Evaluation of the effects on underwater noise levels from shifting vessel traffic away from Southern Resident Killer Whale foraging areas in the Strait of Juan de Fuca in 2018

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EVALUATION OF THE EFFECTS ON UNDERWATER NOISE LEVELS FROM SHIFTING VESSEL TRAFFIC AWAY FROM SOUTHERN RESIDENT KILLER WHALE FORAGING AREAS IN THE STRAIT OF JUAN DE FUCA IN 2018

by

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Between August 20 and October 31, 2018 the Vancouver Fraser Port Authority and Transport Canada led a voluntary program where all outbound deep sea vessels and inshore vessels (tugs) in a portion of the Strait of Juan de Fuca were requested to shift their outbound tracks southwards, and further away from areas of critical importance to the endangered Southern Resident Killer Whale (SRKW) population. The main goal of this study was to investigate the efficacy of lateral vessel displacement to reduce the impact of underwater vessel noise on SRKW at three locations off Port Renfrew, Jordan River and Sooke. The mean distance between the monitoring location off Jordan River and the outbound deep sea vessels increased by 632 m (from 5256 m to 5888 m) during the study and resulted in a broad-band (10-100,000 Hz) noise reduction varying between 0.6 and 1.0 dB, dependent on vessel type. These are small reductions when compared to vessel-to-vessel noise output and acoustic propagation variabilities. However, the mean lateral displacement of tugs increased by 1896 m (from 2010 m to 3906 m), which resulted in a significant broad-band noise reduction of 4.3 dB.

RÉSUMÉ

Vagle, S., and Neves, M. 2019. Evaluation of the effects on underwater noise levels from shifting vessel traffic away from Southern Resident Killer Whale foraging areas in the Strait of Juan de Fuca in 2018. Can. Tech. Rep. Hydrogr. Ocean Sci. 329 : vi + 64 p.

Entre le 20 août et le 31 octobre 2018, l’Administration portuaire Vancouver Fraser et Transports Canada ont dirigé un programme volontaire dans le cadre duquel tous les navires de haute mer et les navires côtiers (remorqueurs) en partance d’une partie du détroit de Juan de Fuca ont dû modifier leur route vers le sud et s’éloigner des zones qui ont une importance critique pour la population en voie de disparition d’épaulards résidants du Sud. L’objectif principal de ce programme était d’étudier l’efficacité du déplacement latéral des navires pour réduire l’incidence du bruit sous-marin sur l’épaulard résidant du sud à trois endroits au large de Port Renfrew, Jordan River et Sooke. Au cours de l’étude, la distance moyenne entre le site de surveillance au large de Jordan River et les navires de haute mer en partance a augmenté de 632 m (elle est passée de 5 256 m à 5 888 m), ce qui a entraîné une réduction du bruit à large bande (de 10 à 100 000 Hz), variant entre 0,6 et 1 dB, selon le type de navire. Il s’agit de faibles réductions par rapport aux variations des émissions sonores d’un navire à l’autre, ainsi qu’aux variations en matière de propagation acoustique. Toutefois, le déplacement latéral moyen des remorqueurs a augmenté de 1 896 m (il est passé de 2 010 m à 3 906 m), ce qui a entraîné une réduction significative du bruit à large bande, soit 4,3 dB.

List of Acronyms

AIS: Automatic Identification System

ATC: ECHO Program’s Acoustic Technical Committee

dB: Decibel

DFO: Department of Fisheries and Oceans / Government of Canada

ECHO: Vancouver Fraser Port Authority’s Enhancing Cetacean Habitat and Observation Program

Hz: Hertz

IQR: Interquartile range measured from the 25th to the 75th percentile.

kHz: kiloHertz

Leq: Equivalent continuous sound level, also known as the time-average sound level.

