gulf Islands (SGI), Aug 2018 to July 2020, based on weekly reports[3], bulk carriers for grain only. The cumulative number of adjusted vessel arrivals can be used to predict the number of ships counted in the SGI overflow anchorages using an exponential equation.

Table 2: Descriptive statistics of the weekly number of vessels that arrived and were processed (loaded and cleared to depart) at Port Vancouver, during the grain years 2018-19 (Aug 2018 – July 2020, bulk carriers for grain only). * = Variances significantly different at $p<0.05$ ($F=0.64$, $df=101$).

	Processed	**Arrived**
Average	**9.88**	**10.02**
Median	**10**	**10**
Variance*	**8.33**	**13.07**
N	**102**	**102**

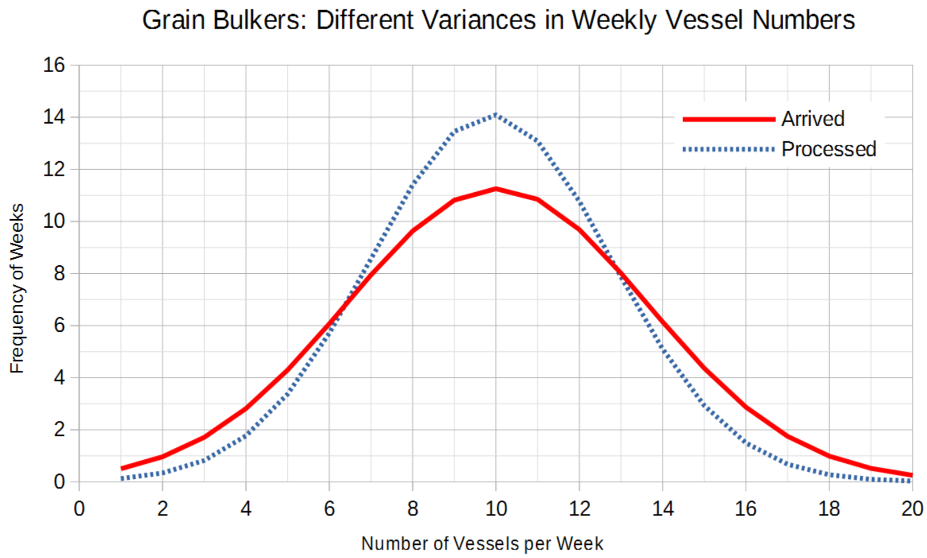

Fig. 17: Difference in variances of the distribution of weekly numbers of arrived and processed ships (grain bulk carriers during the grain years 2018-2019, normal distributions using the descriptive statistics in Tab. 2). Arriving vessels have a wider variance in numbers and are not ideally tracking the weekly capacity of loading vessels at port.

adjusted vessel arrivals can be used to predict the number of ships counted in the SGI overflow anchorages. As suggested by the results of comparing annual data in Fig. 4, the weekly numbers of anchored vessels counted in the SGI are an exponential response to a growing line-up in ship numbers waiting to load. This number can be predicted by applying an exponential equation based on cumulative vessel arrivals.

Of particular interest is the question of how the numbers of ships being loaded at terminals compare with the numbers of vessels arriving per week. Descriptive statistics are summarized in Table 2. The means are very similar, with 9.88 vessels per week processed and 10.02 vessels arriving per week.

A larger difference is apparent in the variances of weekly vessel numbers (Table 2). The variance of 8.33 for the number of ships being loaded at terminals is relatively narrow. The variance of 13.07 in the number of arriving ships is over 150% larger than the variance in the number of ships being processed. The difference is statistically significant at $p<0.05$ ($F=0.64$, $df=101$).

As a more informal explanation, variances describe how far the individual numbers tend to stray from the mean. The frequency distributions of weekly numbers of processed and arrived ships very much resemble a normal distribution. There is a weak negative skewness, meaning that the distribution leans slightly from the mean towards smaller numbers. This is understandable particularly for the number of ships loaded at terminals. Limitations in infrastructure prevent the loading of an excessively high number of vessels in a given week, while very low numbers are possible under difficult conditions. Despite such slight deviations, the frequency distributions are not statistically different from a typical normal distribution (Kolmogorov-Smirnov $D=0.11$, $p>0.1$).

Fig. 17 visualizes the difference in variances of the distribution of weekly numbers of arrived and processed ships. Arriving vessels have a wider variance in numbers and are not ideally tracking the weekly capacity of loading vessels at port.

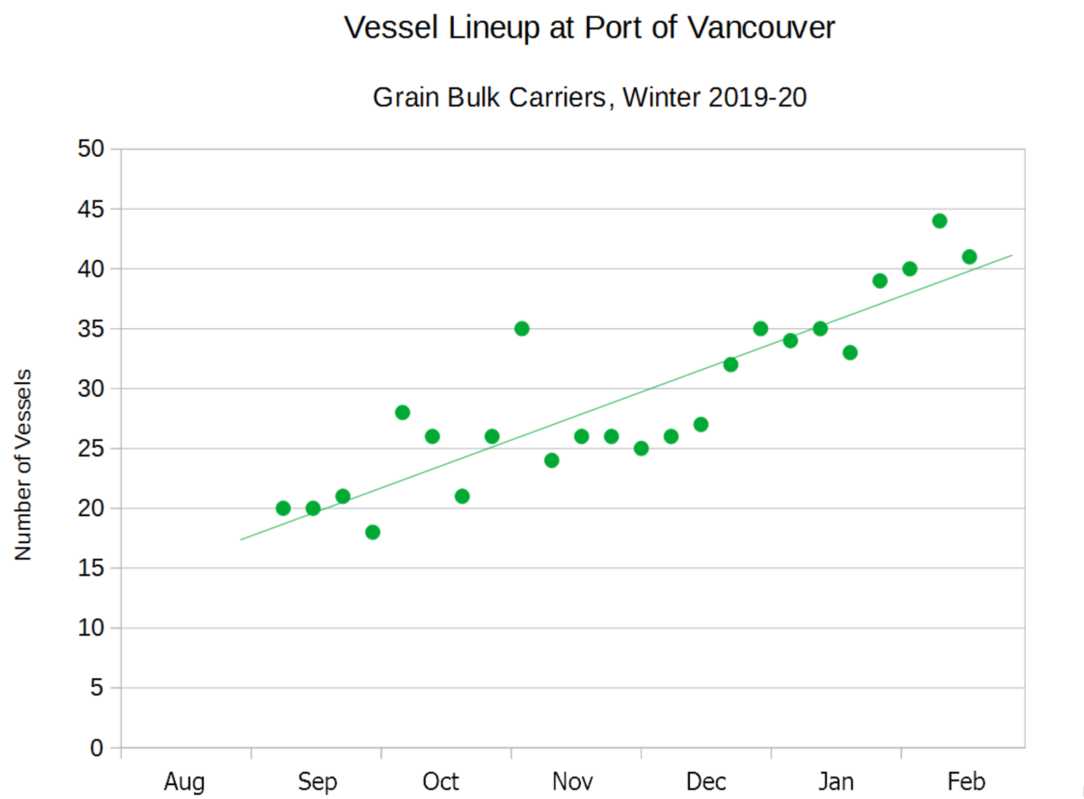

Fig. 18: Buildup in port congestion by bulk carriers waiting to be loaded at the Port of Vancouver, winter 2019-2020 (number of vessel lineup reported by Quorum). Delays in loading are cumulative and the lineup will increase unless active measures are taken to reduce the arrival of incoming vessels.

While some of these differences may appear small, it has to be kept in mind that any delays are cumulative. Waiting ships are carried over into the next and following weeks, and imbalances in the rates of arriving and processing can add up every week and it will take time to return to regular values.

An example of port congestion was observed in the winter months of 2019-20 (Fig. 18), when the vessel lineup waiting to be loaded increased to numbers that reached the capacity of available anchorage even in overflow destinations. Usually the causes for port congestion is seen in incidents such as strikes or disruptions of railway lines, and this interpretation is repeated by the media[10].

