Quiet Sound Vessel Traffic Comparison Study

Prepared for Washington Maritime Blue

July 22nd, 2025

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Prepared by SMRU Consulting for Washington Maritime Blue

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Executive Summary

The Quiet Sound Vessel Traffic Comparison Study was commissioned by Washington Maritime Blue to identify and rank three candidate areas for potential vessel slowdown zones, in addition to the existing Quiet Sound slowdown in Admiralty Inlet. These slowdowns aim to reduce acoustic disturbance in key habitats used by the critically endangered Southern Resident killer whales (SRKWs), which rely on echolocation for foraging and communication. Existing slowdowns have demonstrated measurable reductions in underwater noise, and identification of new slowdown areas requires an evidence-based approach to prioritize zones with the greatest potential conservation benefit.

To support this, we analyzed commercial vessel activity and SRKW presence in the central Salish Sea using Automatic Identification System (AIS) data from September 2023 to August 2024, and SRKW sightings data from 2019 to 2023. We focused on three vessel speed categories currently targeted by Quiet Sound: 10.0 knots (tugs and towing vessels), 11.0 knots (bulk carriers, general cargo, and tankers), and 14.5 knots (car carriers, container ships, and cruise ships). Vessel intensity (hrs km^{-2} $month^{-1}$) was calculated for these categories and an 'Interaction Index' was developed to quantify the potential for whale-vessel co-occurrence, normalized by area size. The analysis showed that the two components of the Interaction Index (whale sightings per km^2 and vessel intensity) followed strong seasonal patterns. During the peak interaction months from July to September, whale density was the dominant driver of interaction values, accounting for 80-100% of the total values. This highlights the importance of SRKW seasonal presence in determining where slowdowns may be the most impactful.

Three candidate slowdown zones were identified: Area A (Rosario Strait), Area B (Southern Haro Strait to Admiralty Inlet), and Area C (Port Angeles to Admiralty Inlet). We ranked these sub-areas using the Interaction Index averaged across all months of the study period, producing a mean value for each location. Higher mean values indicated greater potential for whale-vessel interaction and therefore, higher potential conservation value. Area B was ranked as the highest priority candidate, driven by a sustained summer peak in SRKW presence that coincided with steady vessel traffic, particularly from tugs and towing vessels. Area A (Rosario Strait) ranked second due to high year-round vessel intensity but exhibited less temporal overlap with whales. Area C (Port Angeles to Admiralty Inlet) ranked lowest, with limited whale activity and low overall potential for whales and vessels to interact. Results indicate that slowdown measures in Area B (Southern Haro Strait to Admiralty Inlet) from June through September could offer the greatest benefit for reducing vessel impacts on SRKWs, capturing 85% of the area's annual whale-vessel interaction potential. Tugs and towing vessels were identified as key contributors to interaction risk during this period, highlighting the importance of broadening engagement with vessel types beyond the 14.5 knot group.

While limitations remained, including potential gaps in whale presence data due to variation in observer coverage and reporting effort, this study provides a robust, spatially explicit framework to guide future slowdown zone implementation in the Salish Sea. The findings highlight the value of targeting seasonal hotspots of whale-vessel overlap to maximize conservation outcomes while minimizing disruption to maritime operations.

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1 Introduction

Anthropogenic underwater noise is a growing threat to marine ecosystems and poses risks to critically endangered Southern Resident killer whales (SRKWs). Vessel noise can mask echolocation, disrupt foraging behavior, and interfere with social communication in these animals (Joy et al. 2019, Tennessen et al. 2024). In response the Quiet Sound program, run by Washington Maritime Blue, has introduced voluntary vessel speed reduction (VSR) measures to help reduce acoustic and physical disturbance in key SRKW habitats.

Building on the success of three seasons of voluntary slowdowns, which take place from October to January each year in Admiralty Inlet and north Puget Sound (Malinka et al. 2023), there is increasing interest to evaluate whether similar mitigation efforts could be expanded to additional areas. To support this, SMRU Consulting was contracted by Washington Maritime Blue with funding from the National Fish and Wildlife Foundation, to conduct a vessel traffic comparison study within the central Salish Sea. The primary objective was to identify three candidate-areas where additional VSR measures could offer the greatest potential benefit for noise reduction and SRKW conservation.

SMRU Consulting analyzed commercial vessel traffic across a defined study area (Figure 1) using Automatic Identification System (AIS) data collected between September 2023 and August 2024, provided by the Marine Exchange of Puget Sound. Vessels were grouped into categories aligned with the 2024-2025 Quiet Sound slowdown target groups: 10 knots (tugs, towing vessels), 11 knots (bulk carriers, general cargo, tankers), and 14.5 knots (car carriers, container ships, cruise ships). Monthly and seasonal vessel intensity metrics were calculated and paired with SRKW sightings data from 2019–2023 to estimate the likelihood of whale-vessel co-occurrence. These data were used to generate an interaction index, which informed a ranking of potential slowdown zones based on their relative conservation value. The results offer a practical, evidence-based framework to identify and prioritize candidate areas for the potential expansion of VSR measures. This analysis is intended to support the stakeholders in weighing ecological benefit against operational feasibility, with the overarching goal of reducing acoustic impacts on the SRKW population.

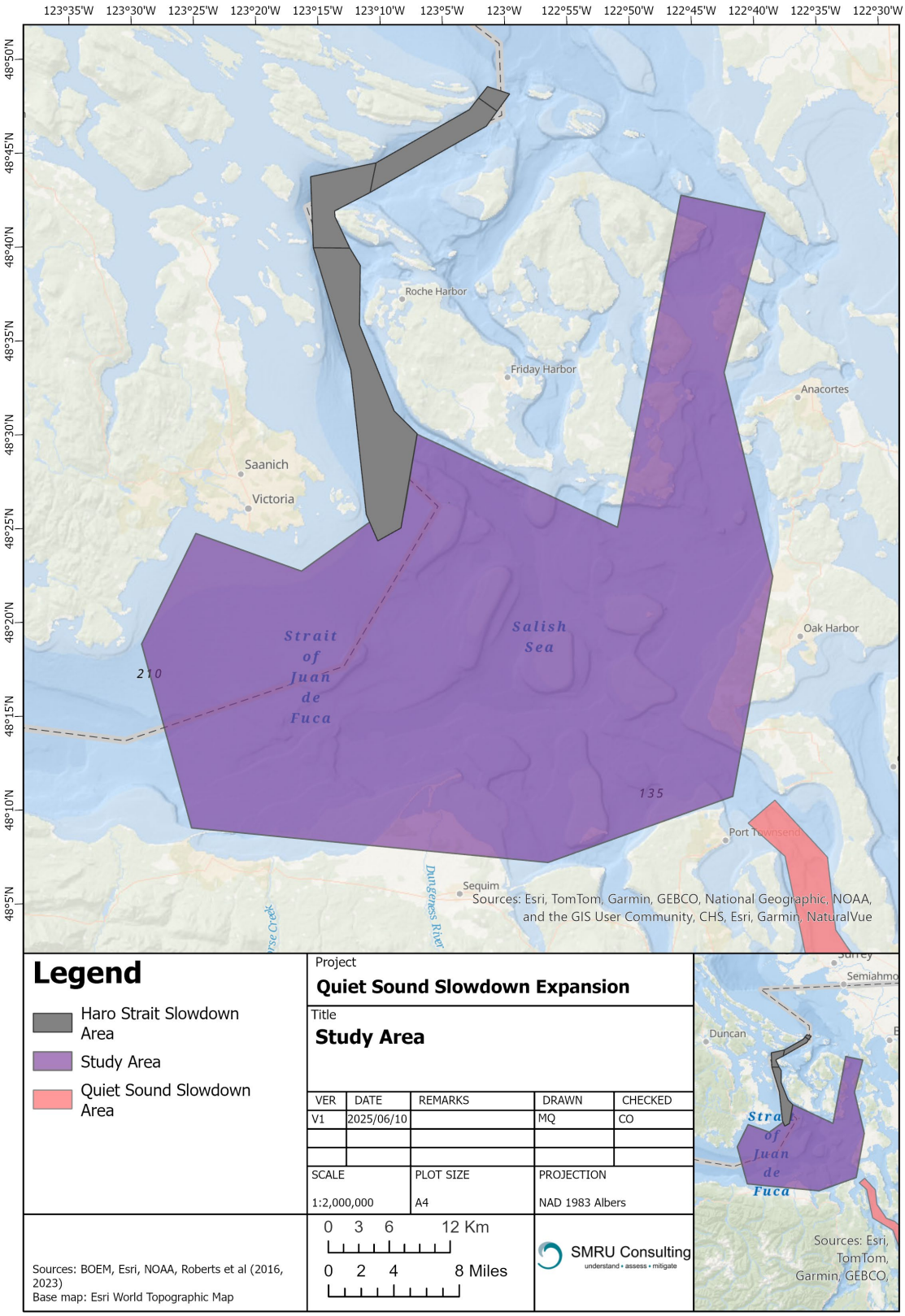


Figure 1. Study area for the vessel traffic comparison study in the central Salish Sea, showing existing slowdown areas in Haro Strait and Admiralty Inlet/Puget Sound.

2 Methods

2.1 Study Area and Data Preparation

The study area (Figure 1) encompassed central regions of the Salish Sea, overlapping with designated critical habitat for SRKWs. To support spatial analysis, a high-resolution land shapefile and study boundary were imported into a GIS environment, and a 1 km buffer was applied around land to exclude AIS vessel data near the shoreline, minimizing the influence of anchorage and port activity. Three sub-areas were delineated using polygon shapefiles to enable comparative assessment of vessel activity and potential whale-vessel interactions across distinct zones within the broader study area.

2.2 AIS Data Processing

AIS data were obtained from the Marine Exchange of Puget Sound and processed using a 1 km² spatial grid encompassing the study area. To maintain data quality, erroneous entries were excluded, including instances where the vessel identifiers were incomplete (i.e., Maritime Mobile Service Identity (MMSI) numbers with fewer than nine digits). In cases where the International Maritime Organization (IMO) identification number had a number of digits other than seven, the IMO number was removed from these records. Additional filtering was applied to records where reported Speed Over Ground (SOG) exceeded 80 knots as well as instances where calculated travel speed between consecutive AIS entries for a given vessel transit was greater than reported SOG by more than 20 knots, to account for discrepancies between the location of the vessel over time and reported SOG.

Unique vessels were identified and classified according to the Quiet Sound slowdown categories (10, 11 and 14.5 knots). For vessels with IMO numbers, a custom MATLAB script was used to retrieve vessel classifications from the www.vesselfinder.com database, which were then cross-referenced with vessel assignment records from the Pacific Pilotage Authority (PPA). For vessels that only had MMSI numbers, the www.vesselfinder.com database did not always contain a specific vessel type, and in these cases the category from the raw AIS dataset was used instead. Final vessel categories were assigned through conditional formatting, incorporating information from raw AIS data, PPA assignments, and www.vesselfinder.com vessel categories. Categories with similar names (e.g., ‘Car carrier’ and ‘Vehicle carrier’) were consolidated into one major category before being assigned a Quiet Sound slowdown category.

The cleaned AIS data were spatially and temporally resampled to 5-minute intervals using linear interpolation to standardize temporal resolution and address data gaps within vessel transits.

2.3 Vessel Intensity Calculation

Vessel intensity was used as the primary metric to quantify vessel activity, expressed as the total hours vessels spent within each square kilometre per month. This metric captures the cumulative presence of vessels over time, providing a more meaningful indicator of potential disturbance to marine wildlife than instantaneous vessel density, which reflects only the number of vessels present at a given moment.

Monthly vessel intensity was calculated for each 1 km^2 grid cell using AIS data and summarized by vessel categories based on Quiet Sound slowdown groups: 10 knots (tugs and towing vessels), 11 knots (bulk carriers, general cargo, and tankers), and 14.5 knots (car carriers, container ships, and cruise ships). Vessels labelled as “Other” were excluded from subsequent analyses to focus on those targeted by existing speed reduction efforts.

2.4 SRKW Sightings Data

Southern Resident killer whale (SRKW) sightings data were provided by The Whale Museum and the National Oceanic and Atmospheric Administration (NOAA), based on a combination of opportunistic reports and systematic monitoring. Whale presence was quantified as “whale days,” defined as the number of unique days with confirmed sightings in each sub-area. Data were aggregated by month over a five-year period (2019 to 2023) to provide a standardized indicator of relative whale occurrence that accounts for variation in both sighting effort and whale distribution over time.

2.5 Map & Time Series Generation

Monthly maps of vessel intensity were generated to visualize spatial patterns in vessel activity across the study area. Using the 1 km^2 grid, maps displayed vessel residence time (hours per km^2) by vessel category, highlighting areas with high levels of vessel intensity. These spatial patterns helped to inform the selection of three sub-areas for more focused time series analysis. To explore temporal trends, vessel intensity data were aggregated monthly for each sub-area and vessel category. In parallel, time series of SRKW ‘whale days’ were created and overlaid with vessel intensity trends to assess potential overlaps between whale occurrence and vessel traffic.

2.6 Sub-area Ranking and Statistical Analysis

To evaluate where vessel slowdowns could offer the greatest conservation benefit, a density-based ‘Interaction Index’ was developed to quantify whale-vessel overlap while accounting for differences in sub-area size. This metric was designed to identify areas with the highest potential for reducing disturbance to whales per square kilometre.

The metric was calculated as:

Monthly Interaction Index = [Average whale days per month / sub-area (km²)] × vessel intensity (hrs km^{-2} month^{-1})

Here, whale days per km² represents the relative 'density' of SRKW presence within each sub-area, while vessel intensity reflects the cumulative monthly vessel residence time. Sub-area sizes were calculated using projected coordinates to ensure accurate area measurements. To rank sub-areas, the Interaction Index was averaged across all months of the study period, producing a mean value for each location. Higher mean values indicate greater potential for whale-vessel interaction and, therefore, higher conservation value for mitigation measures such as VSRs.

3 Results & Discussion

3.1 Vessel Traffic Patterns and Intensity

Analysis of AIS data from September 2023 – August 2024 revealed distinct spatial and temporal patterns in vessel traffic throughout the study area, where average vessel intensity (hrs km^{-2} month^{-1}) varied spatially and seasonally (Figure 2).

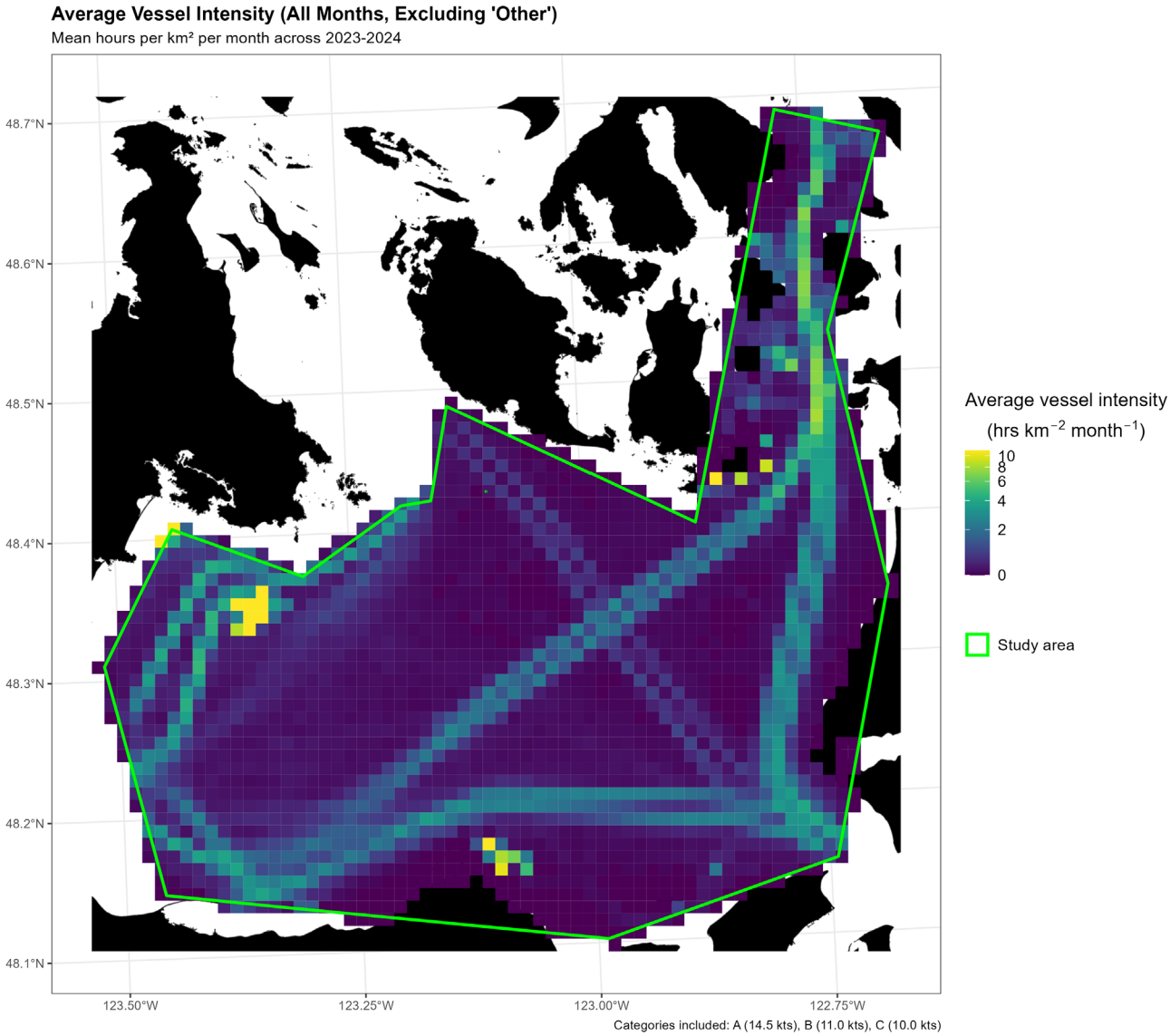


Figure 2. Average vessel intensity across the study area for all months combined (September 2023 – August 2024), including vessels in the Quiet Sound slowdown categories only: 10.0 kts (tugs, towing vessels), 11.0 kts (bulk carriers, general cargo and tankers), and 14.5 kts (car carriers, container ships and cruise ships). Vessels in all other categories are excluded.

The overall spatial distribution of vessel intensity across the study area, averaged across all months of data, showed clear shipping lanes and areas of concentrated vessel use (Figure 2), where the highest vessel intensities were observed along established shipping lanes such as in Rosario Strait. Note that Figure 2 shows the spatial distribution of all vessel categories (excluding 'Other), for the entire year – monthly maps of vessel intensity parsed by vessel category are in the Appendix (section 5).

A temporal analysis of vessel activity revealed distinct seasonal patterns within the study period (September 2023 – August 2024) across the main vessel categories (Figure 3). The 14.5 kt group (car carriers, container ships, and cruise ships) showed the strongest seasonal signal, with traffic peaking in winter before declining through spring and summer and gradually increasing again into autumn. In contrast, tugs and towing vessels (10.0 kt) maintained relatively stable traffic levels year-round. Bulk carriers, general cargo ships, and tankers (11.0 kt) also followed a relatively steady pattern, with a peak in November and a dip in May.