m: meter

OPP-MEQ: Ocean Protection Plan-Marine Environmental Quality Program

PSD: Power Spectral Density

RMS: Root Mean Square

SL: Source Level

SPL: Sound Pressure Level

SRKW: Southern Resident Killer Whale

TC: Transport Canada / Government of Canada

1 EXECUTIVE SUMMARY

Between August 20 and October 31, 2018 the Vancouver Fraser Port Authority and Transport Canada led an initiative that requested all deep sea vessels leaving Victoria, B.C. to voluntarily shift their outbound tracks to a more southern part of the existing shipping lane. The initiative also requested all inshore traffic to move southbound, while still operating outside the deep sea shipping lanes. This effort is part of an ongoing study to investigate the efficacy of different mitigation techniques to reduce the impact of underwater noise from vessels on areas of critical importance to the endangered Southern Resident Killer Whale (SRKW) population. The trial area was between longitudes 124° and 124.66° West, over a distance of approximately 34 nautical miles. In this study we used acoustic data from 3 passive acoustic monitoring moorings deployed by the Department of Fisheries and Oceans in Strait of Juan de Fuca of Port Renfrew, Jordan River, and Sooke to monitor the soundscape in important SRKW foraging areas in a portion of their critical habitat. Hydrophone data from April 16th to August 20th and between November 1st and 30th were used as a baseline data set. Only vessels with Class-A AIS transmitters were used.

All acoustic metrics showed noise reductions at the Jordan River location inside the trial corridor, while there were mixed results at the Sooke location, East of the actual trial area, and at the Port Renfrew location towards the end of the trial area.

Findings for the Jordan River (48.397N 124.134W) location within the lateral displacement area:

- Deep-sea vessels moved approximately 600 m further south in the outbound shipping lane; from approximately 5300 m to approximately 5900 m. Tugs moved approximately 1900 m further south; from approximately 2000 m to approximately 3900 m.
- Lunar-month weekly and daily variability cannot be explained by Class-A commercial vessels. This variability needs to be assessed based on changes in oceanographic conditions and non-AIS vessel activity.
- Frequency band cumulative distribution function SPL analysis suggested that the overall median ambient noise reduction at the Jordan River location (L50) during the trial was 2.8 dB in the 0.5-15 kHz band (SRKW communication band), 1.2 dB in the 10-100,000 Hz band (broad-band), 1.1 dB in the 10-100 Hz band, 0.6 dB in the 100-1000 Hz band, 3.1 dB in the 1-10 kHz band, and 1.4 dB in the 10-100 kHz band.
- Investigating individual vessel classes found that bulk carriers had a 0.8 dB reduction in broad-band (10-100,000 Hz) SPL, tankers had a 0.9 dB reduction; container ships had a 0.6 dB reduction; cruise ships had a 0.6 dB reduction, and vehicle carriers had a 1.0 dB reduction. None of these vessel classes contributed to the measured noise level at any acoustic frequencies above 15 kHz. The vessel to vessel variability in Source Level and variability in sound propagation characteristics are much larger (several dBs) than these 0.6-1.0 dB reductions. Therefore, the reduction in noise levels from shifting deep-sea vessels approximately 600 m further south in the existing outbound shipping lane in this portion of SRKW critical habitat is negligible.
- The corresponding reduction in the observed noise levels as a result of southward shift of the tugs was significant. In the 500-15,000 Hz band the noise was reduced by 5.8 dB, while in the 10-100,000 Hz and 10-100 Hz bands, the reduction was 4.3 dB. In the 15-100 kHz band the reduction was as much as 11.9 dB for these vessels. Therefore, by moving tugs to a distance of 3900 m from the monitoring location, reduced the high-frequency noise contribution from these vessels to below the ambient noise level. They would not be detectable in this frequency band.