Fig. 18 shows that the vessel lineup increased cumulatively over winter, and is a property of the system at least as much as an effect of exceptional external events. Delays in loading are cumulative and the lineup will increase unless active measures are taken to reduce the arrival of incoming vessels when loading capacity is exceeded.

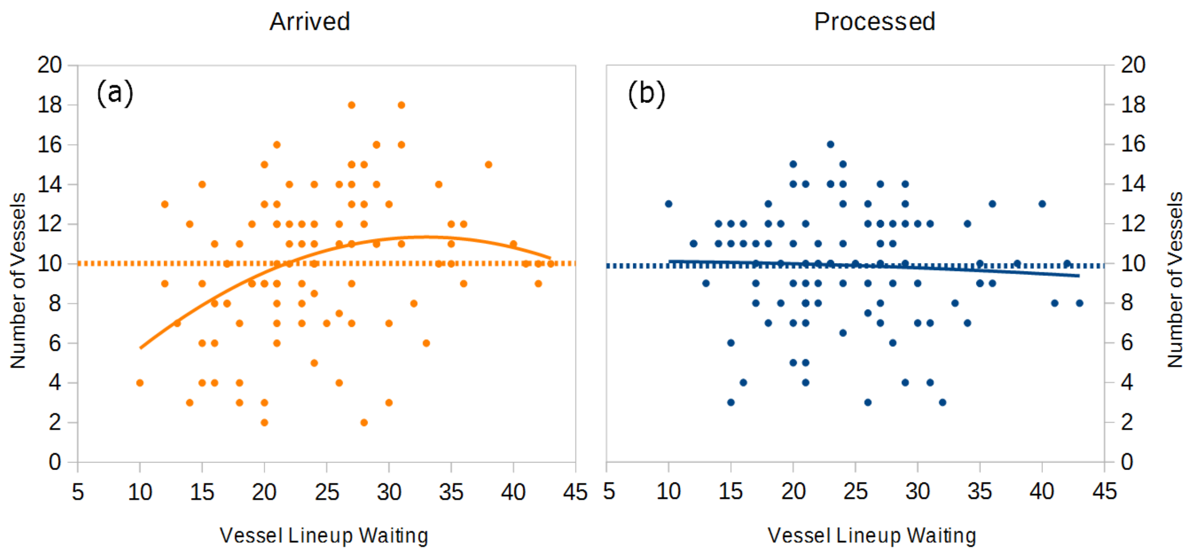

Fig. 19: Vessel arrivals are not tracking the capacity at port: **(a)** Vessel arrivals and **(b)** vessels processed at terminals, in response to increasing lineups of waiting ships at anchor. Data points are weekly numbers of grain bulk carriers at the Port of Vancouver, for the grain years 2018-19 and 2019-2020, with fitted polynomial solid lines. Average numbers are displayed with a dotted level. Arrivals increase with growing congestion, but despite some flattening of the curve they stay higher than the number of ships that can be processed in an average week. An efficient feedback mechanism slowing down the input of new arrivals would show a strongly negative trend below the dotted line in weeks with larger lineup and port congestion.

Feedback loops can prevent deviations from the normal state in a balanced system, both in engineered and natural systems. Negative feedback describes a decreasing input into a system when growing numbers are exceeding a desired value. The question is to what degree vessel arrivals are compensating for variance in loading capacity at port. In order to avoid port congestion, vessel arrivals should decrease when loading capacity at terminals is lower and drives ship numbers up, whereas Fig. 19 demonstrates that the pattern of weekly vessel arrivals does not track the processing capacity at port.

When vessel arrivals are plotted in response to increasing lineups of waiting ships at port, Fig. 19(a) reveals a lack of efficient negative feedback. The fitted line representing the number of arriving vessels rises and crosses the dotted line of the mean, and despite some flattening it stays higher than the number of ships that can be processed on average. This lack of adjustment will lead to further port congestion.

In contrast, with negative feedback, the rising line should drop below this average number of vessels that can be processed per week. This is not the case. Note that in Fig. 19(a) the majority of weeks during port congestion on the right side of the graph show arrival numbers that are not falling below the dotted average (about 10 vessels can be processed in an average week).

The number of processed vessels at terminals in Fig. 19(b) has no strong connection with vessel lineup and is largely dependent on other factors in the supply chain.

Simplified Model: Avoidance of Port Congestion

A simplified balance model can be used for a very basic sensitivity analysis of the major components driving port congestion. This approach is only meant to reveal how components work in principle. A more refined system would be required for specific commercial applications in real life.

Weekly data was used from August 2018 to February 2020. A simplified model using data on vessels 'arrived' and 'processed' (loaded and cleared for departure) was used to estimate the vessel lineup at port in Fig. 20. The simulated numbers were close to the actual counts in recorded data. Regression of the points predicts the observed values with a coefficient of determination $R^2 = 0.95$.

For evaluating the basic response to different conditions, some of the components can be altered to simulate different scenarios.

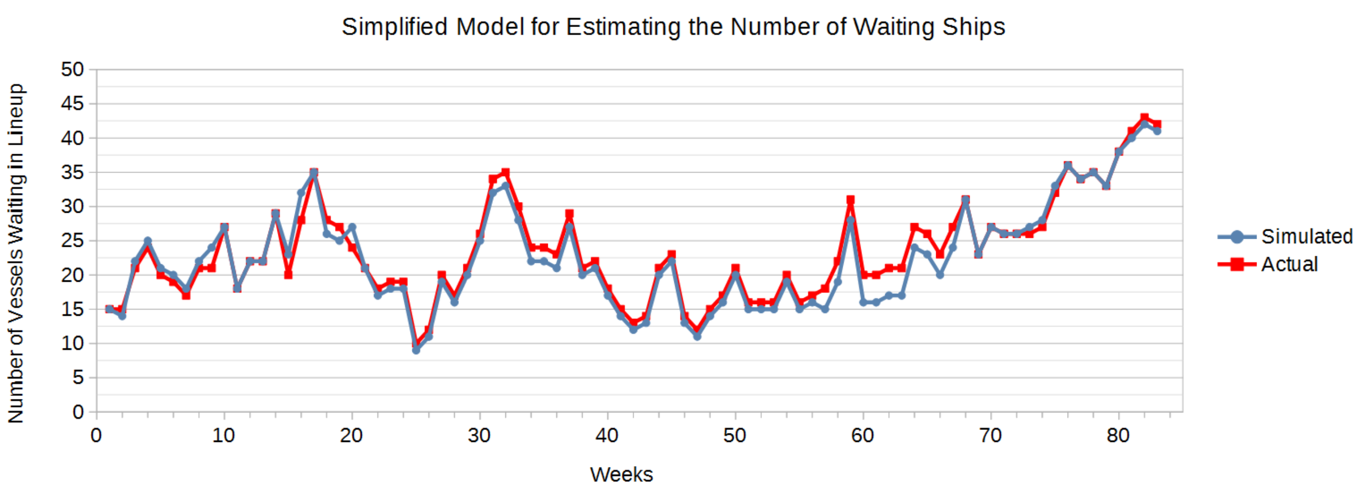

Fig. 20: Lineup of grain bulk carriers at the Port of Vancouver (Aug-2018 to Feb-2020). A simplified model using data on vessels 'arrived' and 'processed' (loaded and cleared for departure) can be used to estimate the vessel lineup at port. The simulated numbers (blue) are close to the actual counts (red). Regression predicts the observed values with a coefficient of determination $R^2 = 0.95$.