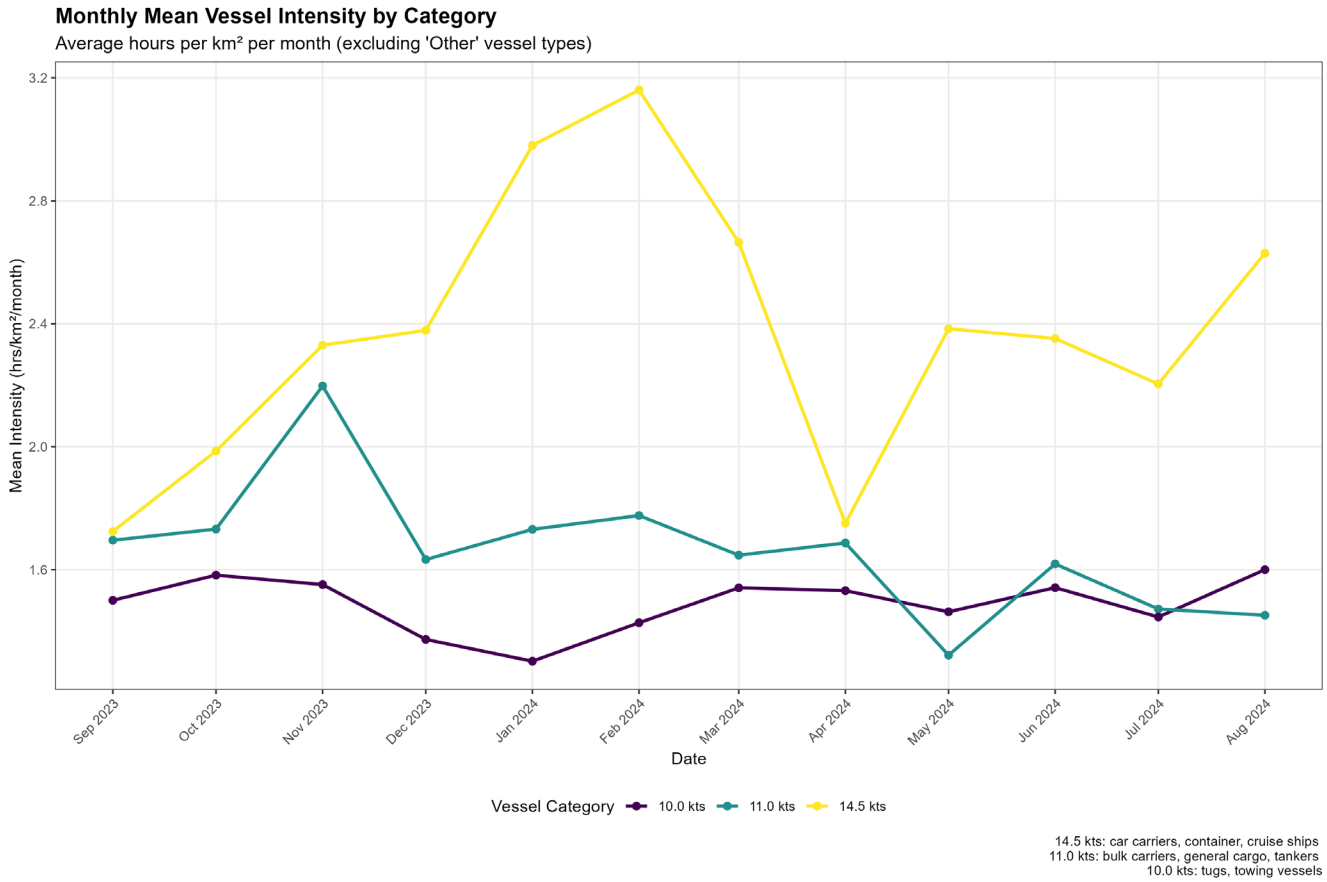


Figure 3. Monthly mean vessel intensity by category across the entire study area, from September 2023 to August 2024, for vessels in Quiet Sound slowdown categories (10.0, 11.0 and 14.5 knots).

Following the study-wide assessment and consultation with stakeholders, three sub-areas were identified for further analysis (Figure 4). These were: Area A (Rosario Strait), Area B (Southern Haro Strait to Admiralty Inlet), and Area C (Port Angeles to Admiralty Inlet).

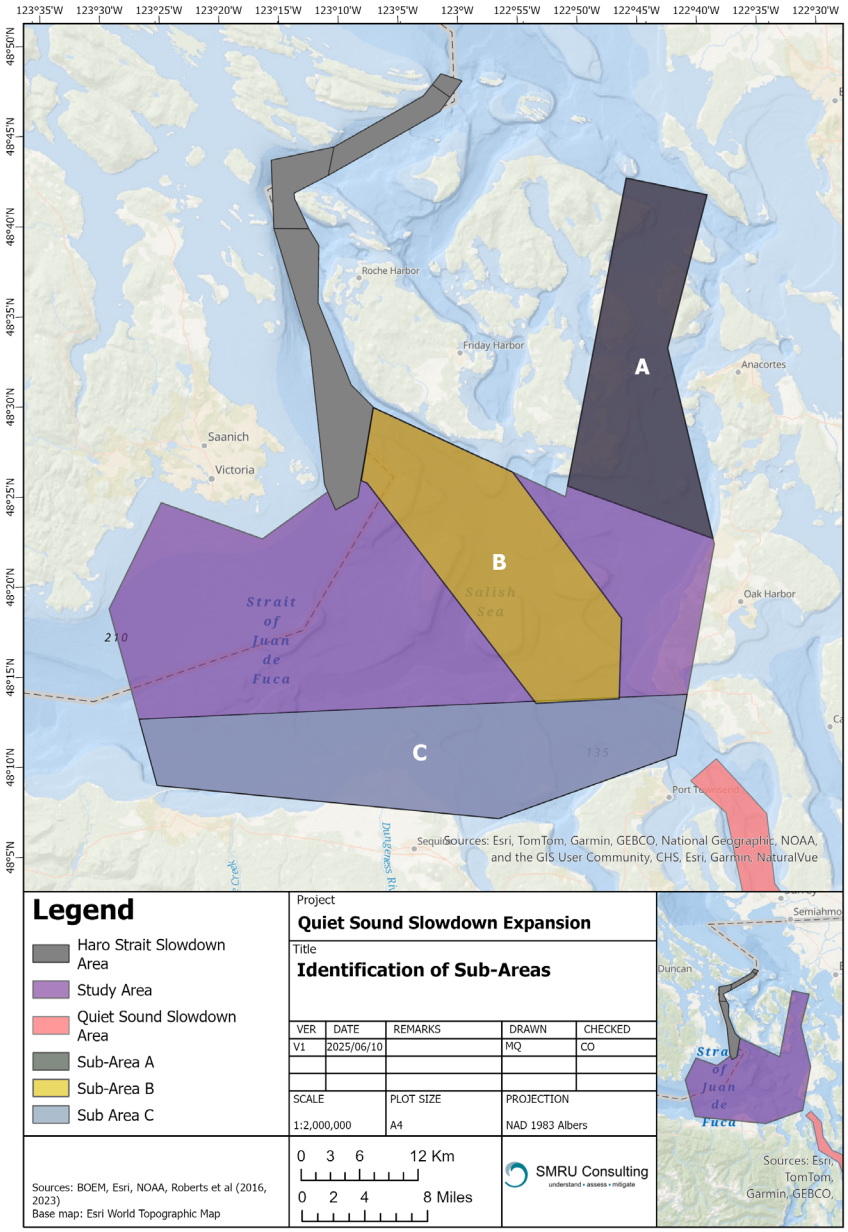
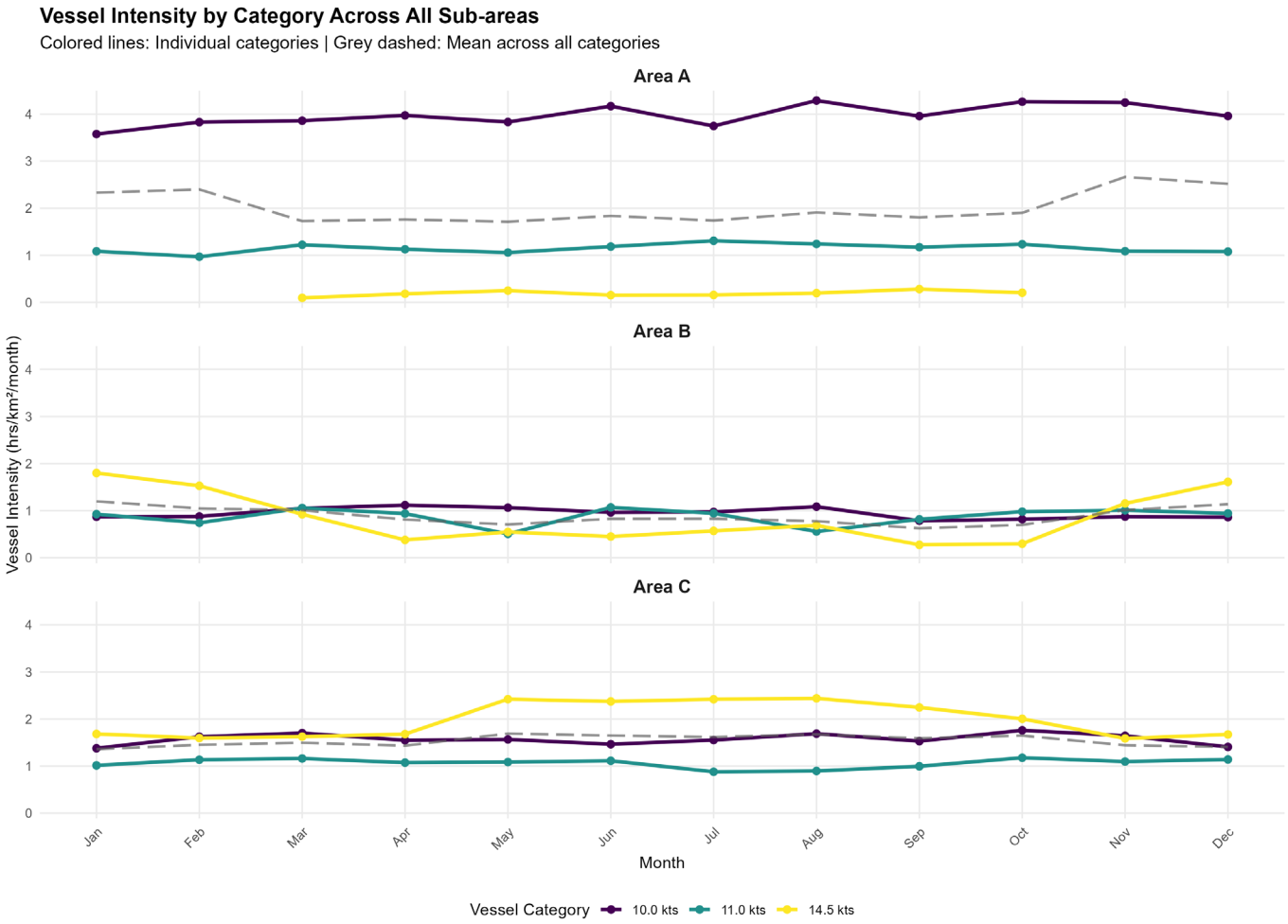


Figure 4. Study sub-areas identified for further analysis: Area A (Rosario Strait), Area B (Southern Haro Strait to Admiralty Inlet) and Area C (Port Angeles to Admiralty Inlet). Existing slowdown areas in Haro Strait and Admiralty Inlet/Puget Sound are also shown.

Vessel activity was varied across the three sub-areas (Figure 5). Area A (Rosario Strait) had the highest traffic levels and the most pronounced seasonal patterns. Traffic here was dominated by 10.0 kt vessels (tugs and towing vessels) which maintained high intensity throughout much of the year. In contrast, activity from the 11.0 and 14.5 kt groups was lower and less variable, with the latter absent entirely from November through February. Area B (Southern Haro Strait to Admiralty Inlet) had much lower overall vessel intensity. The 14.5 kt group was the most dynamic, with relatively high activity early in the year that declined through spring and summer before picking up again in late autumn. The

10.0 and 11.0 kt vessels remained at low, steady levels throughout. Despite some fluctuation in individual categories, overall traffic intensity in Area B (Southern Haro Strait to Admiralty Inlet) remained consistently low. In Area C (Port Angeles to Admiralty Inlet), seasonal changes were again most apparent in the 14.5 kt group, which dipped in winter and peaked mid-year. Both the 10.0 and 11.0 kt categories showed moderate, steady traffic across the year.



Note: Gaps are genuine absence of vessel activity (e.g. Nov – Feb, no 14.5 kt vessels were present in Area A).

14.5 kts: car carriers, container, cruise ships
11.0 kts: bulk carriers, general cargo, tankers
10.0 kts: tugs, towing vessels

Excludes 'Other' vessel category

Figure 5. Vessel intensity by Quiet Sound slowdown category across three sub-areas from September 2023 – August 2024. Colored lines represent individual vessel categories (10.0 kts, 11.0 kts and 14.5 kts), while the grey dashed line shows the mean intensity across all categories.

To better understand how each vessel category uses the three sub-areas, the data were also separated according to vessel category (Figure 6). For the 10.0 knot vessels, the dominance of Area A (Rosario Strait) becomes even more pronounced and vessel intensity here is consistently ~two to four times higher than in Areas B (Southern Haro Strait to Admiralty Inlet) and C (Port Angeles to Admiralty

Inlet) throughout the year, reflecting the use of Rosario Strait as a predominant route for tug traffic traveling to and from Cherry Point Areas B and C show low but steady traffic for this vessel category.

In contrast, the 11.0 knot group (bulk carriers, general cargo, and tankers) is much more evenly distributed across all three areas, and seasonal variation is minimal. This suggests that vessels in the 11.0 knot category are more evenly distributed across the study area, unlike tugs and towing vessels which are concentrated in Area A (Rosario Strait).

The 14.5 knot vessels (car carriers, container ships, and cruise ships) follow a different pattern with pronounced seasonal variation; this may reflect seasonal vessel traffic such as the Seattle cruise season which typically occurs from April through October Area C (Port Angeles to Admiralty Inlet) had the most activity for this vessel category, peaking in mid-year. Area B (Southern Haro Strait to Admiralty Inlet) had moderate seasonal variation, starting high in winter before declining through summer and then recovering. Area A (Rosario Strait) had minimal activity from the 14.5 kt vessels, with a complete absence during several months (indicated by gaps in the line).

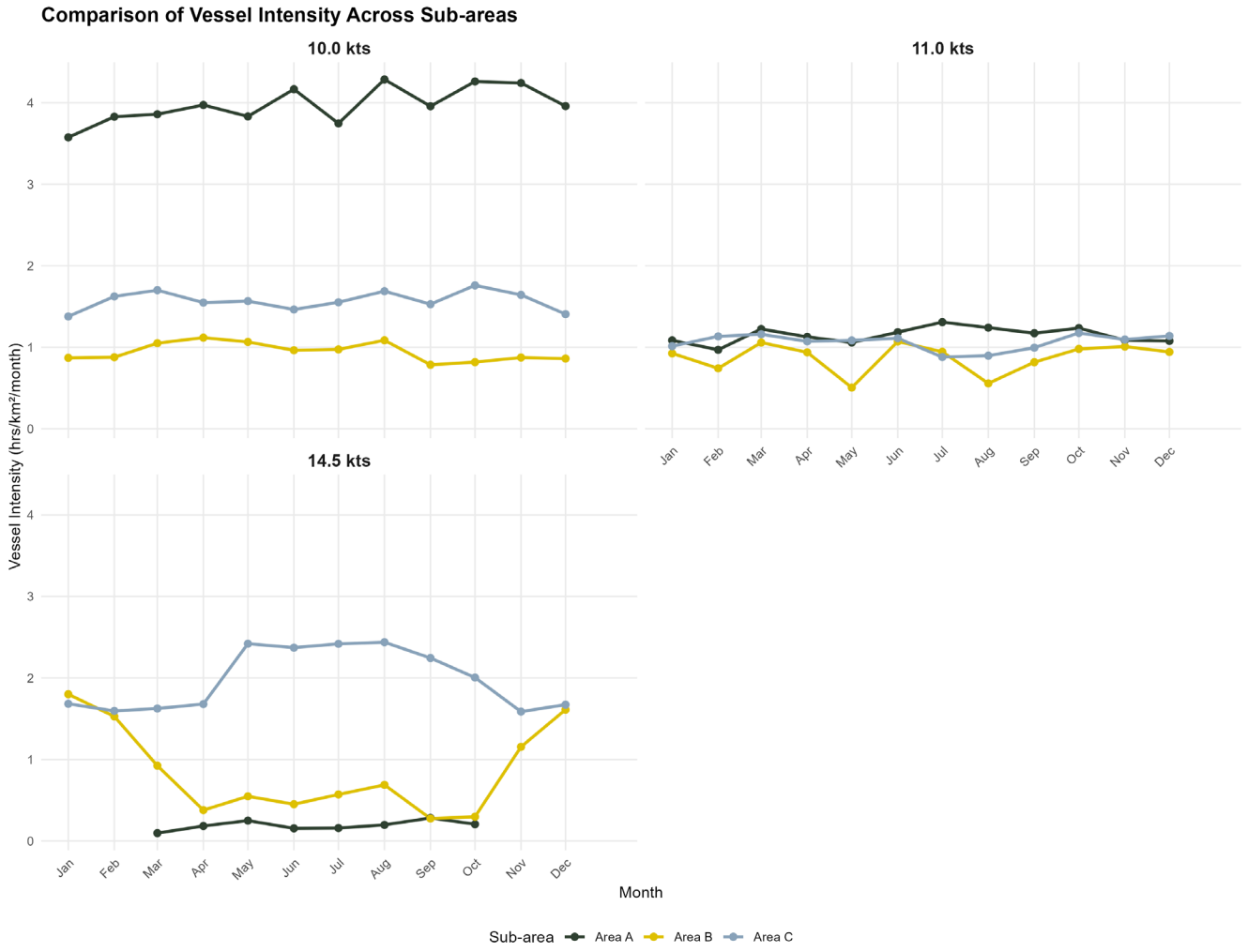


Figure 6. Comparison of vessel intensity across sub-areas, by Quiet Sound slowdown vessel category. Each panel shows temporal variation in vessel intensity for a specific category: 10.0 knots (tugs, towing vessels), 11.0 knots (bulk carriers, general cargo and tankers), and 14.5 knots (car carriers, container ships, cruise ships). Lines represent different sub-areas (Area A – green, Area B – yellow, and Area C – blue).

3.2 Inclusion of whale sighting data

To assess potential interactions with SRKWs, whale sighting data were overlaid with vessel traffic data to explore spatial and temporal overlap. This enabled us to identify areas where speed restrictions could offer the greatest conservation benefit.

Whale sighting data showed clear seasonal trends in SRKW presence across the three sub-areas (Figure 7). Area B (Southern Haro Strait to Admiralty Inlet) displayed the highest whale activity, peaking from June through October, and showed the strongest seasonal signal. In contrast, Area A (Rosario Strait) had a more moderate and variable presence, with a brief peak in March followed by

low, steady sightings through to October. Area C (Port Angeles to Admiralty Inlet) saw the fewest whale days overall, with low but stable activity during the summer and no sightings outside of that period. These patterns suggest that of the three sub-areas, Area B (Southern Haro Strait to Admiralty Inlet), may represent the most important habitat for SRKWs within the study area.

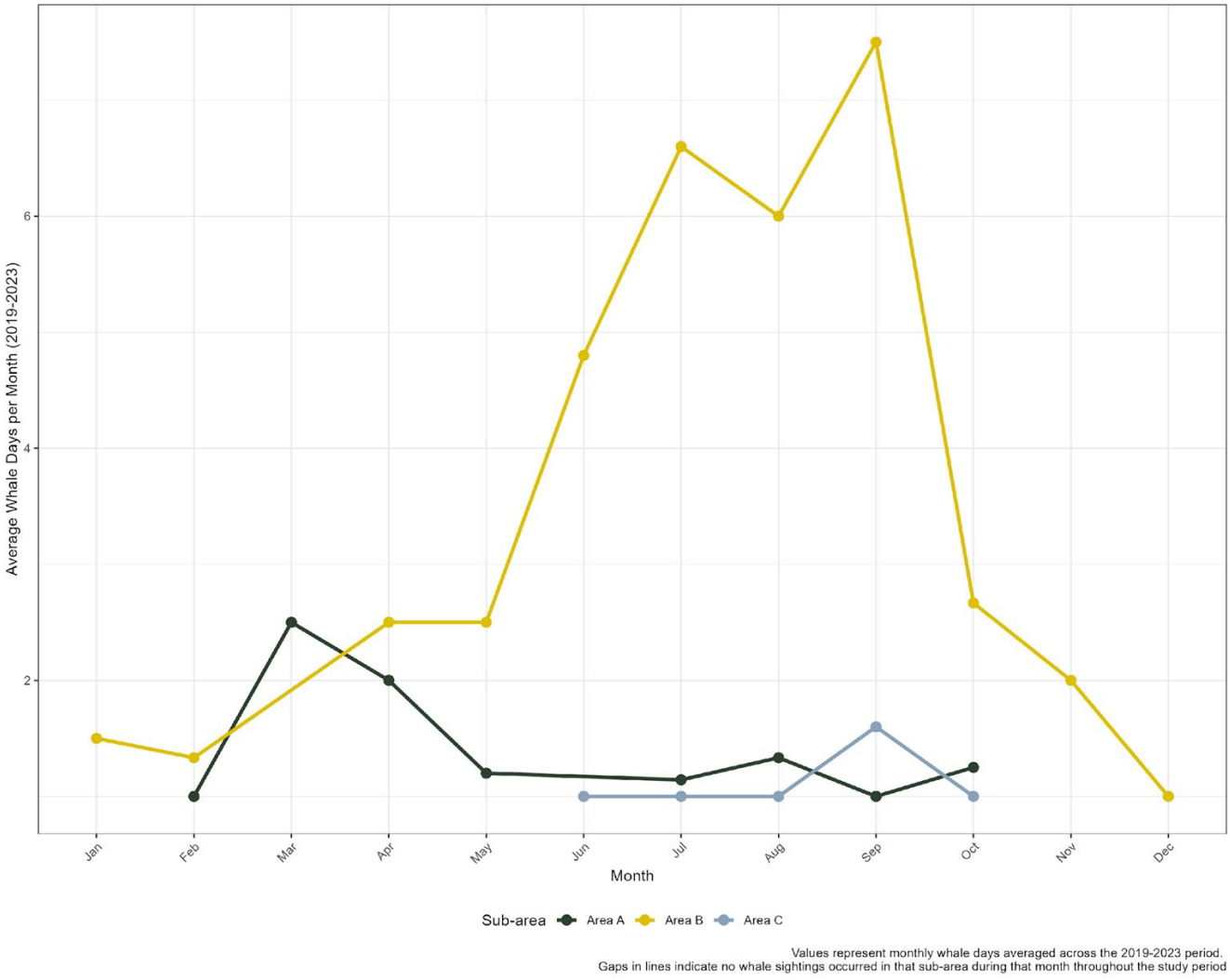


Figure 7. Temporal variation in Southern Resident killer whale (SRKW) presence across sub-areas A, B and C from 2019-2023. Values on the y-axis represent the average unique sighting days per month within each sub-area, calculated as the mean across the five-year study period (2019-2023). Gaps in lines indicate months with no whale sightings recorded in that sub-area throughout the study period.