2 INTRODUCTION

As an experiment to investigate possible mitigation effects of shifting shipping lanes away from some of the important foraging areas within the critical habitat of the endangered Southern Resident Killer Whale (SRKW) in the Strait of Juan de Fuca, the Vancouver Fraser Port Authority initiated a lateral displacement trial which began on August 20, 2018 and continued until October 31, 2018. During this time deep sea vessels were requested to voluntarily shift their outbound tracks to a more southern part of the existing shipping lane, and inshore traffic (e.g. tugs) were requested to move southward, while still operating outside the deep sea shipping lanes. The trial area was between longitudes 124° and 124°40' West, over a distance of approximately 34 nautical miles (Fig. 1).

Using Automatic Information System (AIS) vessel tracking the Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation (ECHO) Program found that over the trial period, the participation rate for deep-sea vessels varied on a weekly basis between 46% and 71% and for tugs between 50% and 100%. (ECHO, 2019).

As part of the Ocean Protection Plan-Marine Environmental Quality Program (OPP-MEQ), Canada's Department of Fisheries and Oceans (DFO) has since February 2018 deployed 3 broad-band (10-100,000 Hz), continuously recording autonomous hydrophone systems at locations off Sooke, Jordan River and Port Renfrew in the Strait of Juan de Fuca (Fig. 1, Table 1). This monitoring program is SRKW centred in that the locations of these recorders are within SRKW critical habitat and were chosen based on more than 10 years of effort-corrected sightings data, passive acoustic monitoring, focal follows and survey results, which demonstrate that these are places where SRKW spend significant time and presumably forage.

An expert workshop in Vancouver 2017 identified three principal impacts of underwater noise on SRKW (Heise et al. 2017). The first is behavioural disturbance, which includes increased physiological stress, disruption of important activities such as resting and foraging, avoidance behaviours and hearing sensitivity threshold shifts. A metric defined to cover this disturbance was determined to be changes in the 95th percentile of unweighted sound pressure levels from 10 Hz to 100 kHz. The second impact is focused on communication masking, which impacts group cohesion and coordination and interferes with important social behaviours. This masking was determined to be changes to the size of space within the 0.5-15 kHz frequency band in which the whales can communicate effectively. The third impact is echolocation masking, which reduces foraging efficiency and may also impair navigation, orientation and hazard avoidance. This masking focuses on noise in the 15-100 kHz frequency band.

In this report hydrophone data from the three moorings in the periods between April 16th and August 20th and between November 1st and November 30th are considered to be baseline data from before and after the lateral displacement trial. These observations are compared to data collected during the trial period (August 20th - October 31th).

The sound pressure levels are considered in the SRKW critical frequency bands as well as the decade bands: 10-100 Hz, 100-1,000 Hz, 1,000 -10,000 Hz, and 10,000 -100,000 Hz.