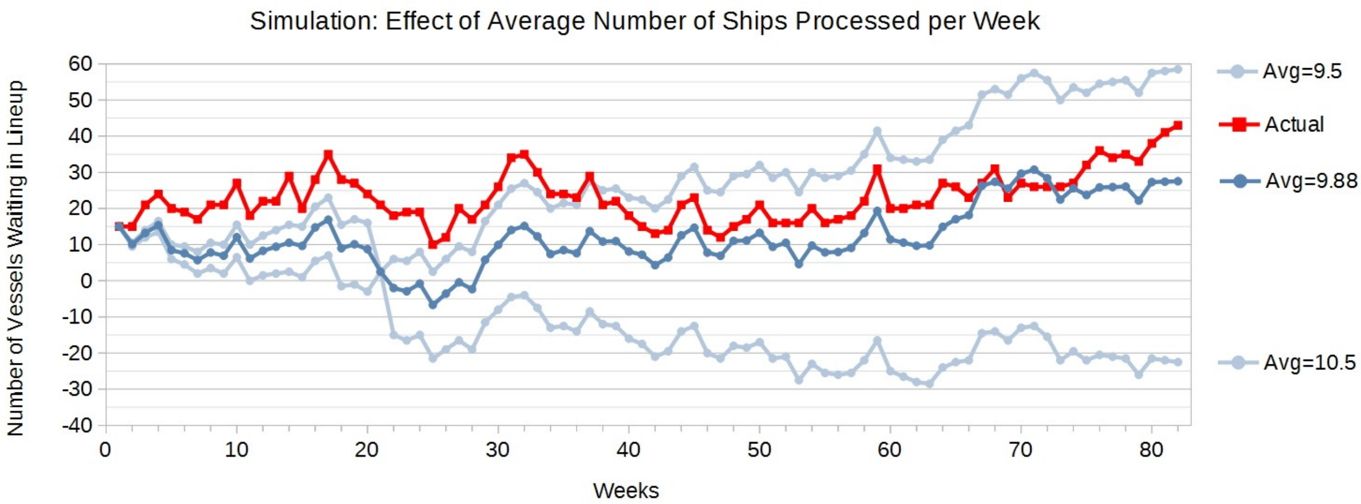

Fig. 21: Scenarios with simulated processing rates at terminals compared to the actual vessel lineup (red) of grain bulk carriers at the Port of Vancouver (Aug-2018 to Feb-2020). Applying the average number of processed vessels per week of 9.88 as a constant for all weeks (dark blue) reduced the vessel lineup but not as much at later stages. Vessel lineups are sensitive to changes in processing rates at terminals (light blue), but improvements in levels and variance of processing rates at terminals can be difficult to achieve and may come with a very high price tag.

The problem of a large number of bulk freighters waiting to load in Vancouver has traditionally been approached with efforts to improve the supply chain and loading capacity at terminals. One objective can be minimizing the variance in the number of vessels that can be loaded from week to week. Fig. 21 shows the actual lineup over time as a red line. A darker blue line shows what would have happened assuming the average capacity of 9.88 vessels loaded was constant for every week, with vessels arriving according to actual data. The results are an improvement with shorter lineups, but even with constant capacity there still would have been high numbers of waiting ships towards the end of the study period.

The light blue lines in Fig. 22 show that the lineups are very sensitive to changes in average terminal capacity, with lower values causing steadily accumulating lineups, and higher capacity leading to falling traffic numbers (and below zero freeing space for additional arrivals).

The practical question with altering processing time, however, is how feasible it is to achieve constant throughput rates, and what price tag is associated with improving infrastructure. Even for best managed supply chains there can be temporary delays due to weather and other unforeseen circumstances, and there are practical limits to investing millions of dollars by industry and taxpayers.

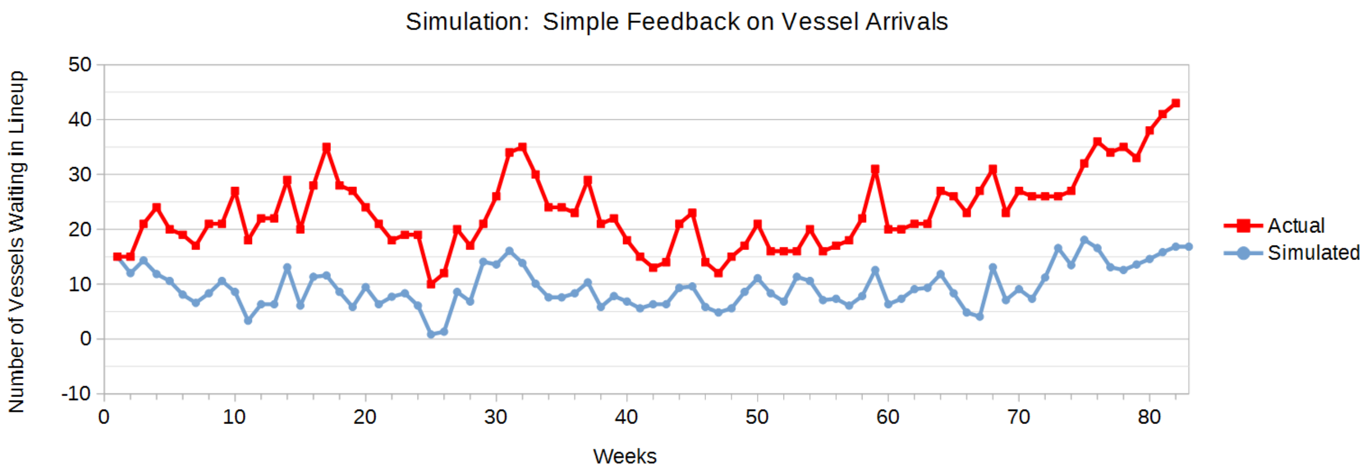

Fig. 22: Simulation of a feedback mechanism in a simplified Vessel Arrival System (VAS, blue), compared to the actual vessel lineup (red) of grain bulk carriers at the Port of Vancouver (Aug-2018 to Feb-2020). A stabilizing effect avoiding port congestion was observed when vessel arrivals tracked loading rates at terminals more closely.

Adjusting arrival rates of vessels, on the other hand, is not as dependent on infrastructure and requires much lower investments for effective results. Fig. 22 demonstrates that introducing a feedback mechanism into arrival rates is a possible avenue to reduce lineups of waiting ships at anchor and avoid port congestion. The mechanism applied was a simple algorithm that used the number of processed vessels of the past two weeks and averaged it with the number of expected arrivals for this week, in order to calculate a new number of arrivals that can be admitted. A stabilizing effect was observed when vessel arrivals tracked current loading rates at terminals more closely.

While this example is a simplified model, a realistic Vessel Arrival System (VAS) can be built with formats of feedback mechanisms that are similar in principle (and include additional parameters of delays at various positions in supply chains) to work in an applied and commercial day-to-day situation.

While numbers of arriving vessels can easily be adjusted in a model, there is more work involved in real life situations to plan the timing and positions of vessels that are contracted for loading cargo at port. Some flexibility in selecting time windows for export contracts and for adjusting the speed of approaching vessels are required. The question of practical consequences and solutions will be addressed in the next section.

DISCUSSION AND CONCLUSIONS

VESSEL ARRIVAL SYSTEMS (VAS): REDUCING ENVIRONMENTAL AND ECONOMIC COSTS

Characteristics and Performance of Vessel Arrival Systems (VAS)

Concerns about efficiency and greenhouse gas emissions have put increasing emphasis on monitoring ships earlier when approaching port, guiding vessels for just-in-time (JIT) arrivals, and applying slow steaming to conserve fuel and reduce pollution and wasted time[11,12,13,14]. Most progress has been made with JIT for container ships, but Vessel Arrival Systems (VAS) have also been applied to bulk exports[15].

In Newcastle NSW, Australia, a VAS was implemented in 2010 and showed drastic improvements in performance (Table 3). Frequent port congestion with dozens of vessels waiting at anchor have become a thing of the past[16]. The plan called for a limitation of 48 hrs at anchor. The percentage of anchoring vessels fell from a high proportion to only 36% in 2017-19. For these vessels, the duration at anchor fell to 3 days, or less than 30% of the situation before 2010. Therefore, the overall average for all vessels arriving at port was 1.1 days at anchor.