Vessel traffic and whale presence data were overlaid to reveal distinct patterns of temporal overlap across the three sub-areas. In Area A (Rosario Strait; Figure 8), the highest levels of vessel traffic were recorded for the 10.0 kt vessels (tugs and towing vessels), which were consistently elevated throughout the year. However, whale presence was sporadic and generally low, with moderate overlap only occurring in March and late summer. This suggests that while Area A (Rosario Strait) has the most intensive vessel activity of the three sub-areas, the temporal mismatch with whale presence may limit the conservation benefits of a vessel speed reduction in this location.

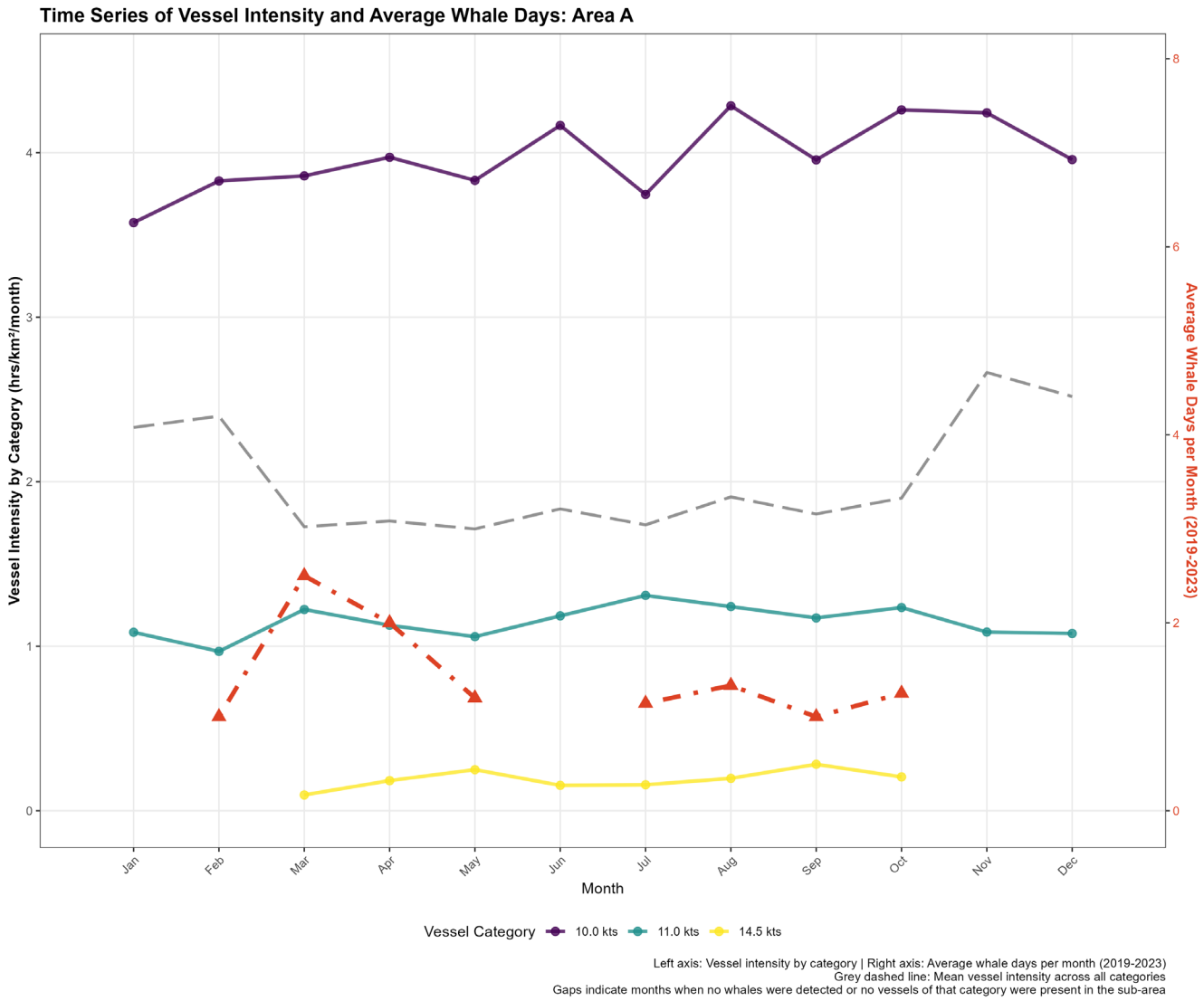


Figure 8. Temporal overlap between vessel intensity and SRKW presence in Area A (Rosario Strait). Solid lines represent vessel intensity by category, grey dashed line is the mean vessel intensity across categories (left axis), and red dashed line shows average whale days per month (right axis, 2019-2023). Gaps indicate months when no whales were detected, or no vessels of that category were present in the sub-area.

In contrast to Area A (Rosario Strait), Area B (Southern Haro Strait to Admiralty Inlet) had overlapping periods of intense vessel traffic and whale presence, particularly from June through September (Figure 9). This suggests that Area B may be a valuable candidate for a slowdown zone, due to the combination of peak whale presence and significant vessel traffic during overlapping time periods.

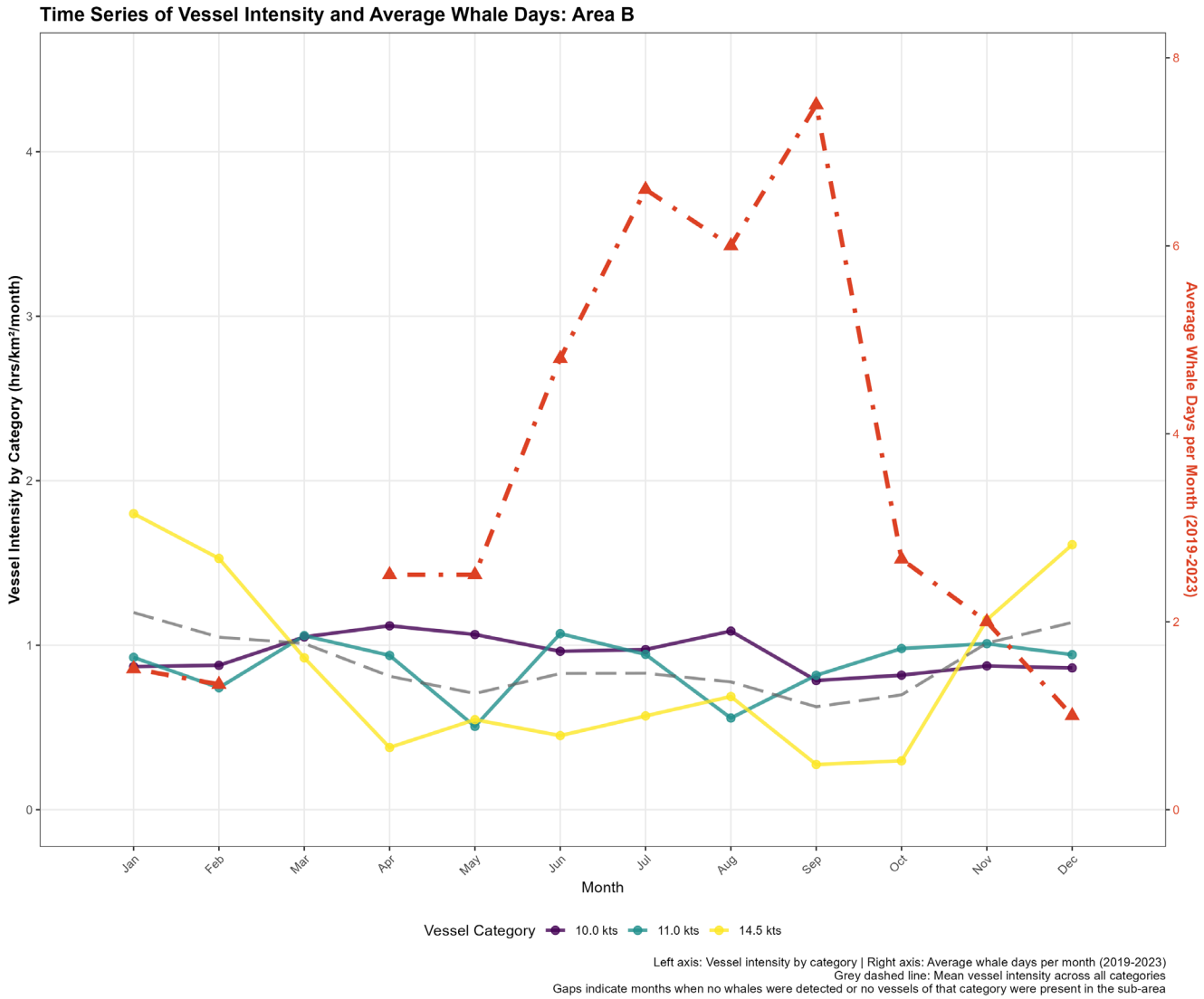


Figure 9. Temporal overlap between vessel intensity and SRKW presence in Area B (Southern Haro Strait to Admiralty Inlet). Solid lines represent vessel intensity by category, grey dashed line is the mean vessel intensity across categories (left axis), and red dashed line shows average whale days per month (right axis, 2019-2023). Gaps indicate months when no whales were detected, or no vessels of that category were present in the sub-area.

Area C (Port Angeles to Admiralty Inlet) had lower levels of whale days (maximum 2 per month) which only occurred from June through October and low but steady levels of vessel traffic (Figure 10).

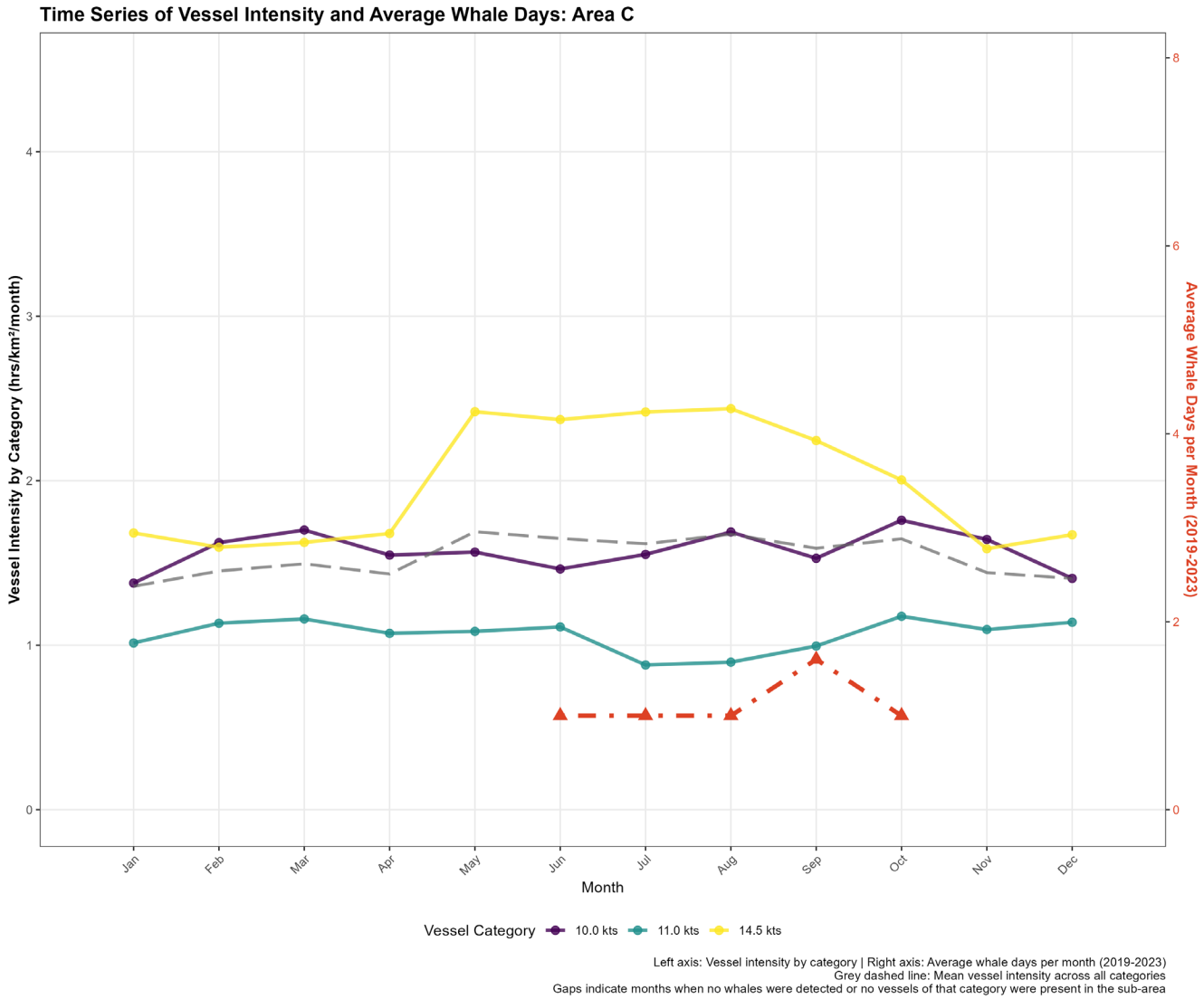


Figure 10. Temporal overlap between vessel intensity and SRKW presence in Area C (Port Angeles to Admiralty Inlet). Solid lines represent vessel intensity by category, grey dashed line is the mean vessel intensity across categories (left axis), and red dashed line shows average whale days per month (right axis, 2019-2023). Gaps indicate months when no whales were detected, or no vessels of that category were present in the sub-area

3.3 Interaction Index

The Interaction Index was calculated for each month and sub-area A, B and C (Figure 11). Area B (Southern Haro Strait to Admiralty Inlet) has the highest interaction values, with peak indices occurring during the summer months from June through September, reaching maximum values in July and August. Area A (Rosario Strait) had moderate interaction values during the spring months of March and April, followed by lower, but consistent values throughout the summer. The elevated spring values in Area A (Rosario Strait) correspond to the brief peak in whale presence during March (Figure 8), despite the areas consistently high vessel traffic throughout the year, especially for tugs and towing vessels.

Area C (Port Angeles to Admiralty Inlet) has the lowest interaction potential of the three sub-areas overall, with modest values only occurring during the summer months and zero interaction potential during winter and early spring when no whale sightings were recorded.

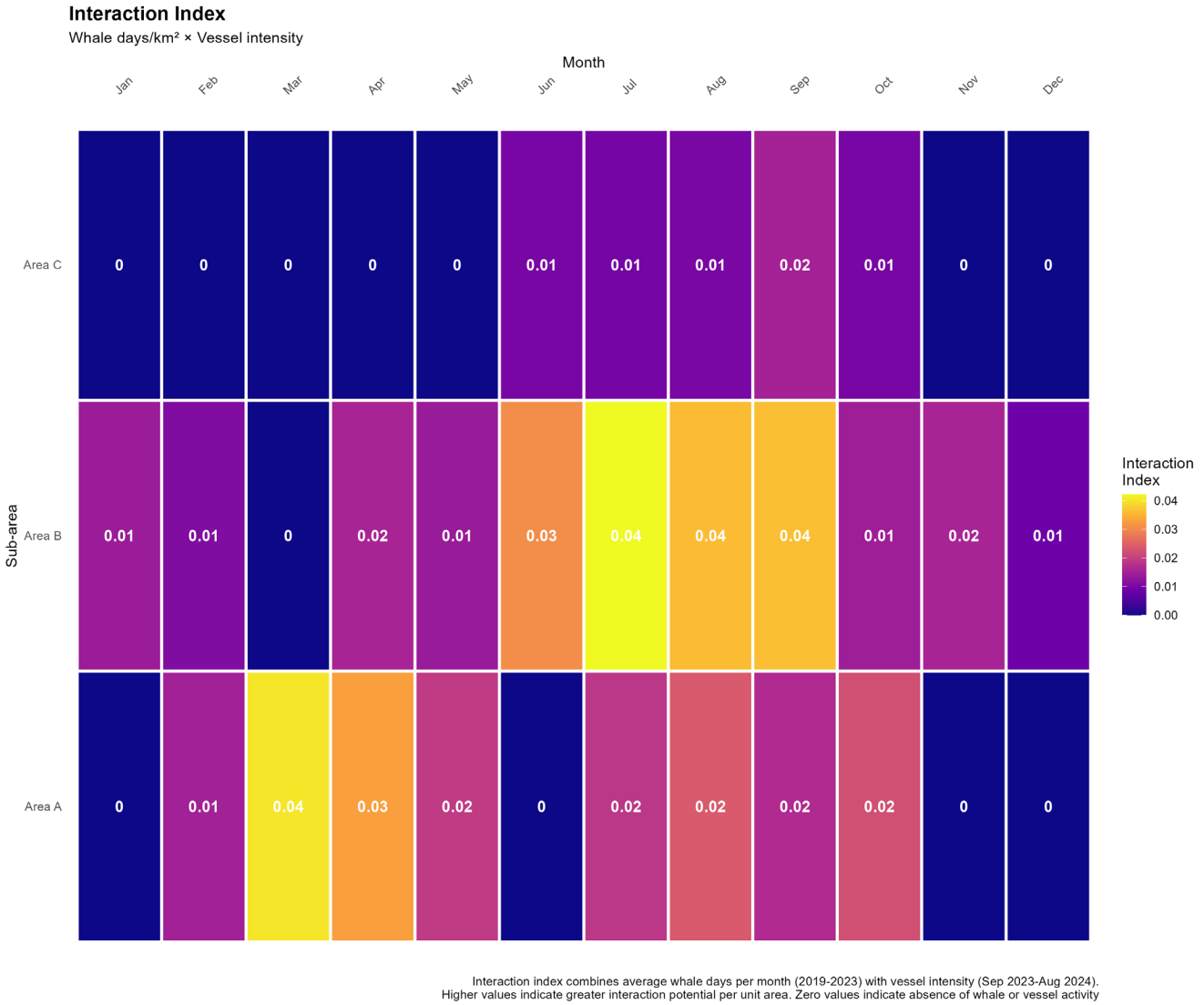


Figure 11. Interaction Index heatmap showing spatiotemporal patterns of potential overlap between whales and vessels, across the three sub-areas. The index combines average whale days per month (2019-2023) with vessel intensity (September 2023-August 2024), normalized by sub-area size. Higher values (yellow) indicate greater potential for whale-vessel interactions. Zero values (dark blue) indicate absence of either whales or vessels during that month.

The temporal patterns of the Interaction Index are further illustrated as time series across the study period (Figure 12). This confirms that Area B (Southern Haro Strait to Admiralty Inlet) consistently demonstrates the highest interaction potential, with a pronounced summer peak which reaches maximum values from June through September before a sharp decline in October. Comparatively, Area A (Rosario Strait) has the highest interaction potential during March, followed by a decline through late spring and early summer before stabilizing at moderate levels from July through October. This interaction potential is temporally offset from the other sub-areas. Area C (Port Angeles to

Admiralty Inlet) maintains consistently low interaction values throughout the year; this in combination with the narrow seasonal window of interaction potential suggests that Area C (Port Angeles to Admiralty Inlet) represents the lowest priority for a slowdown area, as it would have the least conservation value.