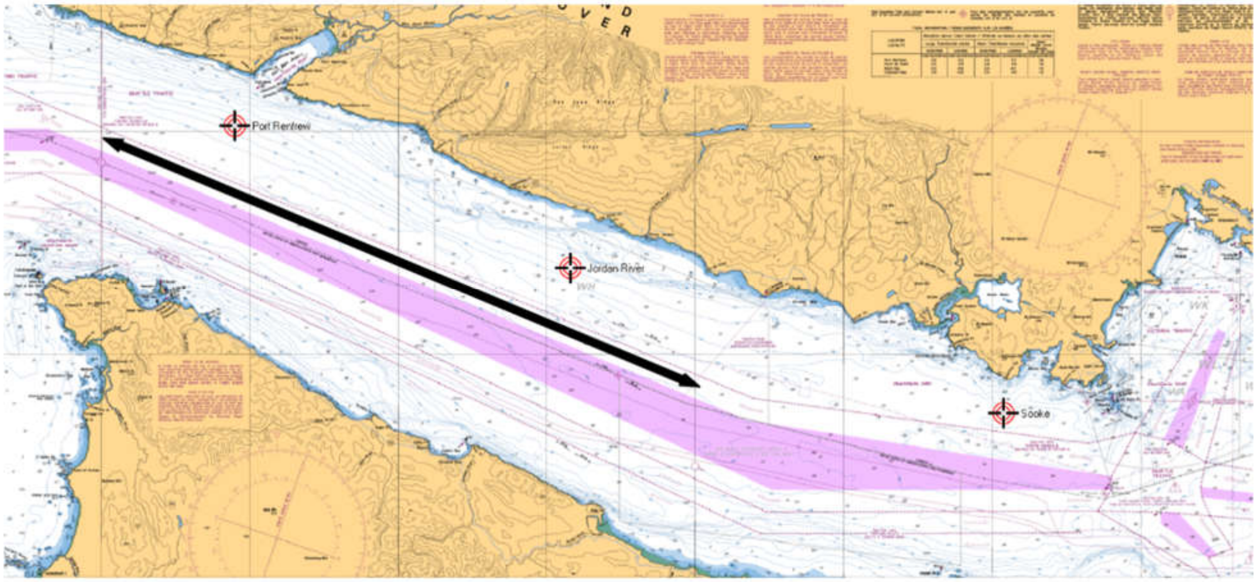

Figure 1. Strait of Juan de Fuca showing shipping lanes with the 34 nm track between 124ºW and 124º 14'W (marked by black thick line in outbound lane) where outbound deep-sea vessels and inbound as well as outbound tugs, were requested to navigate as far south, and away, from Vancouver Island as possible during the trial period between August 20 and October 31, 2018. The three Department of Fisheries and Oceans hydrophone moorings used in this study are also shown (Port Renfrew, Jordan River and Sooke).

Table 1. Moorings deployed in Strait of Juan de Fuca.

Mooring	***Position***	***Water depth (m)***
Port Renfrew	48.504N 124.517W	167
Jordan River	48.397N 124.134W	120
Sooke	48.290N 123.654W	168

3 Methods

3.1 Vessel class composition and movements

In the present analysis all available Class A and B Automatic Identification System (AIS) vessel information data were received from the Canadian Coastguard for the relevant area in the Salish Sea for the period from April 16th to the end of November 2018.

These data were classified into 13 vessel classes: 1) Bulk carriers, 2) Container ships, 3) Ferries, 4)Fishing vessels, 5)Government/Research, 6) Naval vessels, 7) Passenger vessels, 8) Recreational vessels, 9) Tankers, 10) Tugs, 11) Vehicle carriers, 12) Registered whale watching vessels, and 13) Others.

The AIS data were processed to determine the distances and vessel classes of the nearest vessels to each of the three hydrophone moorings within five minute periods from April 16th to the end of November. Figure 2 shows the percentage of time within all five minute periods over a 7-day period between April 16th and November 20th when a vessel of a given class is closest to each of the three moorings and within 20 km of a given mooring (If at any given time the nearest vessel was more than 20 km away, these data were not included in further analysis). It is clear that the times in which vessels are within 20 km of any of the moorings increases significantly in June, primarily as a result of an increase in fishing activity. The proportion of time with AIS equipped vessels increased from a low of 20-30 % to 40-60% at the Port Renfrew location, from between 20 and 30 % to between 40 and 55 % at the Jordan River location and from 15-28 % to 35-55 % at the Sooke site.

The range of vessel speeds observed varied considerably from vessel class to vessel class and within a given class, but as expected did not vary between trial (red) and non-trial periods (blue) (Fig. 3).