Different commodities and specific characteristics of supply chains will require adaptations in VAS used at different ports. For more complex supply chains, where export contracts can predate the delivery at port by several months, an acute awareness of time scale for corresponding feedback mechanisms and adjusting actions is necessary.

For example, a complex supply chain such as grain for Vancouver, may require a system addressing three fundamentally different time scales:

(a) Short-term Time Scale (Days to Weeks): Synchronizing vessel arrivals with most current predictions for loading at terminal can be achieved with a JIT-type system that ensures a virtual Notice of Readiness (NOR) so that vessels can maintain their positions in a lineup without requiring an actual arrival at port. The Port of Newcastle requires that vessels report and enter the system 15 days before arrival[17]. The Port of Vancouver currently requires that vessels report only 48 hrs before anticipated arrival[18].

(b) Medium-term Time Scale (Weeks to Months): To avoid port congestion and the associated problems, time windows of export contracts should not be selected independently of the current and predicted performance at terminal. Some type of information system needs to be connected to terminal performance and vessel lineup, and use current and anticipated conditions in the supply chain to predict what time windows can be selected for export contracts. Unless time windows for delivery of new contracts are delayed when vessel arrivals overwhelm terminal performance, port congestion cannot be avoided and processing of lineups will take excessive amounts of time to return to normal conditions. It may even be necessary to not only adjust time windows for new contracts, but use special clauses for existing contracts to maintain flexibility and the ability to fine-tune delivery dates that allow just-in-time arrival of vessels at port.

(c) Long-term Time Scale (Months to Years): One important lesson for the successful implementation of VAS in Newcastle called for the ‘shifting of expectations’ by both sellers and buyers[15]. This meant applying more realistic throughput values for planning rather than assuming that terminals can always work at maximum capacity. Seasonal delays and average frequency of external factors disrupting the supply chain are not entirely unknown. They can be estimated from previous years, and optimizations can provide realistic procedures for the scheduling of exports and avoid the pitfall of ‘overbooking’. This will create a more reliable and predictable business environment that will benefit both sellers and buyers.

In summary, it should be noted that none of these measures will reduce the actual productivity and export numbers at port. Improvements are only directed at synchronizing arrivals with deliveries, and therefore enhance efficiency, profitability, waste, and negative effects on the environment.

Reducing Economic Costs

It is a persistent myth in the public and with some policy makers that a large number of ships anchored near port are a necessity and a sign of a good economy. In fact, the opposite is true[15]. Waiting time at anchor is unproductive time wasted, produces avoidable pollution, and costs the Canadian economy in late fees that have to be paid as penalties in export contracts.

The amount of time vessels spend waiting at port is reflected in dispatch earnings (early delivery) or demurrage costs (late delivery), and is often considered a monetary indication of how efficiently grain is flowing through Canadian ports[4]. Perhaps more accurately, it should be considered a measure of how well vessel arrivals are synchronized with expected deliveries at port.

In recent years, the economic losses due to ships waiting for deliveries have become consistently high. For the crop year 2018-19, the losses at the Pacific Seaboard (Vancouver and Prince Rupert) reached $28.2 million. These costs are reducing the income of farmers in the Prairie Provinces.

Fig. 23 shows how these economic losses increase with longer average duration that vessels spend at port, with data from the years 2008-2019. A regression line with R^2=0.94 fits the relationship well, and the equation can be used for predictive purposes.

Some economic consequences of growing port congestion are illustrated in Fig. 24. Increasing numbers of ships lined up at anchor will add to the individual waiting time of each vessel, and will cumulatively increase the overall waiting times and economic losses. The economic cost was calculated by using the linear regression from Fig. 23. Annual economic losses on the y-axis can be predicted by a given average annual number of vessels in the lineup on the x-axis. This demonstrates future financial costs of inaction, if vessel arrivals are not better synchronized to deliveries, and port congestion is allowed to escalate.
The following sections address other costs that are not included in these economic costs. The total economic costs are much higher if all actual costs are included. For example, excessive air pollution burdens public health by increasing morbidity and premature mortality from cardiovascular and pulmonary diseases (e.g. asthma and COVID-19), and other environmental damages are causing economic costs associated with climate warming and disrupted ecosystem function, as well as costs to other local economies that are based on natural landscapes and resources.

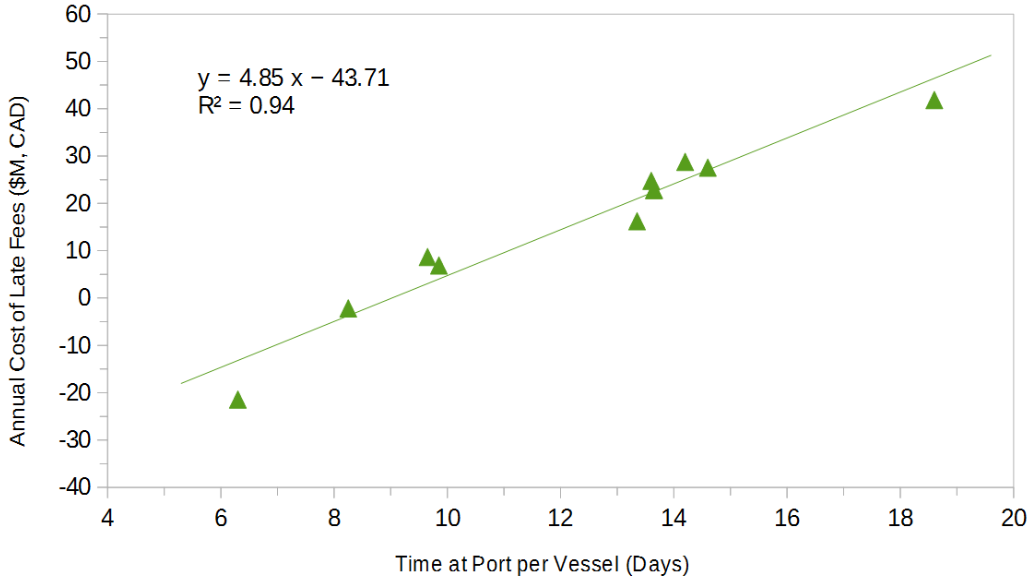

Fig. 23: Economic cost of waiting time by grain bulk carriers at Vancouver and Prince Rupert, for the crop years 2008-09 to 2018-19 (time from Notice of Readiness until loaded and cleared to depart).