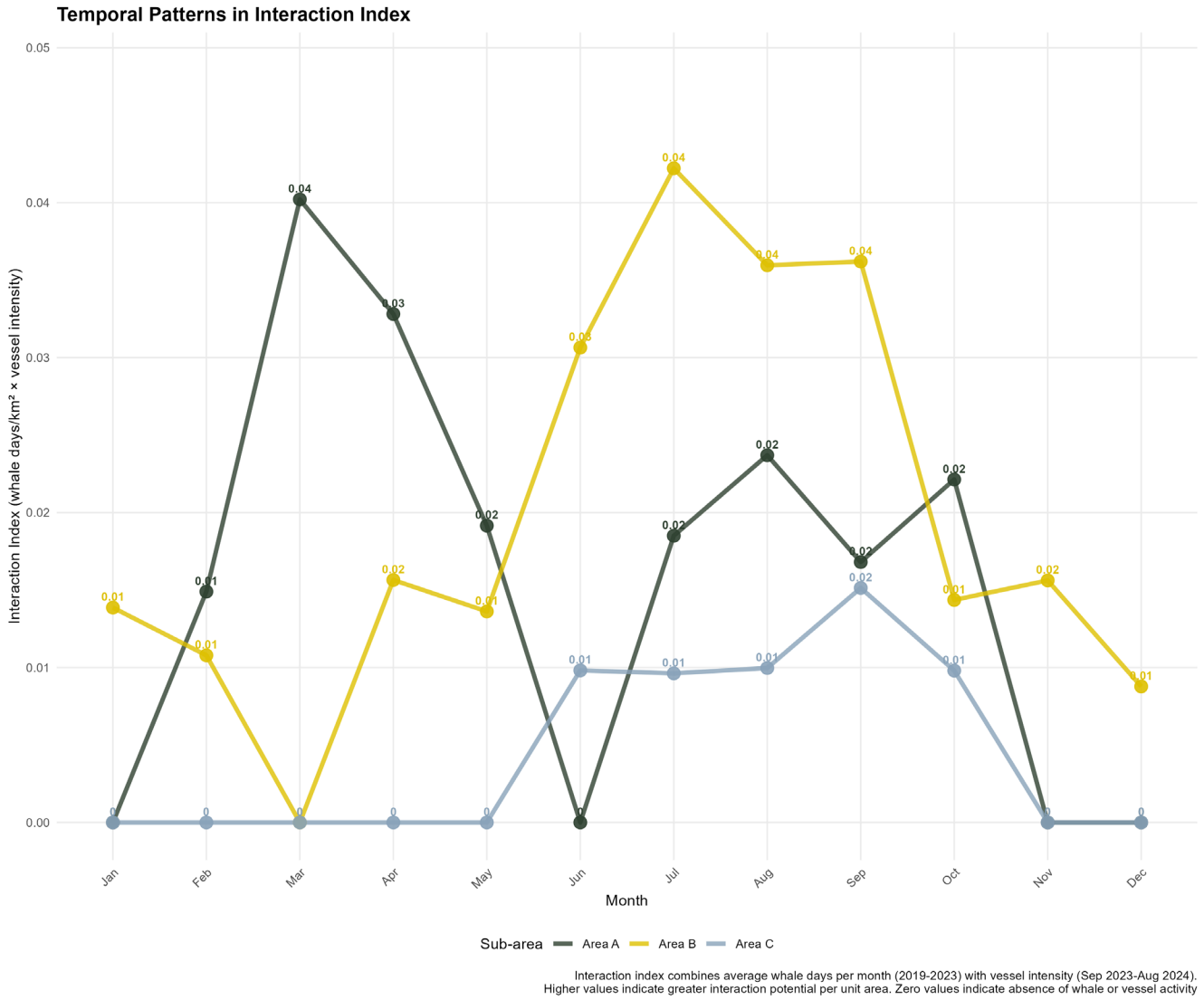


Figure 12. Temporal patterns in Interaction Index across the three sub-areas, from September 2023 to August 2024. The index combines average whale days per month (2019-2023) with vessel intensity (September 2023-August 2024), normalized by sub-area size. Higher values indicate greater potential for whale-vessel interactions per unit area. Zero values indicate an absence of either whales or vessels during that month.

3.4 Ranking of candidate slowdown areas

The Interaction Index was used to rank the three sub-areas, according to how valuable a slowdown would be if it were to be implemented (Table 1).

Table 1. Summary statistics for the Interaction Index across the three candidate slowdown areas. Mean index represents the average monthly interaction potential across the study period, while the total annual interaction index shows the cumulative interaction potential for each area. Peak month indicates when the maximum interaction potential occurs in each area.

Sub-Area	A	B	C
Mean Interaction Index	0.016	0.020	0.005
Max Interaction Index	0.040	0.042	0.015
Peak Month	Mar	Jul	Sep
Total Annual Interaction Index	0.19	0.24	0.05

Area B (southern Haro Strait to Admiralty Inlet) is ranked as having the greatest potential value if a slowdown were to be implemented there, with the greatest mean interaction index and total annual value, reflecting sustained whale–vessel overlap during the peak summer season. Area A (Rosario Strait) ranks second, primarily due to a strong spring peak in whale presence and consistently high vessel traffic. Area C (Port Angeles to Admiralty Inlet) has the lowest potential value, with limited overlap in whale presence and vessel activity throughout the year. Monthly patterns underscore the seasonal variation between areas: interaction potential in Area B (Southern Haro Strait to Admiralty Inlet) peaks in July during the summer foraging period; Area A (Rosario Strait) peaks earlier in March, and Area C (Port Angeles to Admiralty Inlet) shows a modest increase in September.

Table 1 provides an overall ranking of candidate slowdown areas, based on the greatest potential to reduce vessel-whale interaction, if a slowdown were to be implemented . We also provide monthly rankings to further illustrate seasonal differences and provide guidance for timing any vessel speed reduction initiatives (Figure 13). Area B is ranked as the first priority for the longest continuous period, from June through October. Area A (Rosario Strait) is more variable, ranked as first priority during the early spring months of March and April, and then again briefly in October. During the summer months Area A (Rosario Strait) is consistently ranked second, indicating it is an important candidate area but with lower potential impact as a slowdown zone compared to Area B during this period. Area C (Port Angeles to Admiralty Inlet) has the most limited potential as a slowdown zone, ranking third during the most active months.

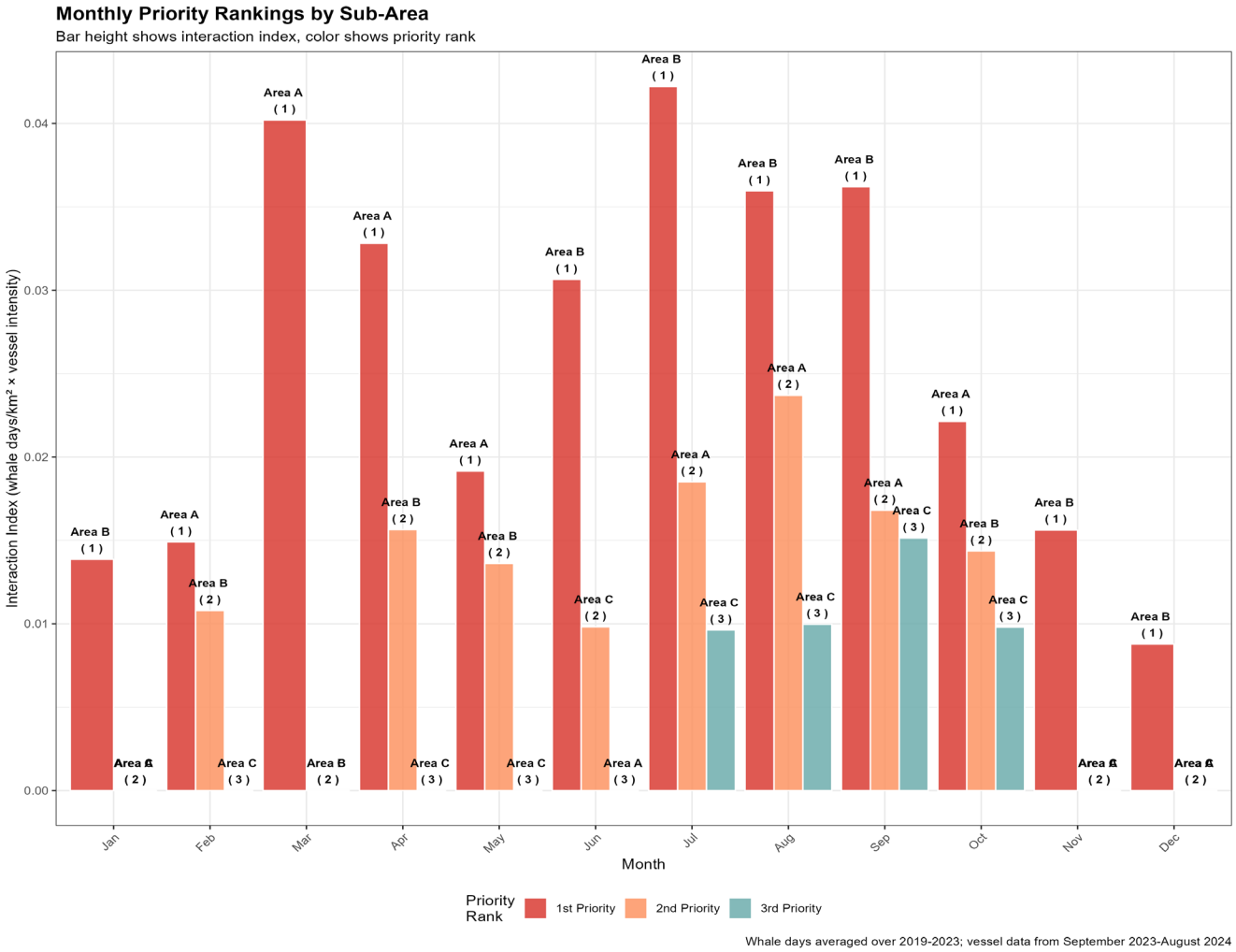


Figure 13. Monthly sub-area rankings by interaction index. Bar height represents the interaction index value, while color indicates the relative priority rank for each month. First priority (red) indicates the area with greatest potential conservation benefit from speed restrictions during that month.

Monthly patterns within each sub-area can inform when a slowdown would be most beneficial, relative to each area's baseline activity levels. We examined months that exceeded each area's annual mean to identify optimal timing windows for implementing vessel speed restrictions that maximize conservation impact, while minimizing any unnecessary burden on shipping during periods with low interaction potential (Figure 14-Figure 16).

Area B (Southern Haro Strait to Admiralty Inlet) showed the most sustained period of above-average interaction, with four consecutive months (June through September) exceeding the area mean of 0.020. The remaining eight months fell well below the area mean. Area A (Rosario Strait) had a pronounced spring-summer split, with March representing the single highest interaction month above the area's annual mean of 0.016, corresponding to the period of whale presence observed in March. Area C (Port Angeles to Admiralty Inlet) had the most limited and concentrated interaction pattern, with only five months showing any whale/vessel interaction potential and only a single peak in September that exceeded the very low area mean, reinforcing Area C's status as the lowest priority candidate for a slowdown.

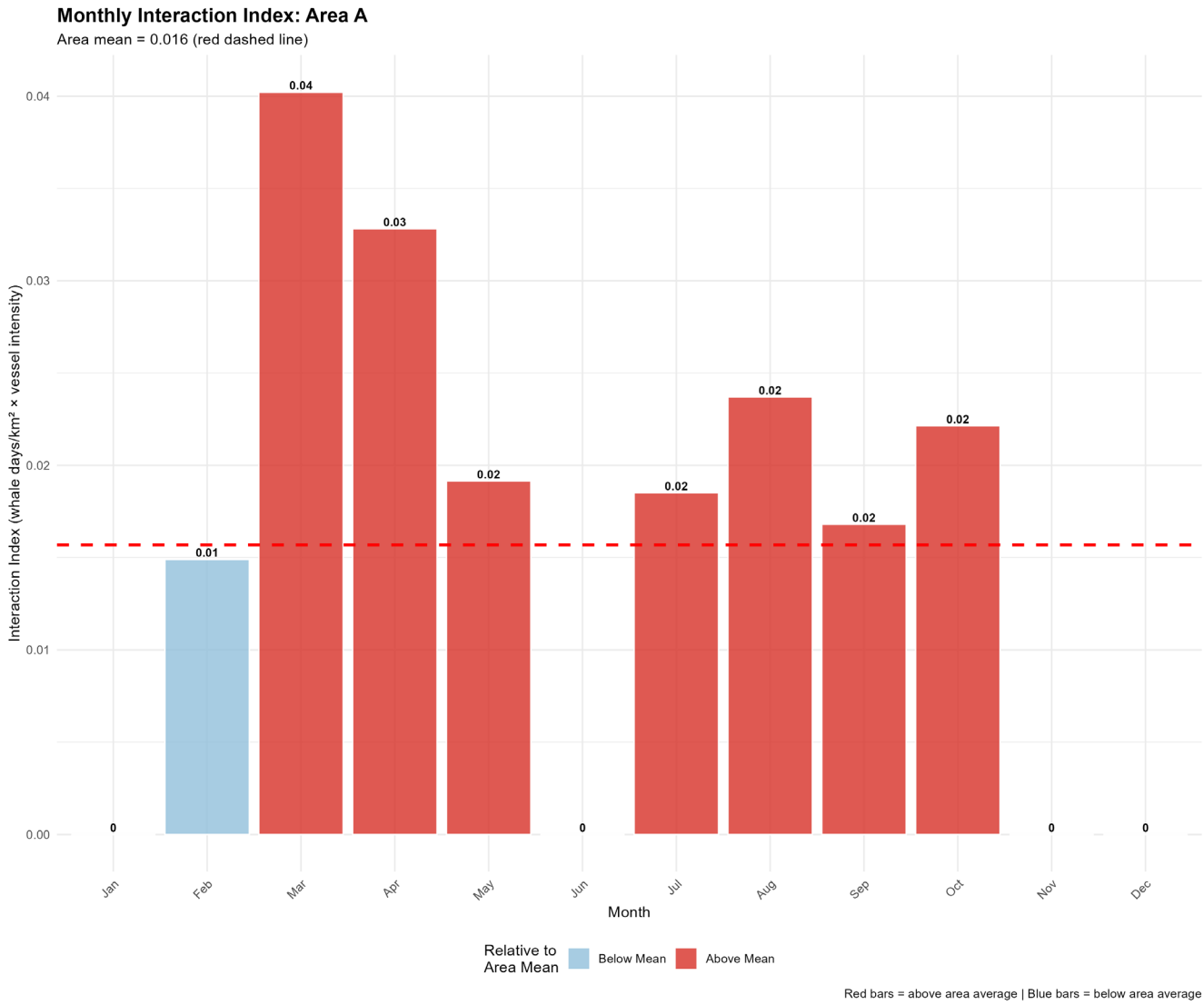


Figure 14. Monthly Interaction Index values for Area A relative to the area's annual mean (0.016, red dashed line). Red bars indicate months with above-average interaction potential, while blue bars show below-average months.

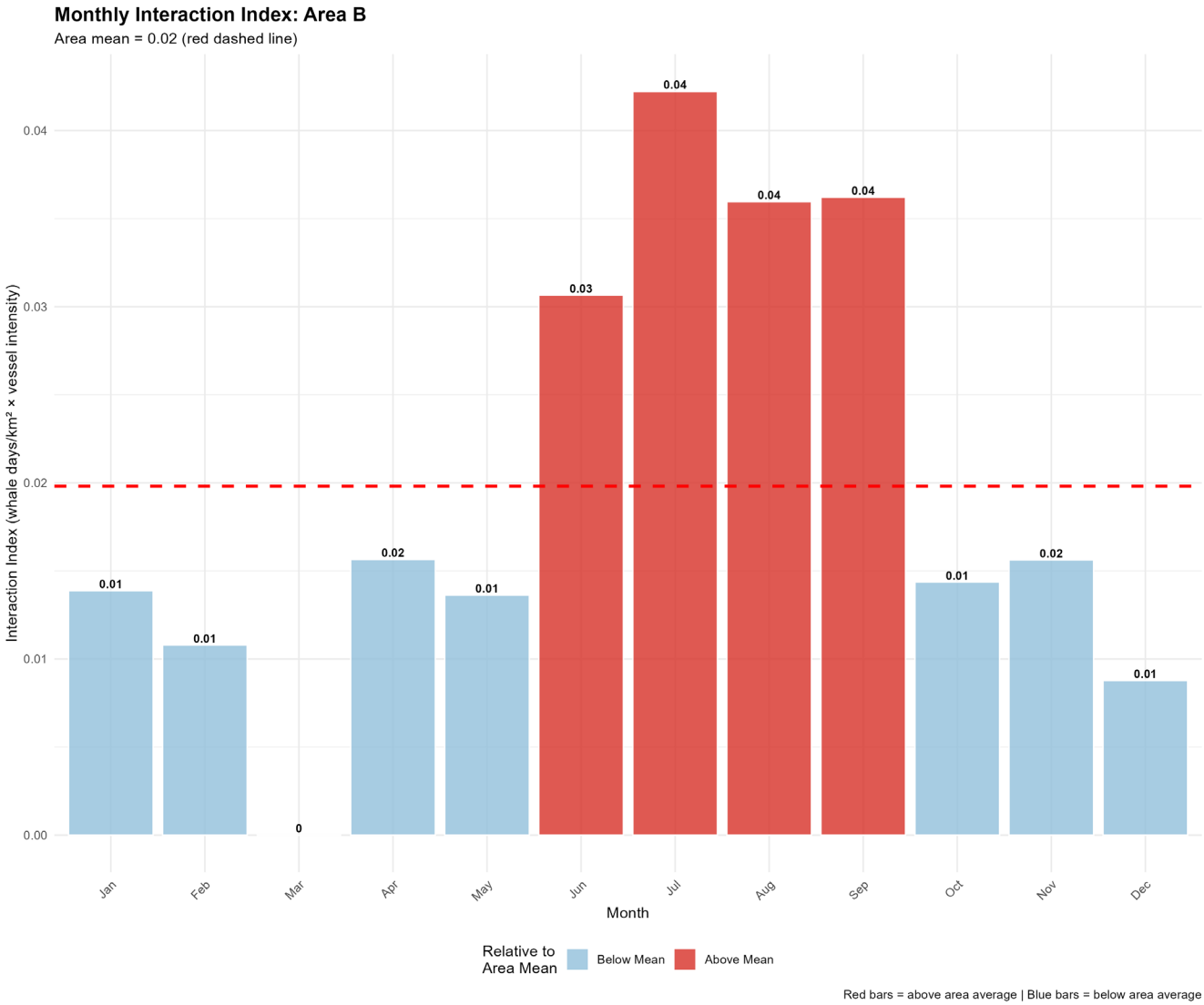


Figure 15. Monthly Interaction Index values for Area B relative to the area's annual mean (0.020, red dashed line). Red bars indicate months with above-average interaction potential, while blue bars show below-average months.