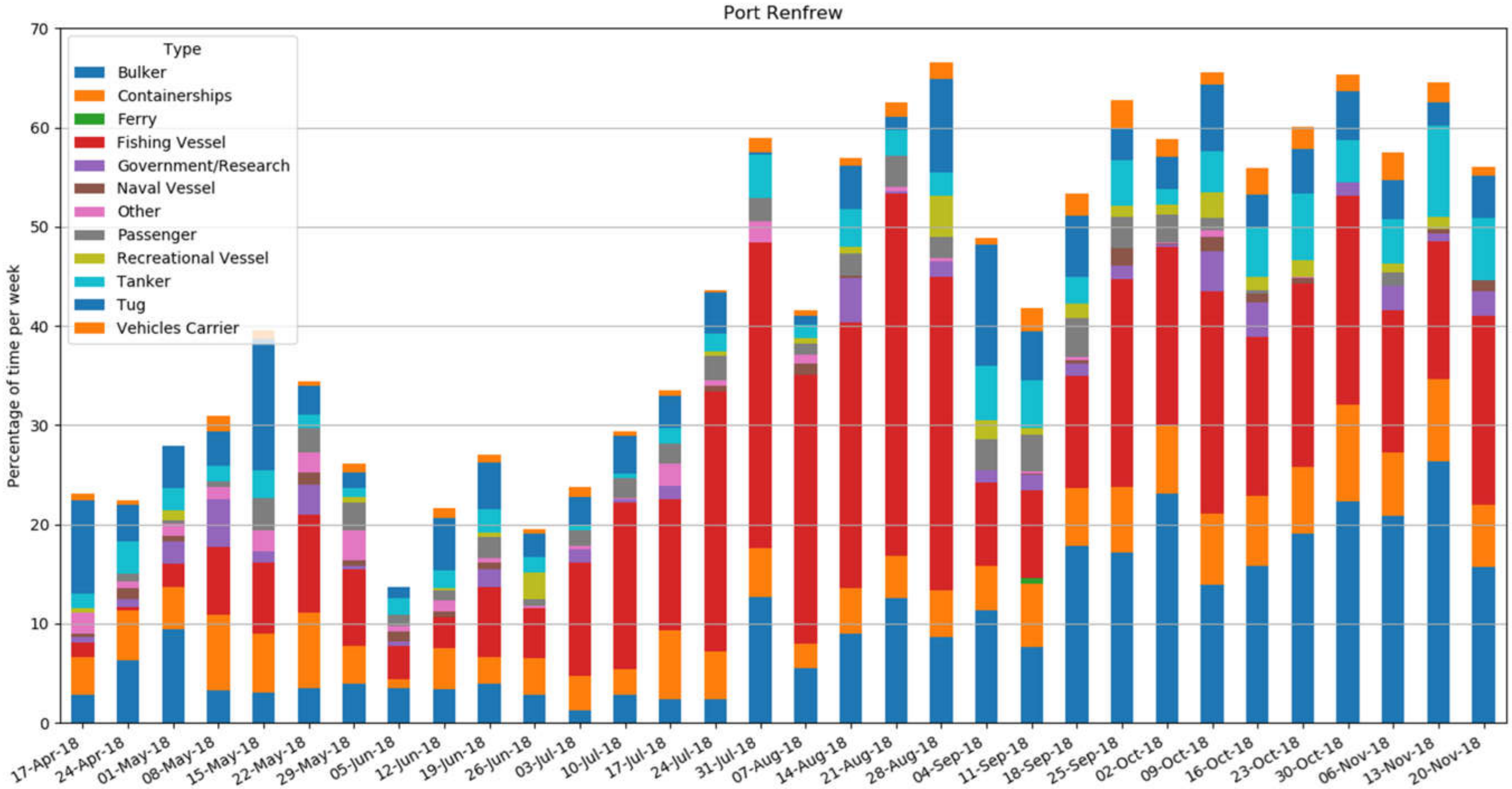

Figure 2a. Proportion of time vessels of given class are within a 20 km range to the Port Renfrew mooring, within each 7-day period. (The order of the vessel types listed in the legend are from the bottom up in the figure.)