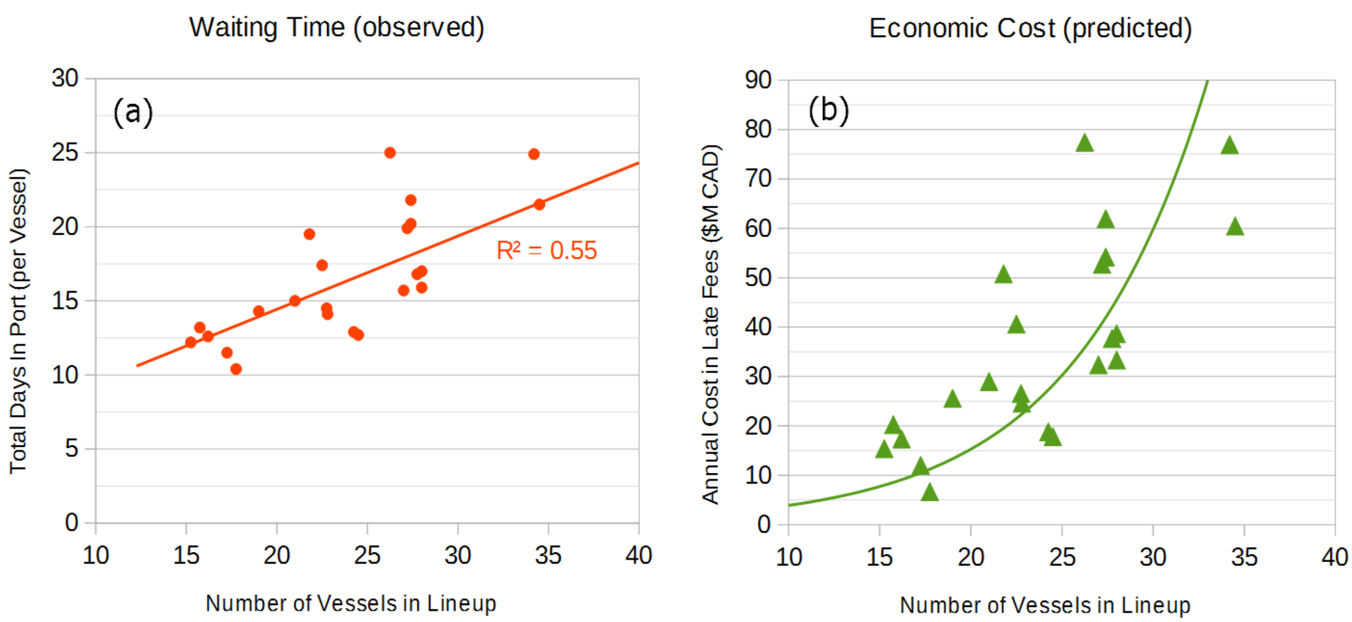

Fig. 24: Consequences of vessel congestion on **(a)** processing time at port, **(b)** economic cost by accumulation of demurrage fees (grain bulk carriers in Vancouver BC, based on monthly data for the grain years 2018-19 and 2019-20). The number of vessels in the lineup are monthly averages from weekly data. Total days in port were reported monthly averages and include the entire port region. The economic cost was calculated by using the linear regression from Fig. 23. Annual economic losses on the y-axis can be predicted by a given average annual number of vessels in the lineup on the x-axis.

Reducing Air Pollution and Greenhouse Gas Emissions

Other consequences of port congestion are elevated air pollution and greenhouse gas emissions. Despite efforts by the shipping industry, vessel emissions are still a problem for public health[19], ocean acidification[20], and climate warming[21]. Projected emissions of this sector are falling short of meeting international agreements to limit climate change, and unless premature scrapping of current ships is undertaken, a combination of slow speeds, operational and technical efficiency measures are necessary[21].

The 2015 Emissions Inventory by the Port of Vancouver[22] found that dry bulk carriers are the highest marine source of air pollution at the Port of Vancouver[5]. Thirty-eight percent of these greenhouse gas emissions were from ships at anchor, and 29% from ships at berth. Thus a total of 67% of greenhouse gas emissions originate from 'idling' ships that are stationary and use auxiliary engines (generators) and boilers. Only 33% of greenhouse gas emissions were from moving vessels, and many of these movements were from and to anchorages, within port or overflow at more remote locations in the SGI.

Emissions at berth could almost be eliminated if shore-to-ship power was implemented. The same technology could be supplied to extended moorage opportunities within the port to replace engine use at anchor.

An easier solution to considerably reducing emissions at anchor is a better integration of the maritime component into the supply chain by applying a VAS[12,13]. At the Port of Newcastle, a plan of limiting anchorage duration of each vessel to 48 hrs or 2 days was achieved (Table 3). If we use the same standard and apply it to the number of vessel arrivals of the years 2018-19 in Vancouver, and apply an average of 10 tonnes of greenhouse gases per day and vessel[23], the calculation results in 59,450 tonnes of greenhouse gases that could have been saved per year.

In addition, further fuel and emissions savings would come from reduced movements to and from anchorages, and from slow steaming of vessels approaching the port for just-in-time arrival[24].

The calculated emissions savings are only an approximation, and depend on the targeted limit for time at anchor. Some parameters will depend on the commodity and the specifics of a supply chain. Newcastle started out with 11.1 days at anchor for coal, while in Vancouver the situation is 8.0 days for coal and 11.0 days for grain (Table 3). The performance of a VAS in Vancouver may not have identical parameters to Newcastle but the same principles apply. While the reduction in greenhouse gases may not be exactly 60,000 tonnes per year, the approximation still demonstrates that savings can be massive, and that the current lack of better integration of the maritime component in supply chains is a missed opportunity of substantial scale for climate action at the Port of Vancouver.

Table. 3: Performance characteristics in relation to the implementation of a Vessel Arrival System (VAS) for bulk exports, a comparison of parameters from Newcastle NSW, Australia and Vancouver BC, Canada. Newcastle implemented a VAS in 2010 for coal[1][11] ('before' data from 2009 with % anchoring inferred from duration at anchor, 'after' data 2017-19). Implementation of a VAS for Vancouver is under consideration ('before' data 2018-19, calculated from PPA database for coal[1] and grain[2], 'after' data currently not realized).

Effect of Vessel Arrival System (VAS)

% Anchoring	Before	After
Newcastle	>90%	36%
Vancouver	95%	-

Days at Anchor	Before	After
Newcastle	11.1[1]	3
Vancouver	8.0[1]-11.0[2]	-

Protection of Areas with Unique Values

Anchoring bulk carriers can have a multitude of substantial negative effects on the environment, as summarized in Appendix3. These effects are particularly damaging in rare ecosystems and landscapes of high conservation value.

The Southern Gulf Islands (SGI) in Canada, along with the adjacent San Juan Islands in the United States, have long been recognized as rare and special places, with intertwined terrestrial and marine landscapes of high biodiversity, ecological and recreational values, and a unique character and economy that is based on tourism and visitors from throughout the world wishing to experience the natural uniqueness of this well preserved area.

In 1974, the Province of BC established a unique governance of the Gulf Islands with the 'Islands Trust Act', with the mandate to restrict development and 'Preserve and Protect' this group of islands. Almost 50 years of effort have been invested into this purpose. Official local community bylaws are in place that are well respected and require sacrifices by the local population to achieve the objective of protecting and preserving the natural character of these islands.

Given the uniqueness and significance of the area, applying for a designation as a UNESCO Biosphere Reserve has been considered.

These islands are also the ancestral territory of several First Nations (including the First Nation with the largest population in British Columbia), and land and water are still under treaty negotiations.

Allowing the expansion of overflow anchorages into such a sensitive area was an unfortunate choice that incited conflicts that require a solution. Regarding the legal situation, according to Transport Canada, 'These anchorages were established under a former system of public ports that no longer exists.'[66] Transport Canada is temporarily allowing the continuation under a Minister's 'Interim Protocol' which contains rules for mitigation of noise and light pollution that are voluntary for vessels[7]. Local residents say the system is ineffective, and thousands of letters were sent to federal ministers asking to phase out the use of these islands as commercial freighter anchorages[67]. Local governments made the same request[68], and some newspapers labelled the topic an election issue.

The Province of BC recognizes the area as a low ventilation zone and issues advisories for air quality to protect public health in the islands[69]. As part of the COVID-19 emergency measures, the province ordered a complete shutdown of any open fires in this area to reduce air pollutants that will cause complications with respiratory diseases. At the same time, vessel lineups expanded under federal jurisdiction and were sent into the exact same area, exposing residents to tonnes of pollutants that are emitted by anchored bulk carriers on a daily basis.

Transport Canada ignores the special status of the Southern Gulf Islands and only refers to them as 'South Coast' or 'Anchorages in Southern BC.'[7] The federal Minister of Transport stated that given the importance of the Pacific Gateway with the Port of Vancouver, there are no plans to eliminate anchorages[70]. In fact, it appears that the federal plans for a National Marine Conservation Area (NMCA) that has been in development for over 20 years, will enforce the use of the islands for industrial purposes such as commercial anchorage sites. Despite the obvious national importance of the Southern Gulf Islands, the federal plan is to break up the provincial mandate of 'Preserve and Protect' and designate only small protected areas, while the majority of the archipelago will be opened for multiple use that includes all industrialization except the drilling for fossil fuels and mining of the seabed[71,72].