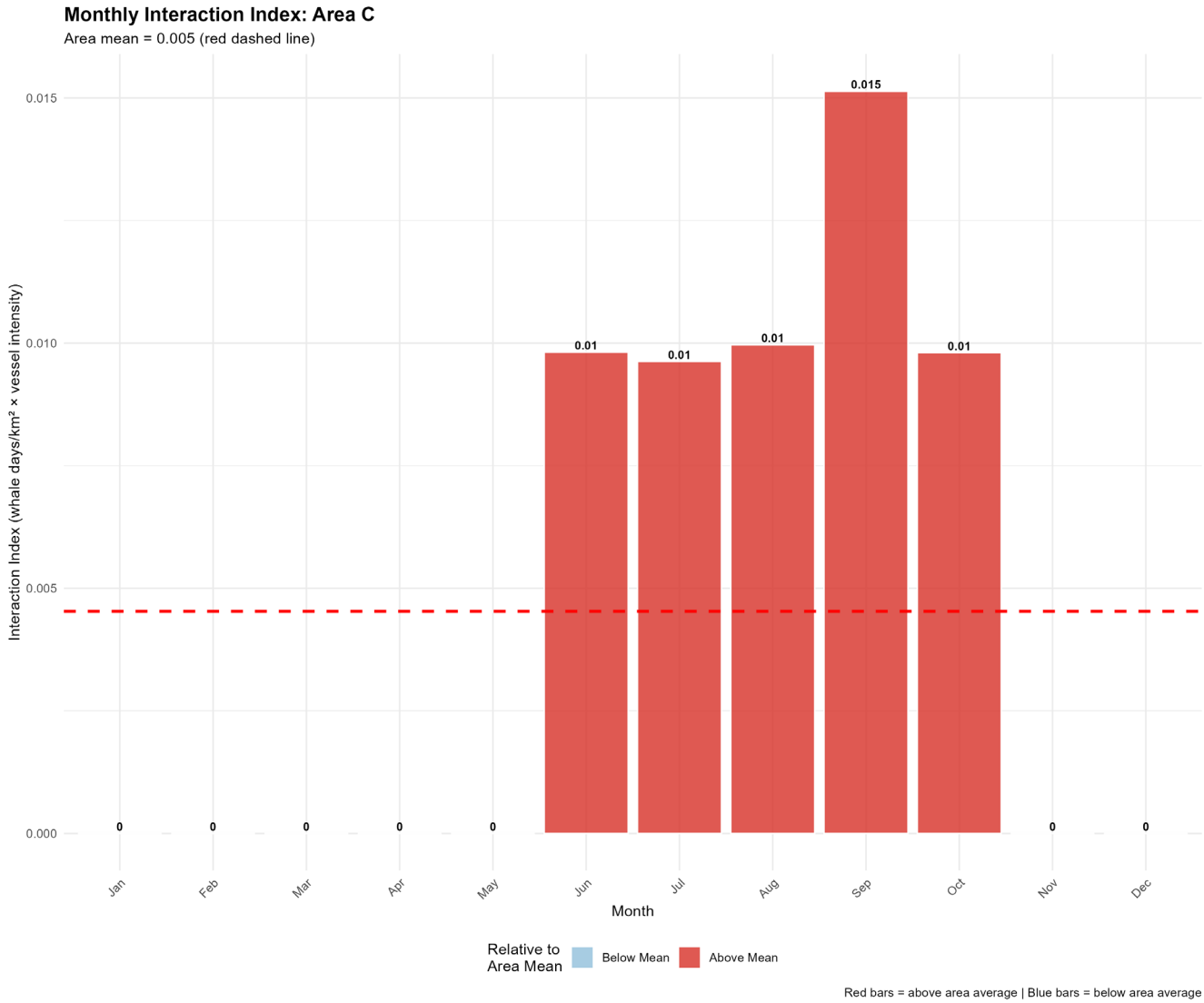


Figure 16. Monthly Interaction Index values for Area C relative to the area's annual mean (0.005, red dashed line). Red bars indicate months with above-average interaction potential. Zero values indicate no whale-vessel overlap during those months.

3.5 Area B: Component Analysis

Given the designation of Area B (Southern Haro Strait to Admiralty Inlet) as the highest priority candidate for a slowdown zone, we examined how whale presence and vessel activity each contributed to the area's interaction potential throughout the year with a component contribution analysis (Figure 17). The two components shown are relative 'whale density' and vessel intensity. Whale density was calculated as the average number of whale days per month in Area B (2019-2023) divided by Area B's size in square kilometers. Vessel intensity represents the total intensity of ship traffic in Area B throughout the study period (hrs km^{-2} $month^{-1}$). To compare these different metrics on the same scale, both Area B values were normalized using the full range observed across all three study areas: each monthly value was converted to a percentage where 0% equals the lowest value found anywhere in the study region and 100% equals the highest value found anywhere in the study

region. This scaling shows how Area B's monthly whale presence and vessel intensity compare relative to the range of conditions observed across the entire study area.

The analysis showed that these two components followed seasonal patterns. During the peak interaction months from July to September, whale density was the dominant driver, accounting for 80-100% of the normalized interaction values. This reflected the seasonal concentration of SRKWs during summer, when their presence was at its highest, while vessel activity remained relatively stable. In contrast, during winter and early spring, when overall interaction levels were low, vessel traffic became the main contributor, making up about 45% of the interaction potential in January and maintaining a steady influence during this period. In transitional months like April and October, whale presence and vessel activity contributed more evenly. These results suggest that Area B's high interaction values were primarily driven by seasonal peaks in whale presence, rather than by changes in vessel activity.

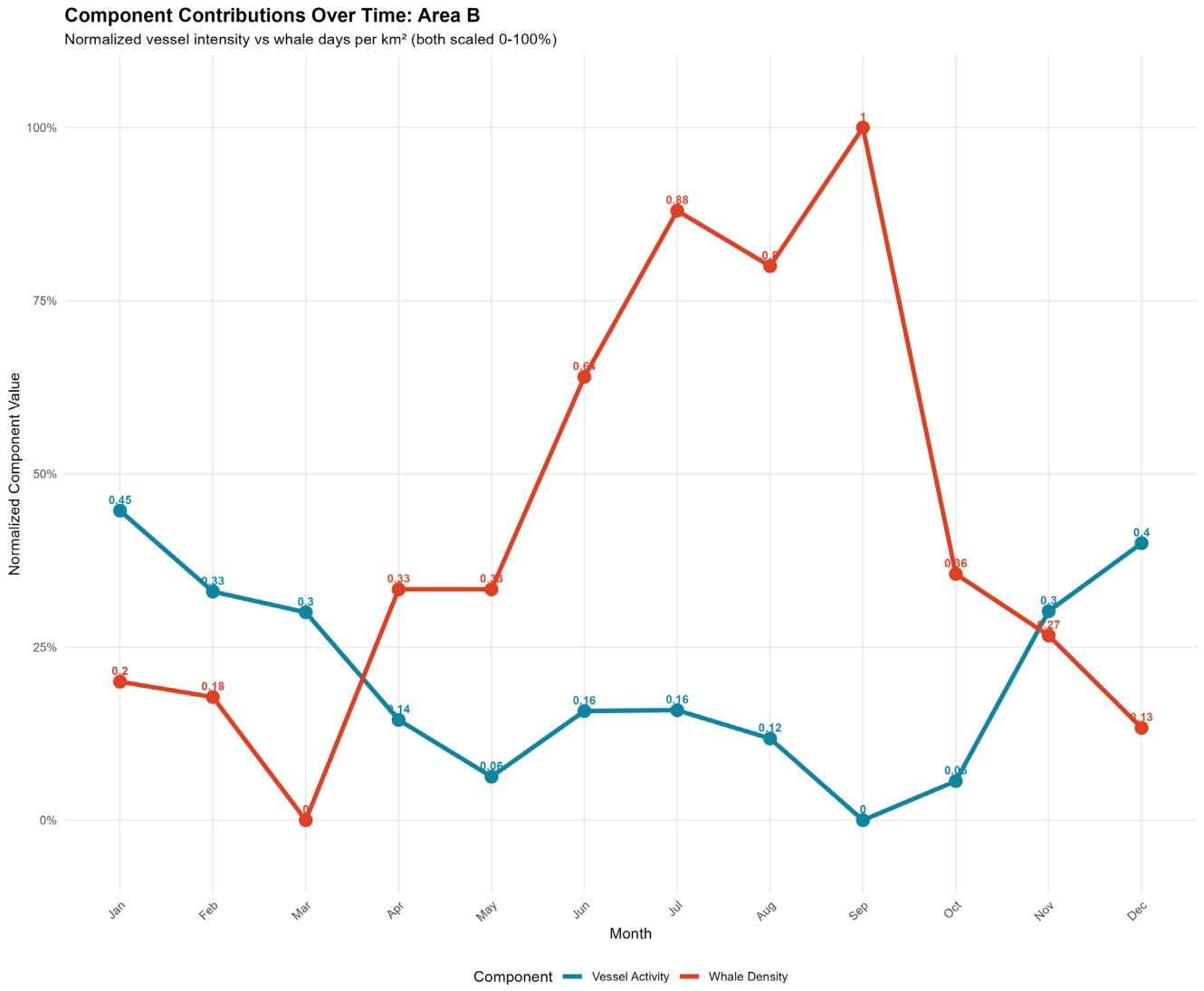


Figure 17. Relative contributions of whale presence and vessel activity to the Interaction Index in Area B throughout the annual cycle. Both components are normalized to 0-100% to show their proportional influence on monthly interaction potential.

A time series visualization of how each vessel category contributes to the interaction index highlighted key differences in the seasonal patterns of vessel-specific interactions in Area B (Southern Haro Strait to Admiralty Inlet; Figure 18). Temporal patterns of vessel category-specific interaction indices in Area B throughout the study period (September 2023- August 2024). Lines show how each vessel category contributes to whale-vessel interaction potential over time, with higher values indicating greater interaction potential for that category during each month. The 10.0 and 11.0 kt groups followed nearly identical patterns, with peak interaction values occurring in July, and elevated levels continuing into September. This similarity suggests that tugs, towing vessels, and cargo ships follow comparable seasonal movement patterns that overlapped closely with peak SRKW presence.

In contrast, the 14.5 kt category peaked in August, and overall interaction values were lower and more variable. This group also had several months with no recorded interaction (particularly in March and during the autumn transition) indicating a more sporadic presence of car carriers, container ships, and cruise ships in the area. Despite these differences, all three vessel types converged during the July to September period, reinforcing this window as the most effective timeframe for targeted speed reductions. The consistently higher interaction values associated with the 10.0 and 11.0 kt groups throughout the active season further emphasize their importance as key targets for mitigation, contributing roughly twice the interaction potential of faster commercial vessels during peak months.

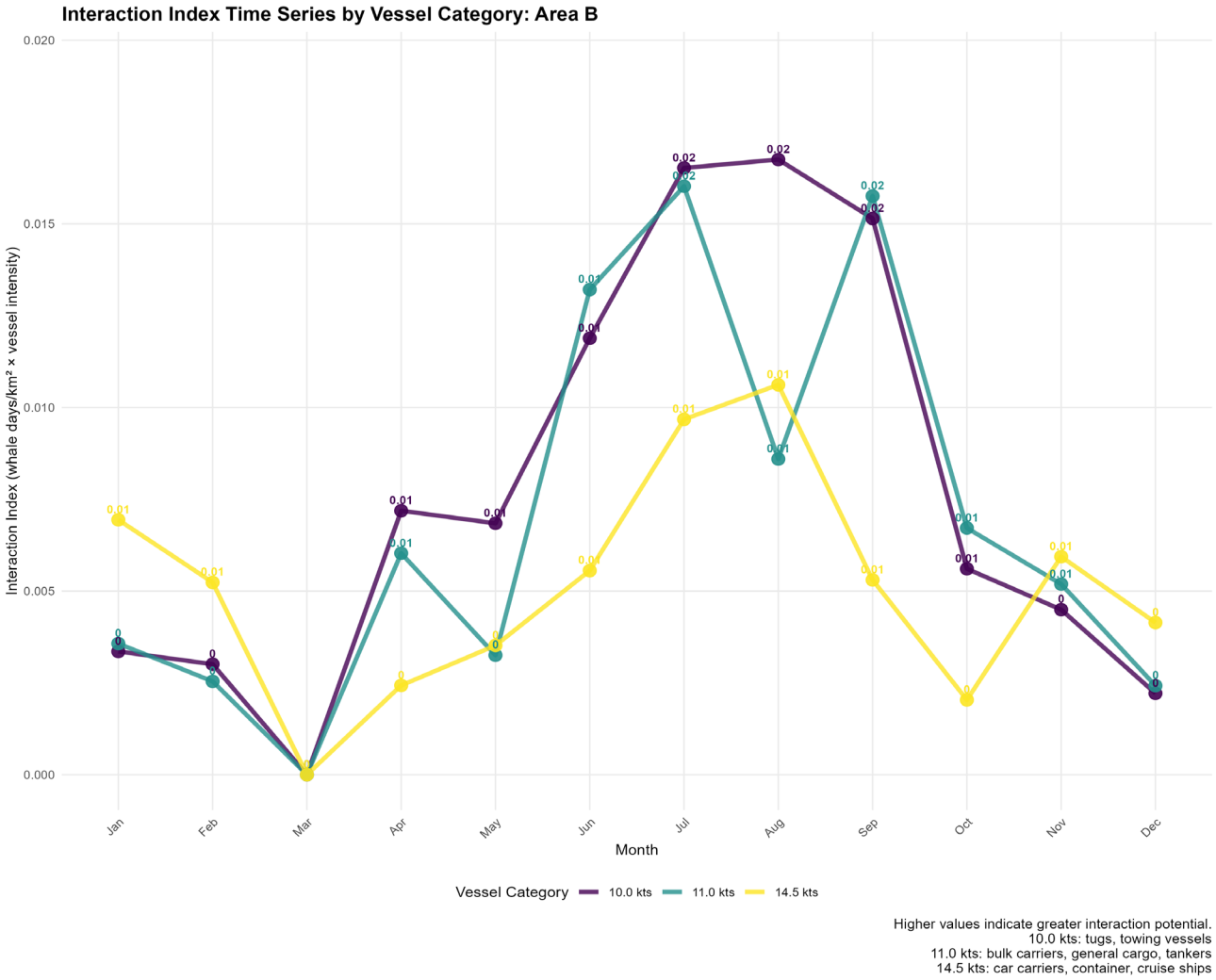


Figure 18. Temporal patterns of vessel category-specific interaction indices in Area B throughout the study period (September 2023- August 2024). Lines show how each vessel category contributes to whale-vessel interaction potential over time, with higher values indicating greater interaction potential for that category during each month.

To complement the time series and heatmap analyses, we also examined how the proportional contributions of each vessel category to Area B's interaction potential changed over the study period (Figure 19. Relative contributions of each vessel category to total monthly interaction potential in Area B. Percentages show how much each vessel category contributes to the interaction index. Note that March shows no bar due to zero whale presence despite vessel activity. During the winter months, when SRKW presence was minimal, the 14.5 kt group (car carriers, container ships, and cruise ships) made up a larger share of the limited interaction potential despite contributing little in absolute terms. This pattern reflected low whale presence rather than increased vessel activity from the 14.5 kt group. As whale presence increased in spring and peaked in summer, the slower vessel groups (10.0 and 11.0 kt) accounted for the majority of potential interactions. From June through September, the 10.0 kt group alone contributed nearly half of the total interaction index, with the 11.0 kt group providing a consistent secondary contribution. Meanwhile, the relative importance of the 14.5 kt group declined sharply, despite their continued presence.

These seasonal shifts highlight that while vessels in the 14.5 kt group appear more dominant during periods of low whale presence, the bulk of potential whale-vessel interactions during the critical summer period involve tugs, towing vessels and cargo ships. Targeting these slower categories with slowdowns during peak SRKW activity would likely offer the greatest conservation benefit.

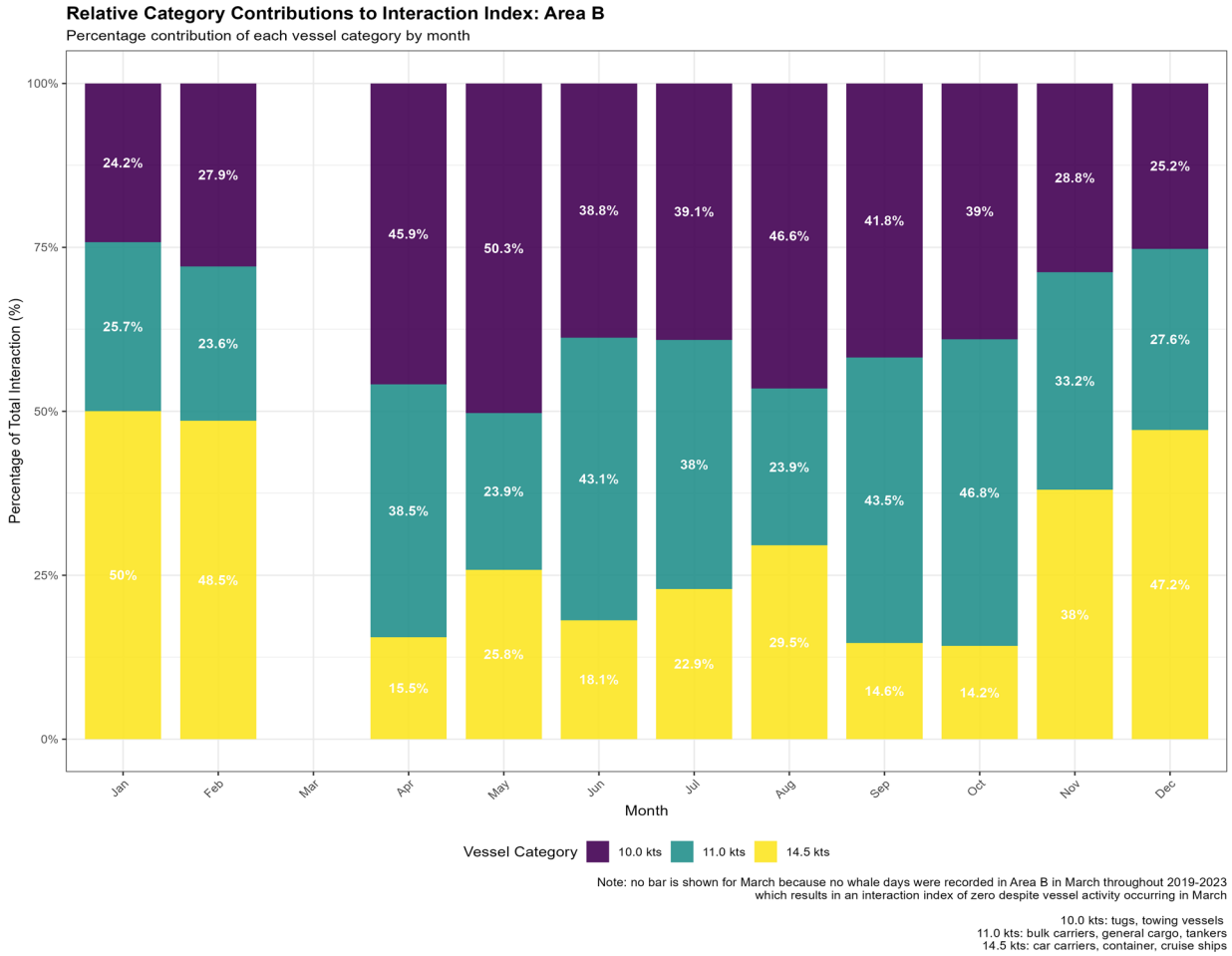


Figure 19. Relative contributions of each vessel category to total monthly interaction potential in Area B. Percentages show how much each vessel category contributes to the interaction index. Note that March shows no bar due to zero whale presence despite vessel activity.

3.6 Contribution of Vessel Categories to Interaction Index

To further explore the role of whale presence in shaping interaction potential across the sub-areas, we examined which vessel categories contributed most to the interaction index during peak periods (Figures 20-22). In Area B, vessels in the 10.0 kt group (tugs and towing vessels) contributed the highest interaction values, particularly between July and September. This group also exhibited the most sustained interaction pattern, with elevated values extending from June into the fall transition period. The 11.0 kt group (bulk carriers, general cargo, and tankers) followed a similar seasonal pattern, though at lower intensity, with notable peaks in July and September. In contrast, the 14.5 kt category (car carriers, container ships, and cruise ships) contributed the least to overall interaction potential, with sporadic presence and very low values, including months of complete absence.

All vessel categories reached their highest interaction values during the July–September window, aligning with the seasonal peak in whale presence. While the overlap is clearly driven by whale distribution, the predominance of the slower vessel types (10.0 and 11.0 kt) in generating interaction potential suggests that a speed reduction in Area B (Southern Haro Strait to Admiralty Inlet) would primarily affect tugs, towing vessels, and cargo ships i.e. vessel types most frequently overlapping with whales during the critical summer period.