Among other commitments, this directly contradicts the following: The pledge to protect 25% of Canada's Oceans[73] and "make Canada's major ports among the cleanest and most efficient in the world"[74] , "for the Port of Vancouver to be the world's most sustainable port"[75], the Mandate Letter regarding Climate Change to the federal Minister of Environment[76], and the promise by the federal Minister of Transport "to reduce marine traffic congestion"[77].

Are the Southern Gulf Islands really essential to the success of port operations in Vancouver? Several alternatives exist. Instead of pursuing divisive policies, a practical solution exists with VAS to improve efficiency at port and better integrate the maritime component into supply chains.

Applying a VAS with performance standards similar to the Port of Newcastle would mean that vessel arrivals will be better synchronized with deliveries of bulk exports and require only 48 hrs at anchor. Assuming vessel numbers of 2018-19 and a current number of 31 port anchorages in Vancouver, an estimate shows that implementing a VAS would require an occupation of only 25.3% of anchorage capacity within port limits for an average day of operations. Of course, this is only an approximation, and exact values for Vancouver would depend on the specific characteristics of the implemented VAS.

A scenario for a Vancouver VAS with only 75% of the efficiency of the Newcastle VAS indicates that only half of the port anchorages would be used on average. A scenario with a low efficiency of only 40% compared to the Newcastle VAS would still make port anchorages sufficient for anchorage demand on average.

A scenario can also be based on reduction of anchorage demand that would be necessary to phase out the use of overflow anchoring in the Southern Gulf Islands, which reached approximately 3,000 days in recent years. This amount could be offset entirely if the approximately 1,500 annual bulk carrier arrivals in recent years spent 2 days less at anchor for each visit, or in other words, if the stays at anchor could be reduced by 20-25% in duration.

Such scenarios are simplified and address average values without variances, but they demonstrate that increasing efficiency with better synchronization of vessel arrivals can bring advantages with significant reductions in anchorage demand.

In conclusion, by implementing a VAS with good performance standards, it will be possible to limit anchorage demand and avoid the use of overflow anchorages in the SGI. The existence of such alternatives raises the question not only if it would be reasonable for the federal government to override lower jurisdictions by industrializing the SGI, but also if it would be constitutional.

Marine Safety and Reduced Risk of Accidents

In February 2020, the Port of Vancouver released a call for proposals for a feasibility study for 'Active Vessel Traffic Management'[78]. This approach is directed primarily at 'Traffic Control Zones' within port limits, and does not explicitly address the problem of synchronizing vessel arrivals with bulk exports through a VAS.

While a national Vessel Traffic Management Information System is already in existence and operated by the Coast Guard, additional components may be required for enhanced marine safety in critical areas, with VAS being one of them.

The expansion of the Trans Mountain pipeline will bring a higher traffic volume of vessels transporting petroleum products from Vancouver through Haro Strait to the Pacific Ocean, and will increase port traffic by about 14%[79,80]. The potential risk of oil and fuel spills requires a variety of proactive measures, including safety systems to avoid traffic collisions.

Bulk carriers consist of about half of the vessel arrivals to the Port of Vancouver[2], but their proportion in traffic is significantly higher because of additional movements from and to anchorages.

Implementing a VAS would not only increase the efficiency at port but significantly reduce vessel movements from and to anchorages, and therefore reduce the probability of encounters and potential collisions with vessels carrying petroleum products.

Avoidable movements to overflow anchoring in the SGI could be eliminated. This would not only increase marine safety in the narrow waterways between the islands due to vessel collisions or accidents arising from other causes (e.g. dragging of anchors). Because vessels from or to the SGI will intersect with the main traffic route in Haro Strait, reducing any avoidable movements will improve marine safety and contribute to the prevention of oil and fuel spills.

In addition, Haro Strait is part of critical habitat for the endangered Southern Resident Killer Whale Population (SRKW). Integrating a VAS may become a necessary component in the efforts to safeguard the survival of the endangered population.

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APPENDIX 1: DEFINITIONS

Arrival	The event of a vessel arriving at port or in the port region (vessel arrivals describe the number of vessels arriving in a certain time period)
Arrived	In connection with Processed, means a vessel that has given NOR, or a number of vessels that have given NOR within a certain time period
Brotchie (Sea)	Location name used by the PPA to describe the anchorage location near Victoria BC, where pilots board vessels arriving from the Pacific Ocean to the port region, and where pilots debark vessels leaving the port region to the Pacific Ocean
Bulk Carrier	Vessel type, also used as a synonym for freighter, bulk cargo ship (vessel), bulker
Certificate of Readiness To Load	Certificate required before vessels are allowed to load, and issued pending inspections by Transport Canada according to the Cargo, Fumigation and Tackle Regulations.
Cleared	Describes in this study when a vessel's loading is completed before departure from port
Demurrage	Costs that the charterer pays to the ship owner for its delayed operations of loading/unloading
Despatch	see Dispatch
Dispatch (or Despatch)	Earnings that the ship owner pays to the charterer if the vessel completes loading or discharging before the laytime has expired
Efficiency of VAS	Measured in this study as the percent decrease in anchorage durations of one VAS compared to another VAS
Estimated	Describes an unknown quantity derived from a sampling method
Fertilizer(s)	Used in this study to describes a category of bulk exports that are mainly used as fertilizers such as Potash, Potassium, and Sulphur.
Foreign	Cargo exported to a foreign destination outside Canada
Freighter	Used as a synonym for bulk carrier
JIT (or J-I-T)	See Just in Time Arrival
Just in Time Arrival	Fine-tuning of exact ship arrivals at terminal, mainly by varying their speeds during the approach
Laytime	Period of time in a voyage charter allowed to load and unload cargo
Line Trade (Line Shipping)	Cargo shipping with a fixed schedule and published rates (e.g. most container shipping). Comparisons described Line Shipping to be operating more like a 'Bus Service', as opposed to Tramp Shipping that is operating more like a 'Taxi Service'.
NOR	see Notice of Readiness
Notice of Readiness (NOR)	Notice as required by the charter party that the Vessel has arrived at the port and is ready to load or discharge

Observed	Describes a counted or measured value
Outbound	Cargo loaded at terminal and departing to another destination outside port limits
Overflow Anchorages	Locations used for anchoring by vessel traffic of the Port of Vancouver when port anchorages are full and no longer available
Pacific Pilotage Authority (PPA)	Crown Corporation established under the Canada Marine Act, responsible for the mandatory piloting services within the port region, reporting to Transport Canada
Port Anchorages	Anchorages located within port limits
Port Authority	Corporation established under the Canada Marine Act to oversee a port within certain limits, and reporting to the federal government (Transport Canada).
Port limits	Jurisdiction of VFPA, see www.portvancouver.com
Port of Vancouver	Short name for Vancouver Fraser Port Authority (VFPA), www.portvancouver.com
Port Region	Not an official designation but used in this study to describe the entire area where anchorage occurs by vessels with destination Port of Vancouver (port limits plus Southern Gulf Islands, including some anchorages of the Ports of Nanaimo and Victoria, see methods)
PPA	See Pacific Pilotage Authority
Processed	In connection with Arrived, means a vessel that completed loading and is cleared to depart, or a number of vessels that completed loading and are cleared to depart within a certain time period.
Quorum Corporation	Corporation reporting quantitative data about the grain supply chain in Canada as part of the grain monitoring program (joint effort of Transport Canada and Agriculture and Agri-Food Canada), www.grainmonitor.ca
SGI	see Southern Gulf Islands
Simulated	Describes a value derived from a simulation model containing observed, estimated, or assumed values
Southern Gulf Islands	Archipelago in British Columbia, located on the east side of Vancouver Island between Nanaimo and Haro Strait
Study Area	see Port Region
Terminal	A place where deep sea vessels are berthed or moored for the purpose of loading or discharging cargo.
Total Days in Port	Average Vessel Time in Port (days), from NOR to being cleared for departure, as reported by Quorum Corporation
Tramp Trade (Tramp Shipping)	Cargo shipping without a fixed schedule by ships that are chartered by contract (e.g. most bulk cargo shipping). Derived from the British meaning of "tramp" as itinerant vagrant, day labourer, or beggar. Comparisons described Line Shipping to be operating more like a ‘Bus Service’, as opposed to Tramp Shipping that is operating more like a ‘Taxi Service’.