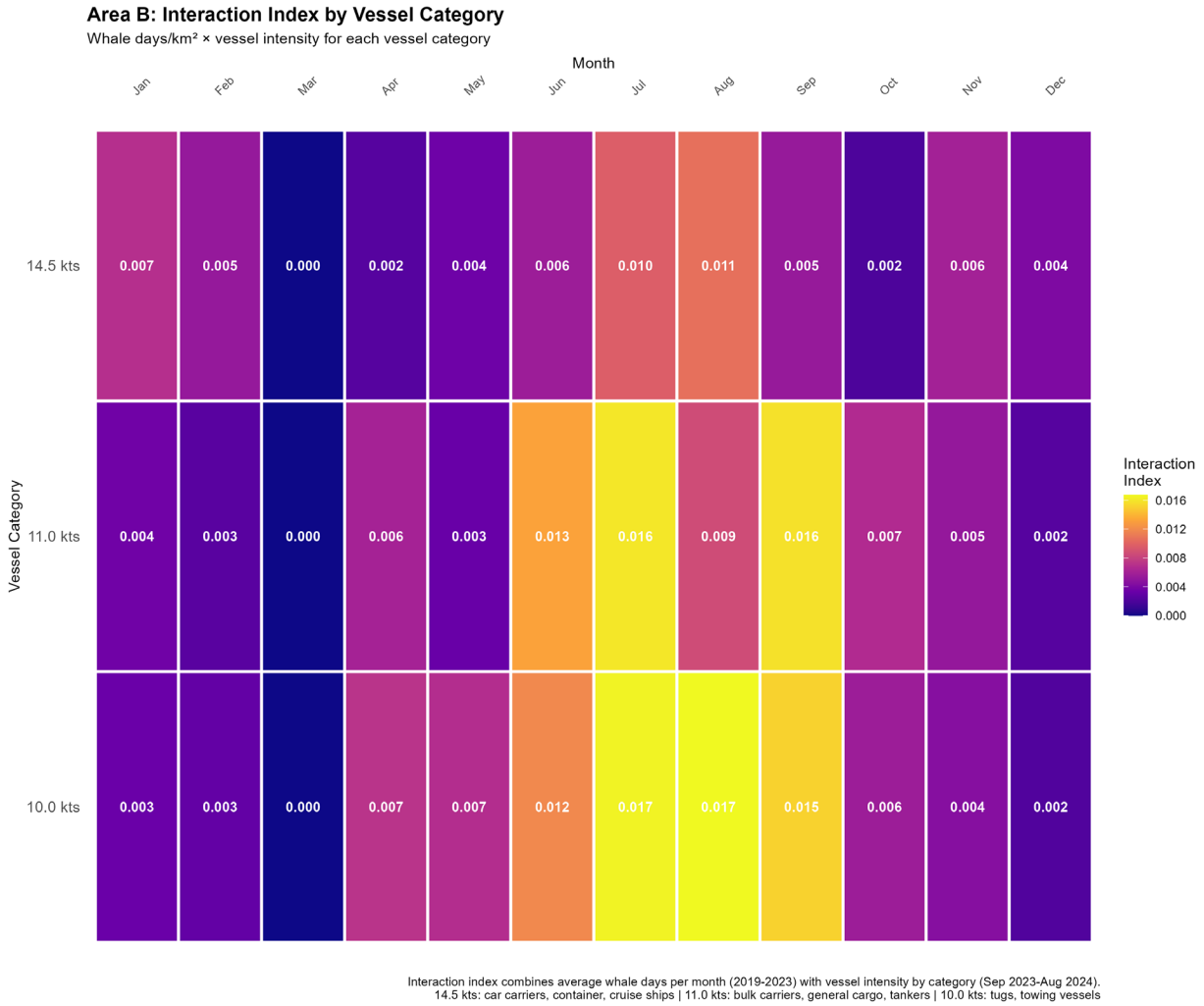


Figure 20. Interaction Index by vessel category in Area B (Southern Haro Strait to Admiralty Inlet). The heatmap shows whale-vessel interaction potential for each vessel category, with higher values (yellow) indicating greater interaction potential. Dark blue indicates zero interaction potential due to absence of whales, vessels, or both.

In comparison, Area A (Rosario Strait) showed interaction potential concentrated from February through October and was dominated by 10.0 kt vessels with peak values occurring during March. Interaction potential in Area C (Port Angeles to Admiralty Inlet) was concentrated from June through October and dominated by 14.5 kt vessels.

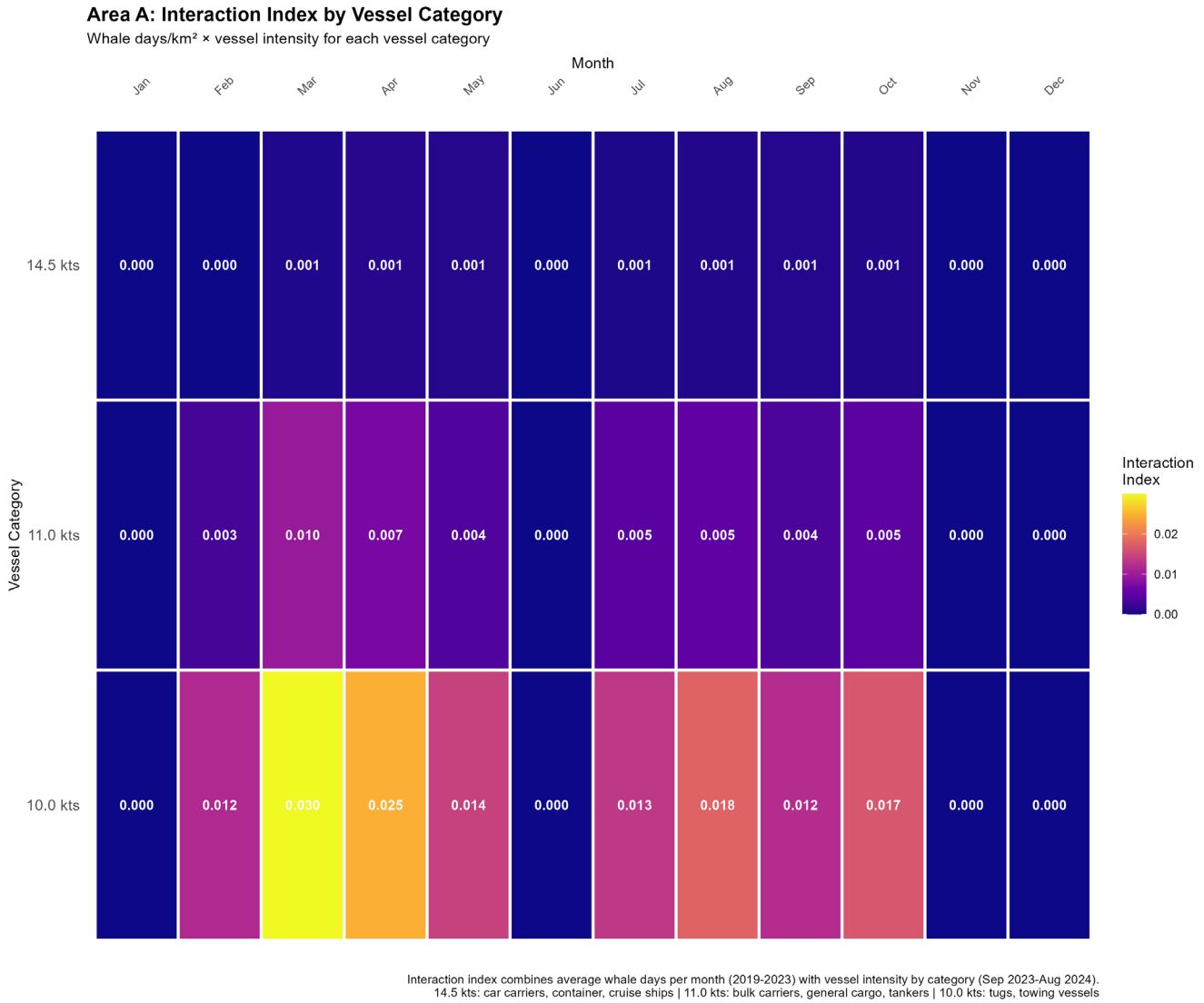


Figure 21. Interaction Index by vessel category in Area A (Rosario Strait). The heatmap shows whale-vessel interaction potential for each vessel category, with higher values (yellow) indicating greater interaction potential. Dark blue indicates zero interaction potential due to absence of whales, vessels, or both.

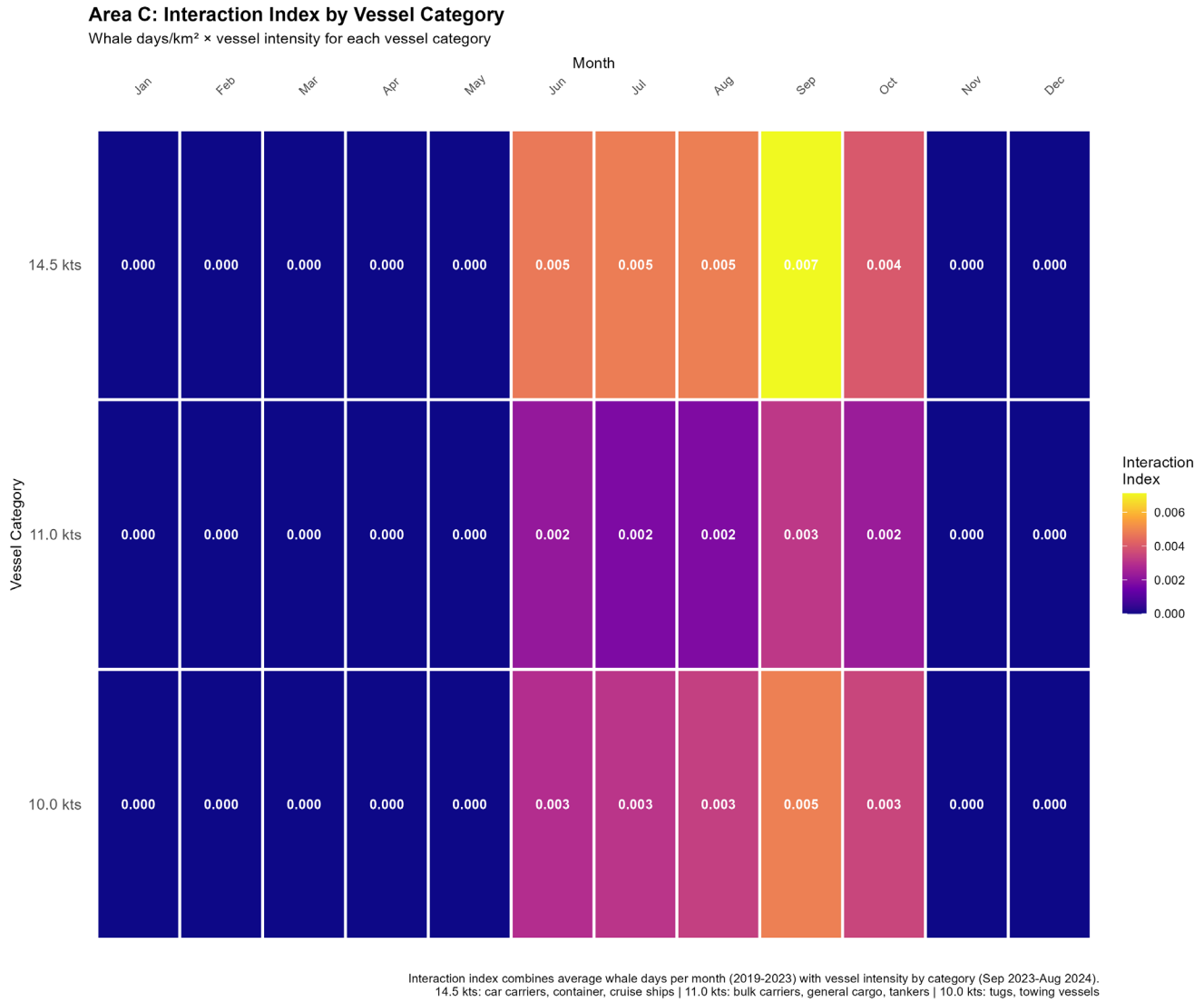


Figure 22. Interaction Index by vessel category in Area C (Port Angeles to Admiralty Inlet). The heatmap shows whale-vessel interaction potential for each vessel category, with higher values (yellow) indicating greater interaction potential. Dark blue indicates zero interaction potential due to absence of whales, vessels, or both.

3.7 Discussion

This study identified and ranked three candidate areas for vessel speed reduction measures (i.e. voluntary vessel slowdowns) in the central Salish Sea, based on their potential to reduce risks to Southern Resident Killer Whales (SRKWs). Using an Interaction Index that integrates whale presence with vessel traffic patterns, the analysis revealed clear spatial and seasonal variation in whale-vessel interaction potential across the region.

Area B (Southern Haro Strait to Admiralty Inlet) was ranked as the highest priority slowdown candidate, with the highest average interaction potential and sustained elevated values from June through October. Peak values occurred in July, coinciding with a peak whale presence. Importantly,

elevated interaction levels in Area B (Southern Haro Strait to Admiralty Inlet) were driven primarily by seasonal increases in whale presence, rather than elevated vessel traffic. The region immediately northwest of Area B (Southern Haro Strait to Admiralty Inlet) has hosted voluntary vessel slowdown initiatives through the ECHO Program since 2017, achieving over 85% participation and up to 55% reductions in underwater noise in critical SRKW habitat (Malinka et al. 2024). These slowdowns are especially effective at reducing noise in frequencies used by SRKWs, more so than in areas like Swiftsure Bank (Burnham et al. 2021). Additionally, the existing Quiet Sound slowdown occurs southeast of Area B (Matei et al. 2024). Prioritizing Area B (Southern Haro Strait to Admiralty Inlet) therefore aligns with established conservation efforts and may benefit from existing industry engagement with speed reduction practices.

Area A (Rosario Strait) ranked second. It exhibited a different seasonal pattern, with a strong peak in March linked to elevated vessel activity particularly from tugs and towing vessels, and more variable whale presence throughout the rest of the year. Area C (Port Angeles to Admiralty Inlet) consistently ranked lowest, with limited whale-vessel interaction potential, which occurred primarily in September. Across all areas, slower-moving vessels, especially tugs, towing vessels, and cargo ships, were responsible for the majority (75–85%) of interaction potential during the key summer months. This highlights them as the most effective targets for speed reduction. The June–October period represented the most critical window for implementing a slowdown, when both whale presence and vessel traffic intensity are highest. In Area B (Southern Haro Strait to Admiralty Inlet) alone, these four months accounted for 85% of annual interaction potential, suggesting seasonal restrictions could achieve most conservation benefits without requiring year-round limits.

3.8 Study limitations

A key limitation of the analysis is the whale sightings data used in this project, which is based on opportunistic sightings that are not effort corrected. The use of unique ‘whale days’ helps to counter the lack of effort correction; however the lowest ranking of Area C (Port Angeles to Admiralty Inlet) could be partly attributed to lower sightings efforts in that area. It is also worth noting the lack of data on recreational vessels, which often do not carry AIS transmitters. In many shallow coastal regions, recreational boats make up the majority of traffic, and studies have estimated that non-AIS vessels can comprise up to 83% of observed boats (Hermannsen et al. 2019). Because AIS use is voluntary for most recreational craft, it is likely that this study underestimates actual vessel intensity and, by extension, the potential conservation benefits of speed reductions. This analysis focused only on vessels currently targeted by the Quiet Sound slowdown program (i.e. those in the 10.0, 11.0, and 14.5 kt categories). Other AIS-equipped vessels were excluded, but maps of their activity (‘Other’ category) are provided in the Appendix.

4 Acknowledgments

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OrcaMaster database, Laura Koehn (NOAA) for sharing R code to analyze whale sightings data, and Meadhbh Quinn of SMRU Consulting for producing the maps in this report.

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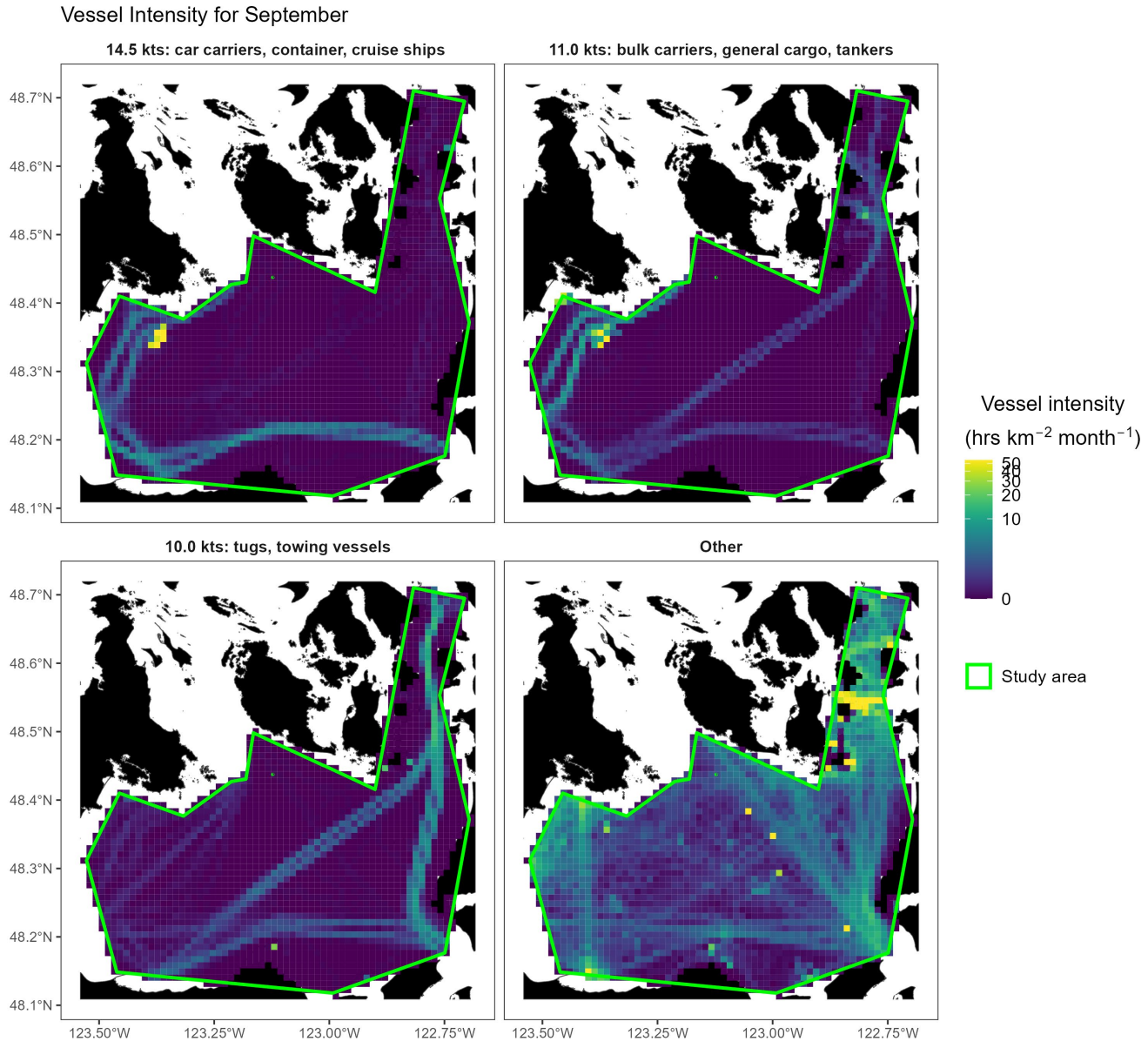
Matei, M., R. Charish, M. Quinn, F. Wilder, S. Tabbutt, and J. Wood. 2024. Quiet Sound Vessel Slowdown 2023. SMRU Consulting report to Quiet Sound.

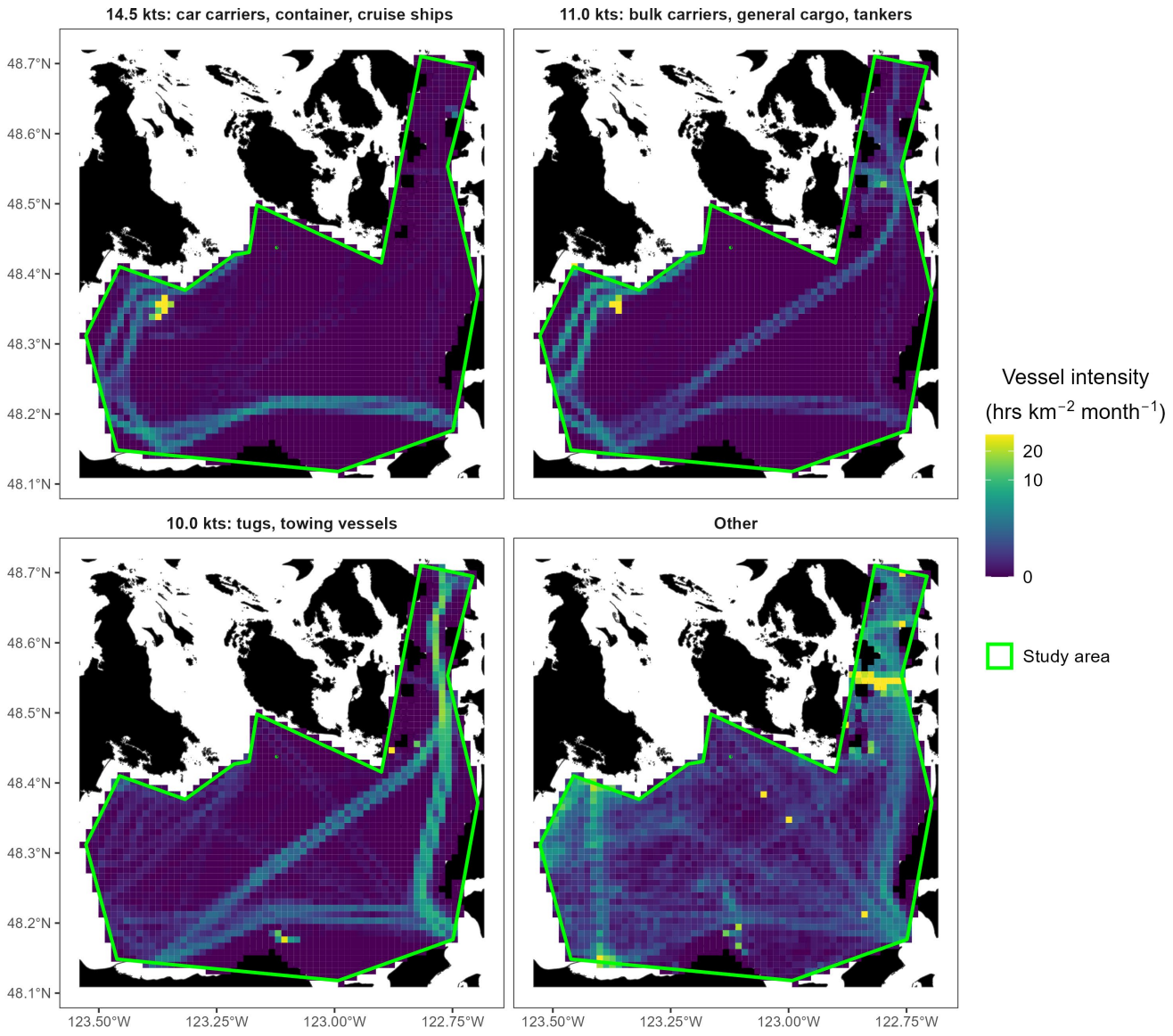
Tennessen, J. B., M. M. Holt, B. M. Wright, M. B. Hanson, C. K. Emmons, D. A. Giles, J. T. Hogan, S. J. Thornton, and V. B. Deecke. 2024. Males miss and females forgo: Auditory masking from vessel noise impairs foraging efficiency and success in killer whales. Global change biology **30**:e17490.

5 Appendix

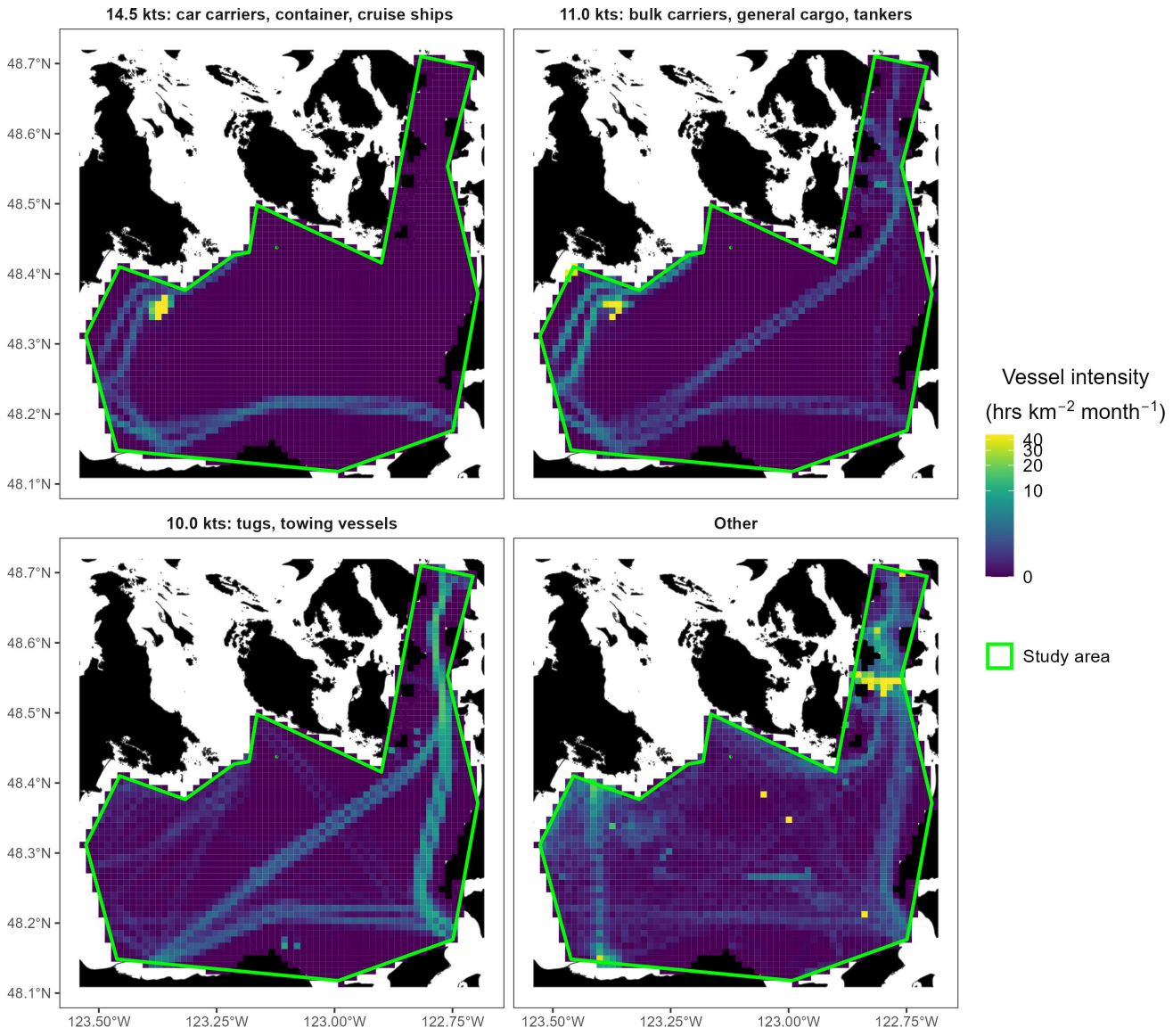
The following 12 figures present the recorded vessel intensity inside of the central Salish Sea study area, split by month and Quiet Sound vessel speed category.