Trip	Used in this study to describe a movement by a vessel during a visit (arrival, from and to anchorages and berths, departure)
VAS	See Vessel Arrival System
Vessel Arrival System	A system that will synchronize the timing of ship arrivals at port with the delivery of cargo at terminal for each vessel.
VFPA	see Vancouver Fraser Port Authority
Vancouver Fraser Port Authority (VFPA)	Corporation established under the Canada Marine Act to oversee port activity in Vancouver and the Fraser River within defined port limits, and reporting to the federal government (Transport Canada), see www.portvancouver.com
Visit	Defined in this study as an event of a vessel arriving, berthing, loading, and departing and includes anchoring in between these stages

APPENDIX 2: LIST OF QUANTITATIVE RESULTS

(1) Bulk carrier anchorage use of the Southern Gulf Islands outside the Port of Vancouver has exploded in less than a decade. The growth follows an exponential pattern and indicates that this practice is not sustainable.

(2) Data show that use of anchorages grew much faster than expected from growth at the Port of Vancouver:

- The overall growth in transported bulk cargo was 3.9% per year, with a resulting growth of 46.1% from 2008-2018.
- Anchoring days inside port limits grew an estimated 11.6% per year, resulting in a two-fold increase of 199.7% during 2008-2018.
- In the Southern Gulf Islands, the annual growth rate of days at anchor was 30.9%, with an over 10-fold increase (1,375%) during the same time period.
- Growth in vessel traffic is not exponential but nearly linear and very moderate compared to the explosive expansion in anchorage demand.

(3) A comparison of annual anchorage days at the Port of Vancouver with the Southern Gulf Islands reveals a distinctive pattern: As vessel traffic builds up to port congestion, the resulting overflow into the Southern Gulf Islands is not linear but exponential. This means that at lower levels of vessel arrivals, the port anchorages are sufficient, but once these are filled, the spillover into overflow areas suddenly becomes massive.

(4) There has been a significant increase in the percentage of bulk carriers directed to anchorages prior to berthing. In the first two years a decade ago (2008-09), an estimated 38.4% of bulk carriers that entered the Port Region proceeded efficiently and arrived directly at their terminal for loading. Now, only 12.3% are estimated to arrive directly at berth. It has become the norm that the vast majority of bulk carriers are first directed to anchorages.

(5) As another indicator of export efficiency, the number of movements (‘trips’) made by bulk carriers during each visit of the Port Region has increased by 39.8% over the time period studied. Instead of arriving directly to a terminal and departing from there, the average movements of a bulk carrier rose to 4.25 separate trips from and to anchorages and berths in 2018. In contrast, container ships rarely need anchorages and their number of trips remained low and constant.

(6) Bulk carrier movements within the Port Region were dominated by trips involving anchorages. During 2018-2019, anchorages were involved in 77.8% of trips for grain, 70.3% for coal, and 70.8% for fertilizers. Movements from berth to berth accounted for only 6.4% of trips for grain, 1% for coal, and 2% for fertilizers.

(7) Bulk exports from the Port of Vancouver are the main reason for anchorage demand, but the use of anchorages is not equal for the main commodities:

- By 2018, almost half of the bulk exports from Vancouver were coal (47.5%). Grain is next in importance, with about a third of bulk exports (29.1%). Potash, potassium, and sulphur were counted together as fertilizers (14.5%). Wood products consisted of 9% of the export volume.
- These proportions were not reflected in anchorage use: Grain shows the highest overall use of anchorages with 60.6%, followed by coal with 30.7%, and fertilizers with 8.8%.

(8) Unexpectedly, the overall anchorage demands by different commodities are different in the Southern Gulf Islands:

- Grain bulkers were not the leading users of anchorages but only represented 39.9% during 2008-2019, while coal accounted for 55.2%, with fertilizers being present at only 4.9%.
- Anchorage use of the Southern Gulf Islands by grain freighters grew rapidly, and by 2019 almost overtook anchorage use by coal freighters.
- Analysis revealed that grain bulkers use overflow anchorages only little when traffic is low, and then shift explosively to the Southern Gulf Islands as port anchorages fill up. In contrast, coal bulkers show a much flatter response in using overflow anchorages as port congestion increases.
- During 2008-2010, only 0.7% of grain vessels and 5.1% of coal bulkers were sent directly to overflow anchorages. This proportion grew drastically over the years, with the highest year in 2018 showing 13.9% for grain, and 43.4% for coal.
- The data presented suggest that overflow anchorages in the Southern Gulf Islands have been used for regular operations of coal terminals even when traffic volumes at port are not extremely high..

(9) There is a strong seasonality in anchorage use with grain peaking during the winter months, while anchorage use for coal is fairly constant throughout the year.

(10) The time spent by vessels at port and at anchor are critical for understanding changes in efficiency of commodity exports, their supply chains, and the mechanics of port congestion:

- The overall time spent at port by grain vessels increased drastically from an average of 6.1 days in 2008 to 17.4 days in 2018. The increase of average visit duration at port was much flatter for vessels transporting coal and fertilizer.
- There has been concern about the extent of delays for grain vessels because of limited capacity for pre-loading inspections. Comparisons of two different sources of data allowed an average a minimum estimate for inspections was 1.0 days throughout a season. February was the month with the longest delay of 2.2 days.
- The data confirm the pattern observed elsewhere that vessels do not arrive excessively early but “rush to wait” at port despite any lineups, because they will collect late fees (demurrage) if terminals are delayed with loading.
- Waiting times at anchor show similar patterns to the average of overall visit time, suggesting that time at anchor accounts for much of the total days necessary at port. Average days at anchor per vessel increased at the Port of Vancouver, and by the years 2018-19 reached 11.0 for grain, 8.0 for coal, and 3.9 for fertilizers.

- Vessels that used overflow anchorages in the Southern Gulf Islands spent 2-3 times longer at anchor than vessels that were processed within port limits only. During the years 2018-19, the total average of days at anchor for vessels including trips to overflow sites were 20.5 days for grain, 9.5 days for coal, and 12.3 days for fertilizer.

(11) A more mechanistic approach, using weekly data and applied to evaluate ship congestion at port, reveals the importance of vessel arrivals:

- Overall, arriving vessels must be in balance with vessels that have been loaded and are departing. At certain times, imbalances can occur. Arriving vessels will accumulate when processing at terminals is slower. A cumulative number of arrivals can be calculated and carried over to the next week after adjusting for ships that were loaded and are cleared to depart.
- The cumulative number of adjusted vessel arrivals, in response to growing ship numbers at port, predicts the exponential rise of overflow traffic directed to the Southern Gulf Islands anchorages (R^2=0.72).
- The means for weekly numbers of arriving and departing ships are similar. The variance of 8.33 for the number of ships being loaded at terminals is relatively narrow, but the variance of 13.07 in the number of arriving ships is over 150% larger than in the number of ships being processed.
- The analysis demonstrates that the pattern of weekly vessel arrivals does not track the processing capacity at port, and could be better optimized.

(12) Further analysis of port congestion in the winter months of 2019-20 shows that the vessel lineup increased cumulatively over winter. This is a property of the system at least as much as an effect of exceptional external events such as such as strikes or railway disruptions. Delays in loading are cumulative, and the lineup will increase unless active measures are taken to reduce the arrival of incoming vessels when loading capacity is exceeded.

(13) The question is to what degree vessel arrivals are compensating for variance in loading capacity at port. In order to avoid port congestion, vessel arrivals should decrease when loading capacity at terminals is lower, or ship numbers at port will go up. Data analysis revealed that there is not a sufficient reduction of vessel arrivals as port congestion is growing. A lack of negative feedback on vessel arrivals prevents an efficient synchronization with current loading capacities at port.