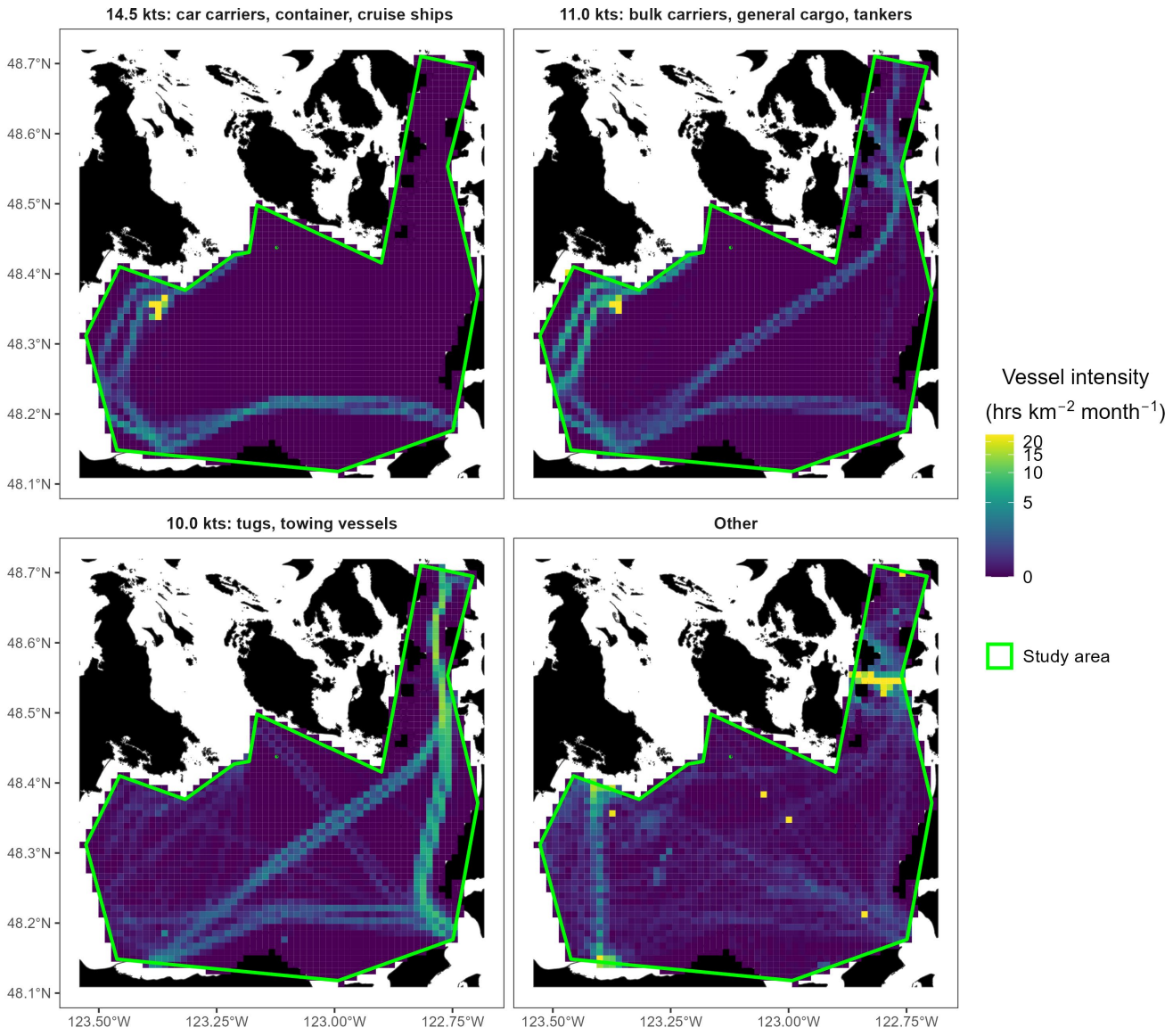
Vessel Intensity for October



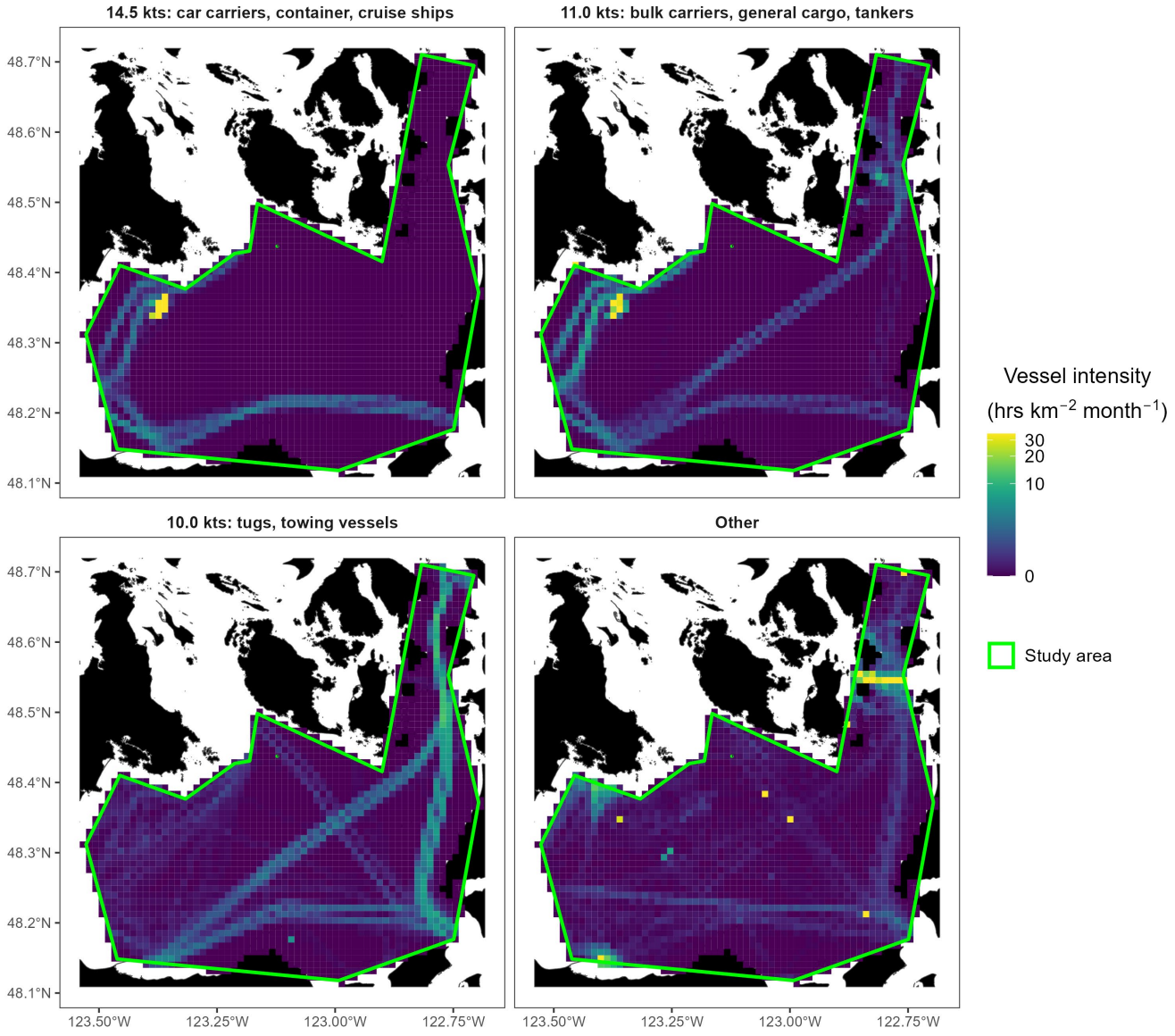
Vessel Intensity for November



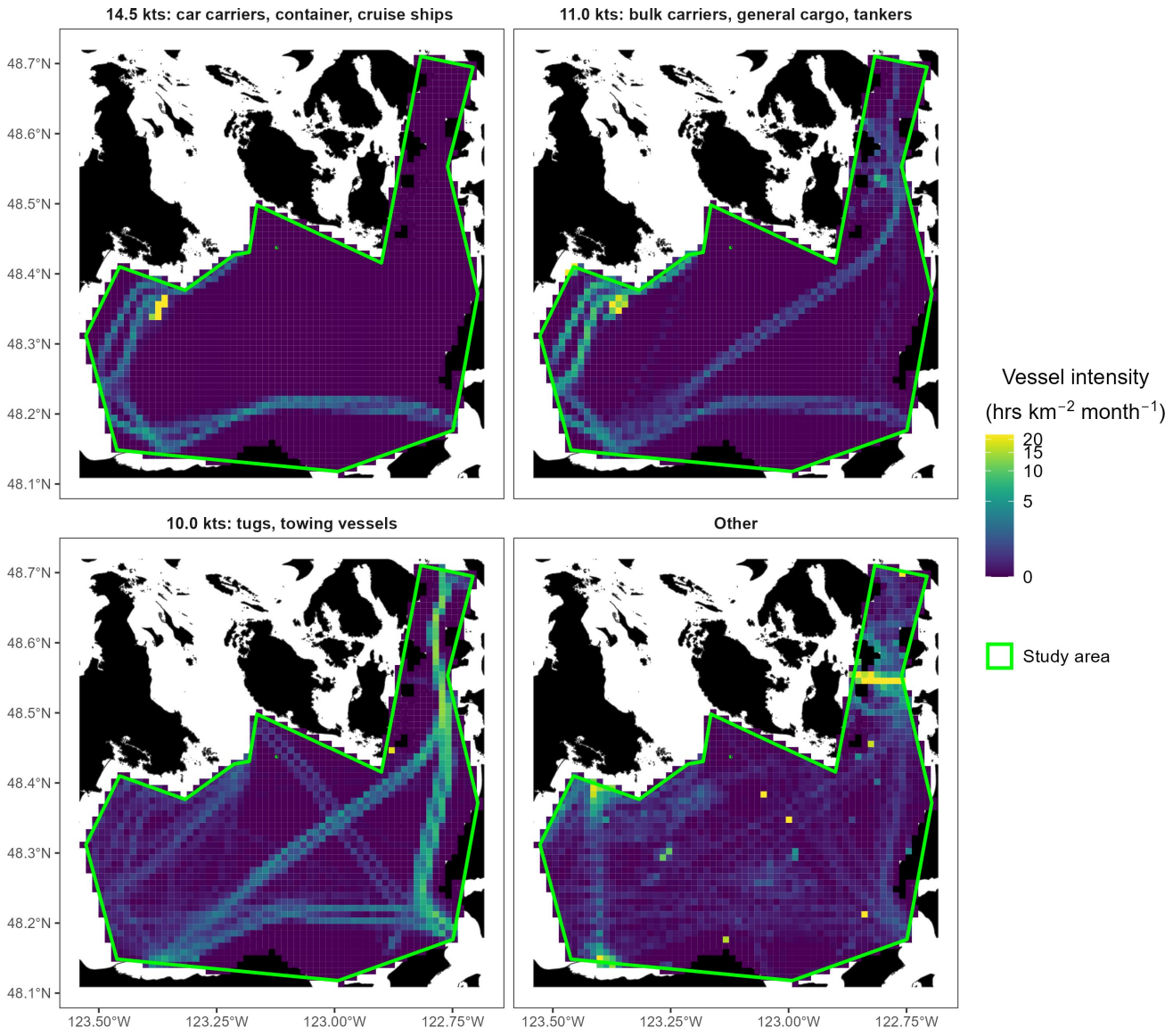
Vessel Intensity for December



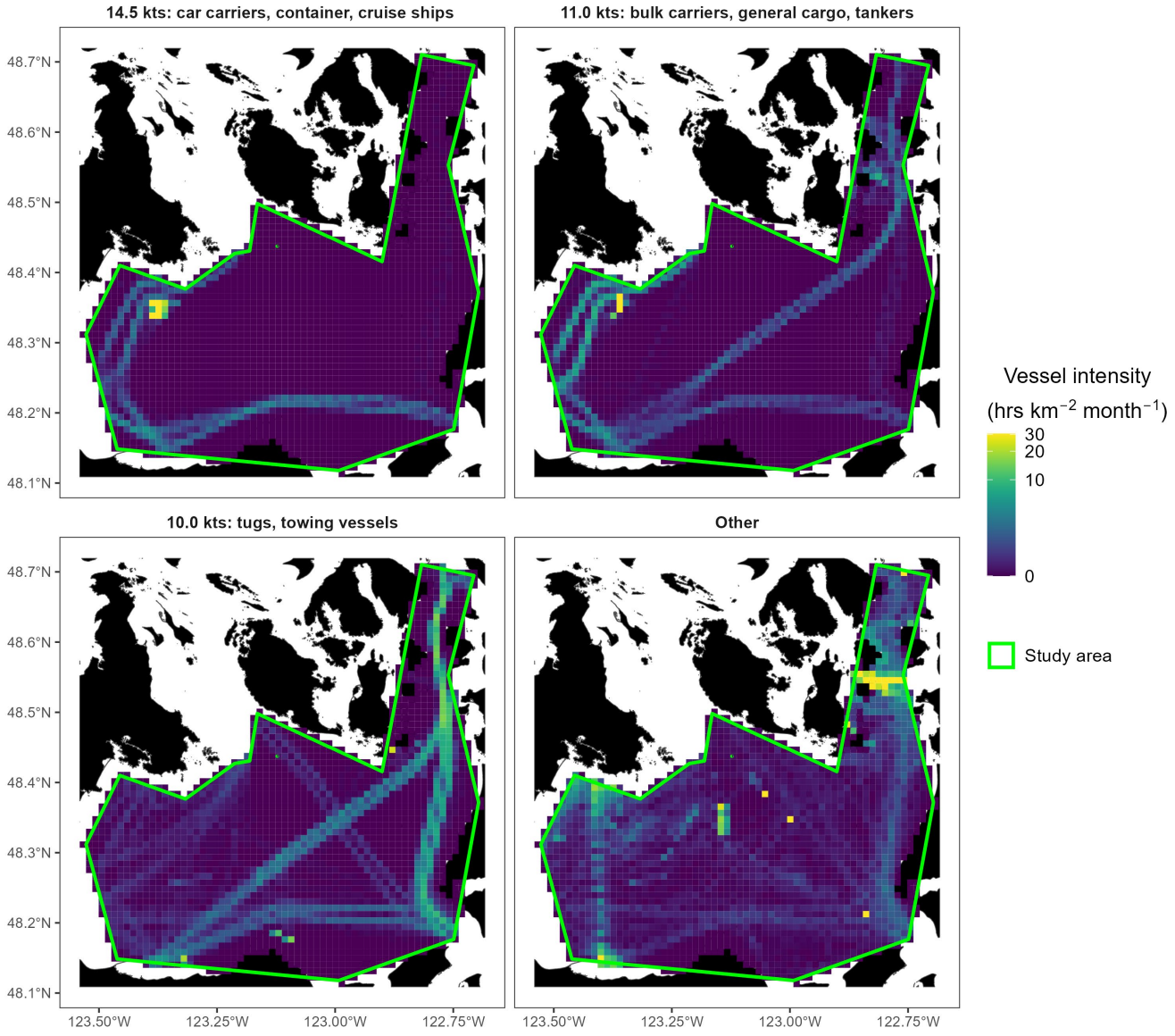
Vessel Intensity for January



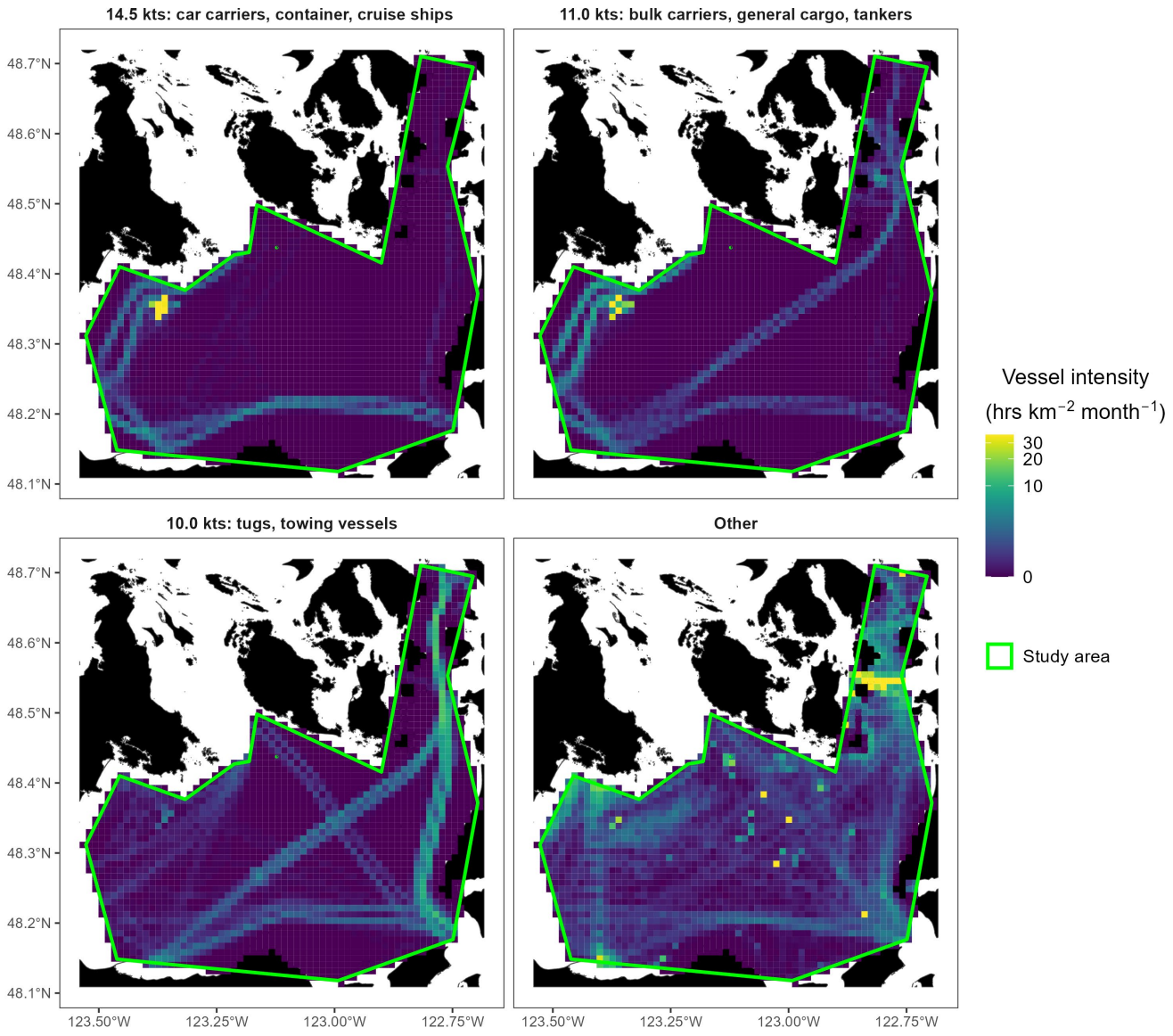
Vessel Intensity for February



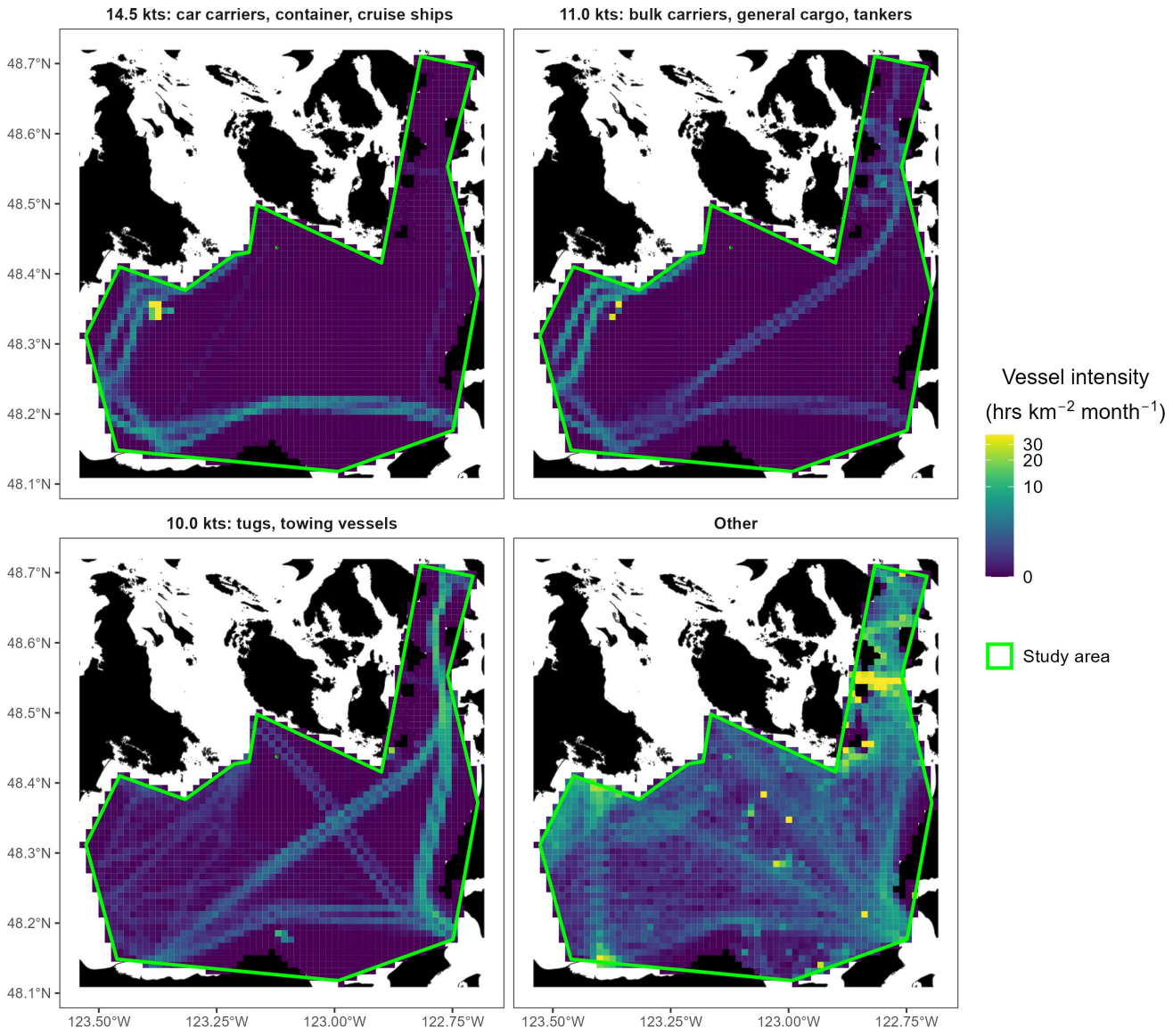
Vessel Intensity for March



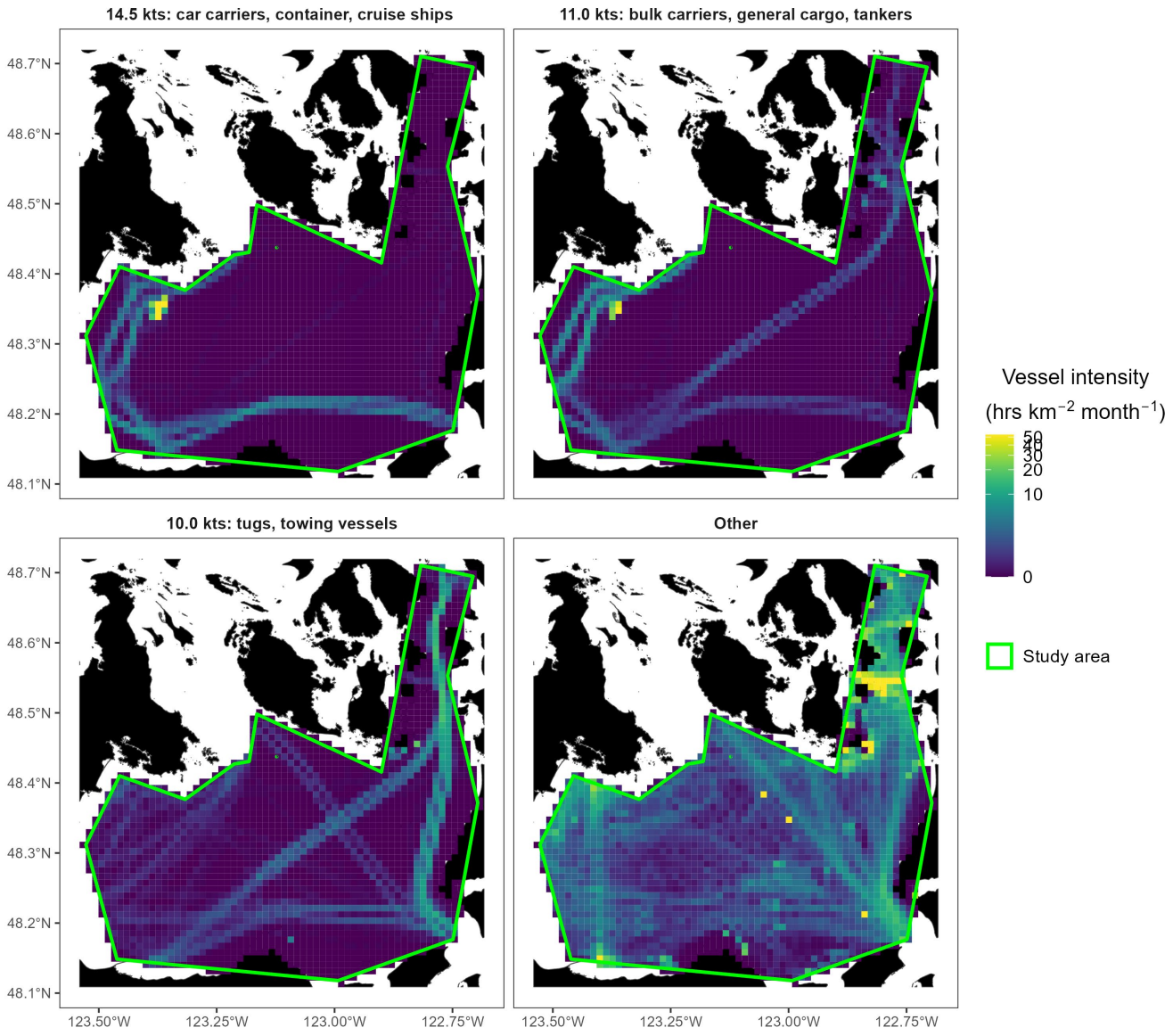
Vessel Intensity for April

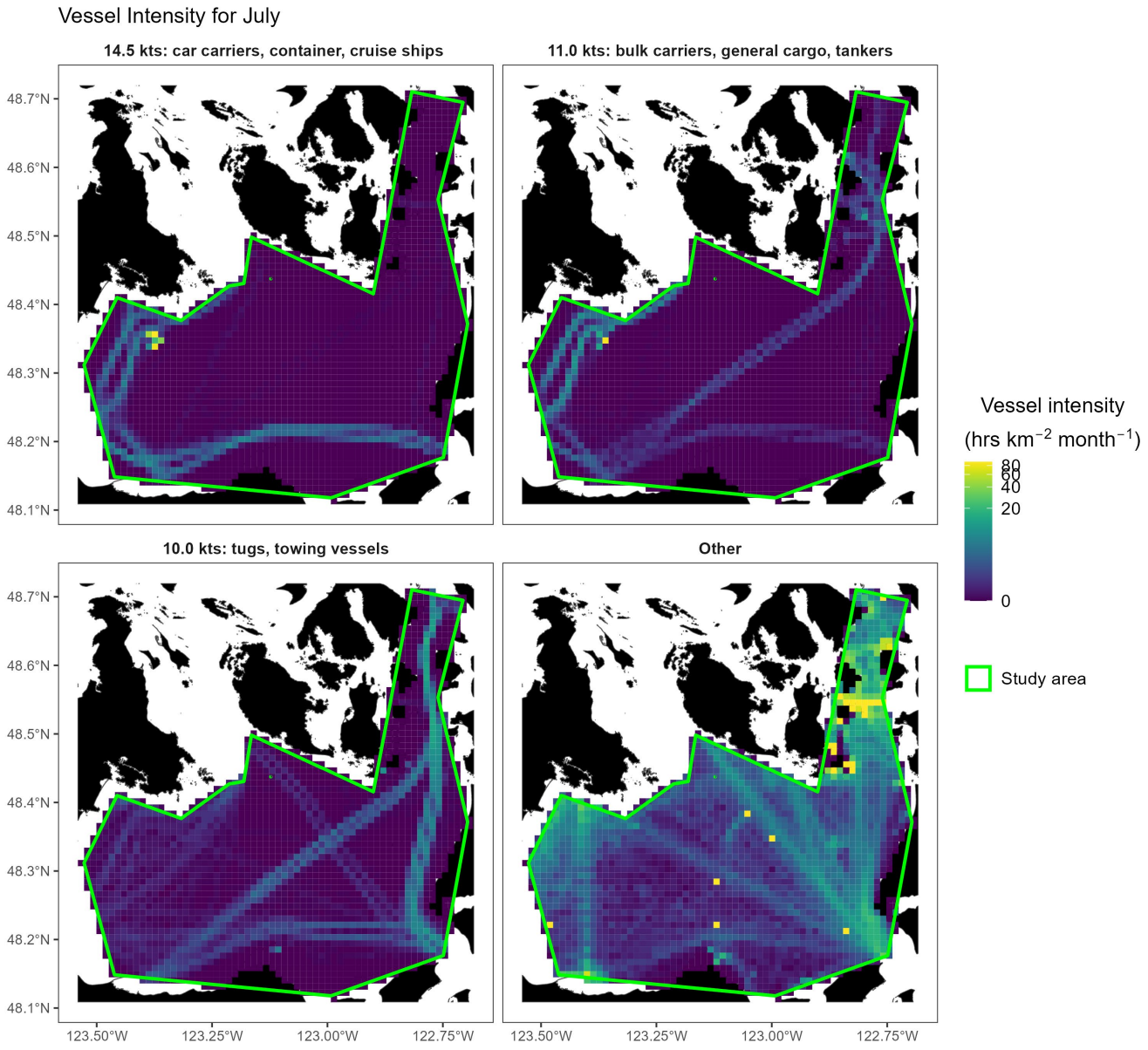
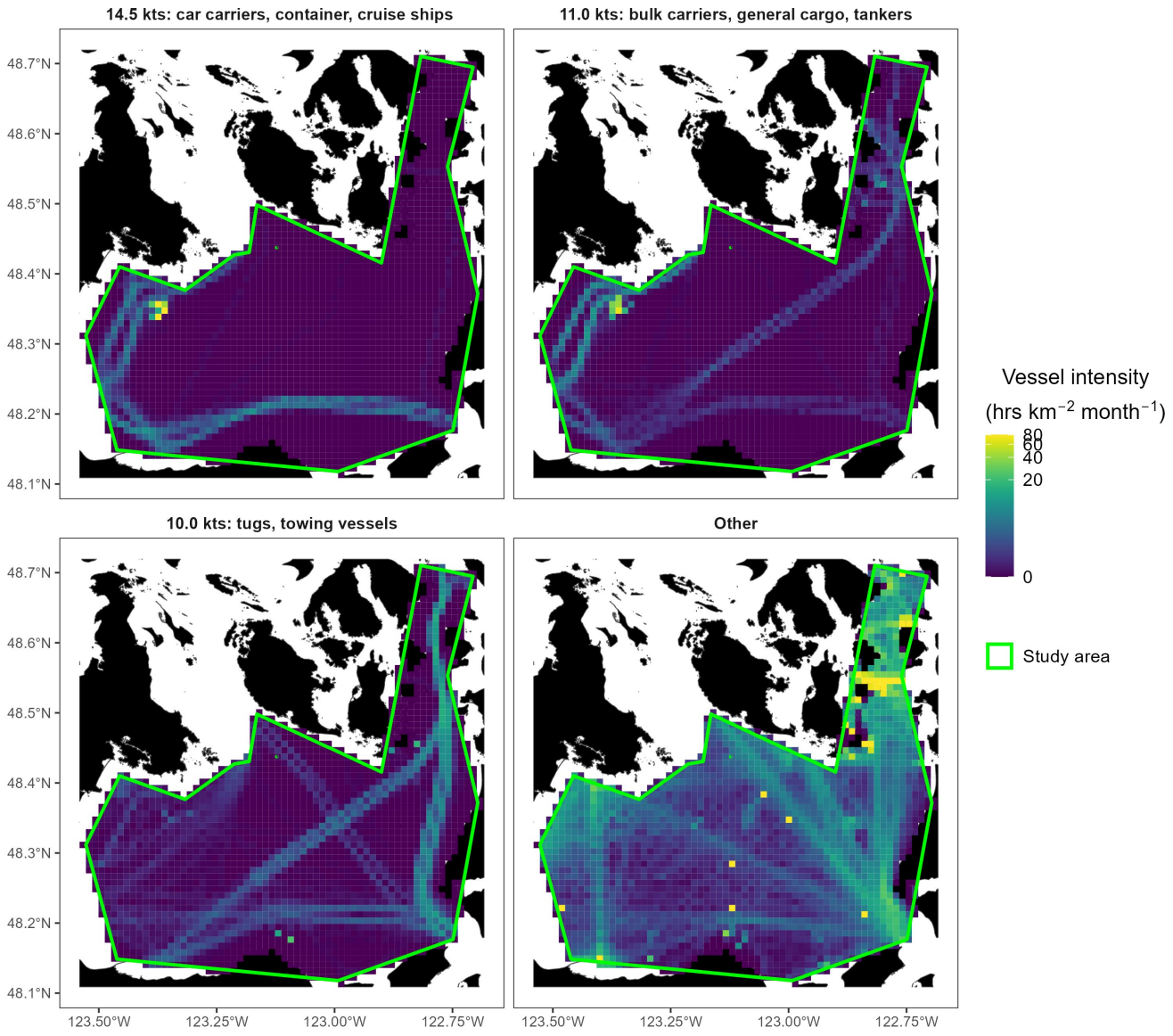


Vessel Intensity for May



Vessel Intensity for June




Vessel Intensity for July
14.5 kts: car carriers, container, cruise ships
11.0 kts: bulk carriers, general cargo, tankers
10.0 kts: tugs, towing vessels
Other
48.7°N
48.6°N
48.5°N
48.4°N
48.3°N
48.2°N
48.1°N
123.50°W
123.25°W
123.00°W
122.75°W
Vessel intensity
(hrs km^{-2} month^{-1})
80
60
40
20
0
Study area

Vessel Intensity for August