(14) A simplified balance model can be used for a basic sensitivity analysis of how to avoid port congestion:

- The simulated numbers predicted the actual ship numbers in reported data (R^2 = 0.95).
- The model is sensitive to changes in the number of vessels that can be loaded from week to week. The time for loading can be improved, but this involves infrastructure and is very costly and difficult, and will only prevent congestion if arrivals are not inflated.
- The model produced stable scenarios of low numbers in vessel lineups when a simple feedback mechanism was introduced. Port congestion can be avoided at much lower cost if arrival rates are tracking current loading rates at terminals.

(15) Vessel Arrival Systems (VAS) have been proven at other ports and can be adapted to specific commodities in Vancouver to reduce a variety of environmental and economic costs:

- In Newcastle NSW, Australia, a VAS was implemented in 2010 and showed drastic improvements in performance. Frequent port congestion with dozens of vessels waiting at anchor have become a thing of the past. The plan called for a limitation of 48 hrs at anchor. The percentage of anchoring vessels fell from a high proportion to only 36% in 2017-19. For these vessels, the duration at anchor fell to 3 days, or less than 30% of the situation before 2010. Therefore, the overall average for all vessels arriving at port was 1.1 days at anchor.
- Adaptations for Vancouver may include several time scales: Short-term (Days to Weeks): Synchronize vessel arrivals using slow steaming; Medium-term (Weeks to Months): Adjust scheduling of new export contracts in response to delays in the supply chain or increasing ship congestion; Long-term (Months to Years): Adjust expected throughput rates at terminal not assuming maximum capacity but reflecting realistic conditions measured in previous season(s).

(16) Waiting time at anchor is unproductive time wasted, produces avoidable pollution, and costs the Canadian economy in late fees that have to be paid as penalties in export contracts. These costs are reducing the income of farmers primarily in the Prairie Provinces.

- For the crop year 2018-19, the losses at the Pacific Seaboard (Vancouver and Prince Rupert) reached $28.2 million.
- These economic losses grow with longer average duration that vessels spend at port (R^2=0.95). Increasing vessel lineup at port predicts increasing economic costs.

(17) Projected emissions of the shipping industry are falling short of meeting international agreements to limit climate change. Unless premature scrapping of current ships is undertaken, a combination of slow speeds, operational and technical efficiency measures are necessary.

- Dry bulk carriers are the highest marine source of air pollution at the Port of Vancouver.
- 38% of these greenhouse gas emissions were from ships at anchor (67% of emissions originate from ‘idling’ ships that are stationary at anchor and at berth, only 33% of emissions were from moving vessels).
- Vessel Arrival Systems (VAS) reduce emissions. Assuming the same efficiency achieved elsewhere, a calculation for Vancouver results in a potential of 59,450 tonnes of greenhouse gases that could have been saved per year if a VAS was implemented, and substantially more if shore-to-ship power was used at terminals.

(18) Anchoring bulk carriers can have a multitude of substantial negative effects on the environment (Appendix 3). These effects are particularly damaging in rare ecosystems and landscapes of high conservation value.

- The Southern Gulf Islands have long been recognized as a rare and special place arguably of international importance, with intertwined terrestrial and marine landscapes of high biodiversity, ecological and recreational values, and a unique character and economy that is based on tourism and visitors from throughout the world wishing to experience the natural uniqueness of this well preserved area.

- Use for anchoring by large seagoing vessels with associated noise and light pollution, as well as other forms of negative effects, are not compatible with the provincial 'Islands Trust Act' from 1974 that is mandating 'Preserve and Protect' as the guiding principle, and are not compatible 50 years of community planning efforts and sacrifices by residents to that effect.
- Scenarios for a Vessel Arrival System in Vancouver operating only at 75% efficiency achieved elsewhere indicate that only half of the port anchorages would be used on average. A scenario with a low efficiency of only 40% achieved elsewhere would still make port anchorages sufficient for anchorage demand on average. An average reduction of 2 days in anchorage durations would amount to about 3000 anchorage days saved, which is the equivalent of the current average of overflow anchoring in the Gulf Islands.
- The federal government is denying the special status of these islands, and is denying the existence of alternative management scenarios to accommodate the anchorage needs by the Port of Vancouver. Given the facts and multiple commitments and promises made by the federal government, the question arises whether their planned policy of breaking up the principle of 'Preserve and Protect' and the objectives of lower level jurisdictions for the Southern Gulf Islands are reasonable or even constitutional.

(19) The expansion of the Trans Mountain pipeline will increase port traffic by about 14% and requires enhanced marine safety to avoid traffic collisions and oil spills.

- Bulk carriers form over half of the vessel traffic at the Port of Vancouver. Reducing all avoidable movements from and to anchorages would significantly reduce port traffic volume and risks of collisions with oil tankers.
- Movements by bulk carriers from and to anchorages in the Southern Gulf Islands are using Haro Strait. These freighters cross not only the major oil tanker route, but also intersect with critical habitat for the endangered Southern Resident Killer Whale population. Reducing this traffic would directly contribute to this important conservation effort.

APPENDIX 3:
ENVIRONMENTAL EFFECTS AND RISKS OF BULK CARRIERS AT ANCHORAGES

(References are given as examples rather than a comprehensive review)

CATEGORY	EXAMPLE EFFECTS	REFERENCES
Greenhouse Gas Emissions (GHG)	Global climate warming: Long-term exacerbation of climate effects, including rising sea levels, effects on ecosystem and food webs, damages to local economies, fisheries and aquaculture.	[23]
Air Pollution: Diesel Particulate Matter (DPM) and other pollutants	Human Health (cardiovascular and pulmonary, exacerbation of COVID-19), ecosystem effects, sensitive species (e.g. Orca)	[23, 25, 26]
Ocean Acidification	CO^2 and NO_x emissions: ecosystems effects, larval stages, food chains (fisheries & aquaculture)	[23, 27, 28]
Water Pollution: Cumulative	Operational discharges (e.g. graywater, bilge, scrubbers): effects on ecosystems and food webs.	[29]
Water Pollution: Catastrophic	Risk of accidents and fuel spills: broad ecosystem effects, human health and local economies.	[30, 31]
Noise Pollution: Air	Ship generators broadcast engine noise at a massive scale, which can affect human health, recreational experience, and local tourist economies.	[32-38]
Noise Pollution: Water	Affecting behaviours, growth, reproduction, and survival of Marine Mammals (e.g. Orca), Rockfish / Herring, invertebrates (particularly larval stages).	[39-45]
Light Pollution	Human residents, recreational experience, local tourist economies, marine organisms and migratory birds. Transforms rural into industrial landscape, similar effect like factories or refineries.	[46]
Anchor Chain Scouring (direct mechanical effects, indirect effects through release of sediment plumes and release of toxins buried in sediment)	Destruction of marine life, covering with sediment (possibly several km away), release of buried PCBs, dioxins, furans: Benthic organisms, Rockfish, ecosystem and food webs, fisheries.	[41, 47-52]
Translocation of Human Pathogens via Ballast (water, sediment, or biofilms on tanks)	Human pathogens such as cholera, which survives in sea water and estuaries. Transport of bacteria, viruses, and other microorganisms.	[53, 54]
Invasive Outbreaks: Marine	Marine organisms in ballast or on hull (e.g. Green Crab), destructive ecosystem and economic effects for fisheries and aquaculture, tourism	[55, 56]
Invasive Outbreaks: Terrestrial	Insects in holds (e.g. Eurasian Gypsy Moth), proximity to land increases risk, damages for agriculture and forestry, requires pesticide use.	[57, 58]
Collision with Marine Animals	Trauma, scarring, and death of marine organisms including endangered whales en route to and from anchorages.	[59, 60, 61]
Protected Areas: Loss of Integrity	Critical disturbance and/or cumulative impacts can degrade protected areas and undermine reasons for protection: Loss of integrity in terms of biodiversity, ecosystem, natural landscape, climate resilience, planning objectives, social factors, visitor experience, other.	[62-65]