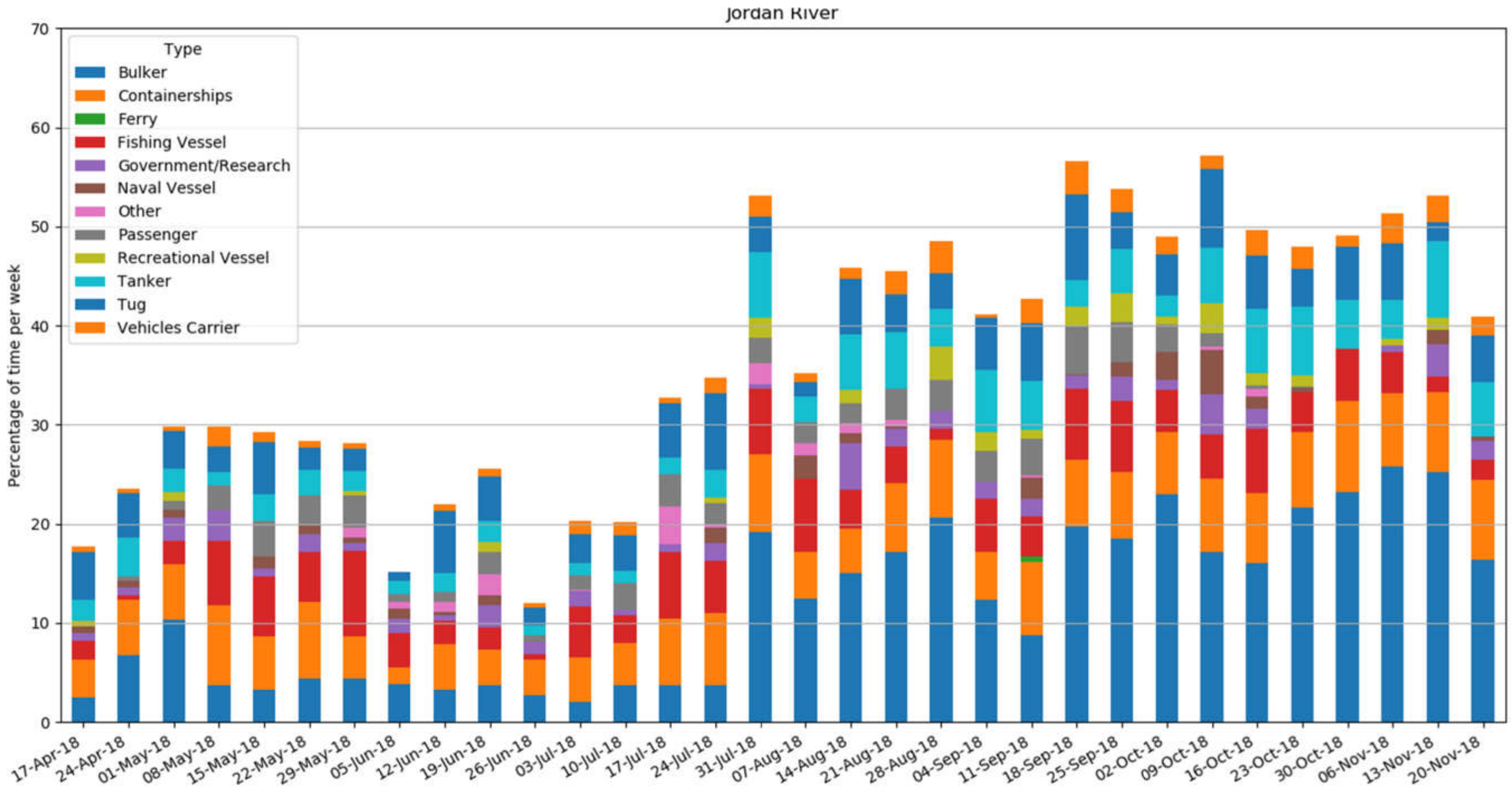

Figure 2b. Proportion of time vessels of given class are within a 20 km range to the Jordan River mooring, within each 7-day period. (The order of the vessel types listed in the legend are from the bottom up in the figure.)

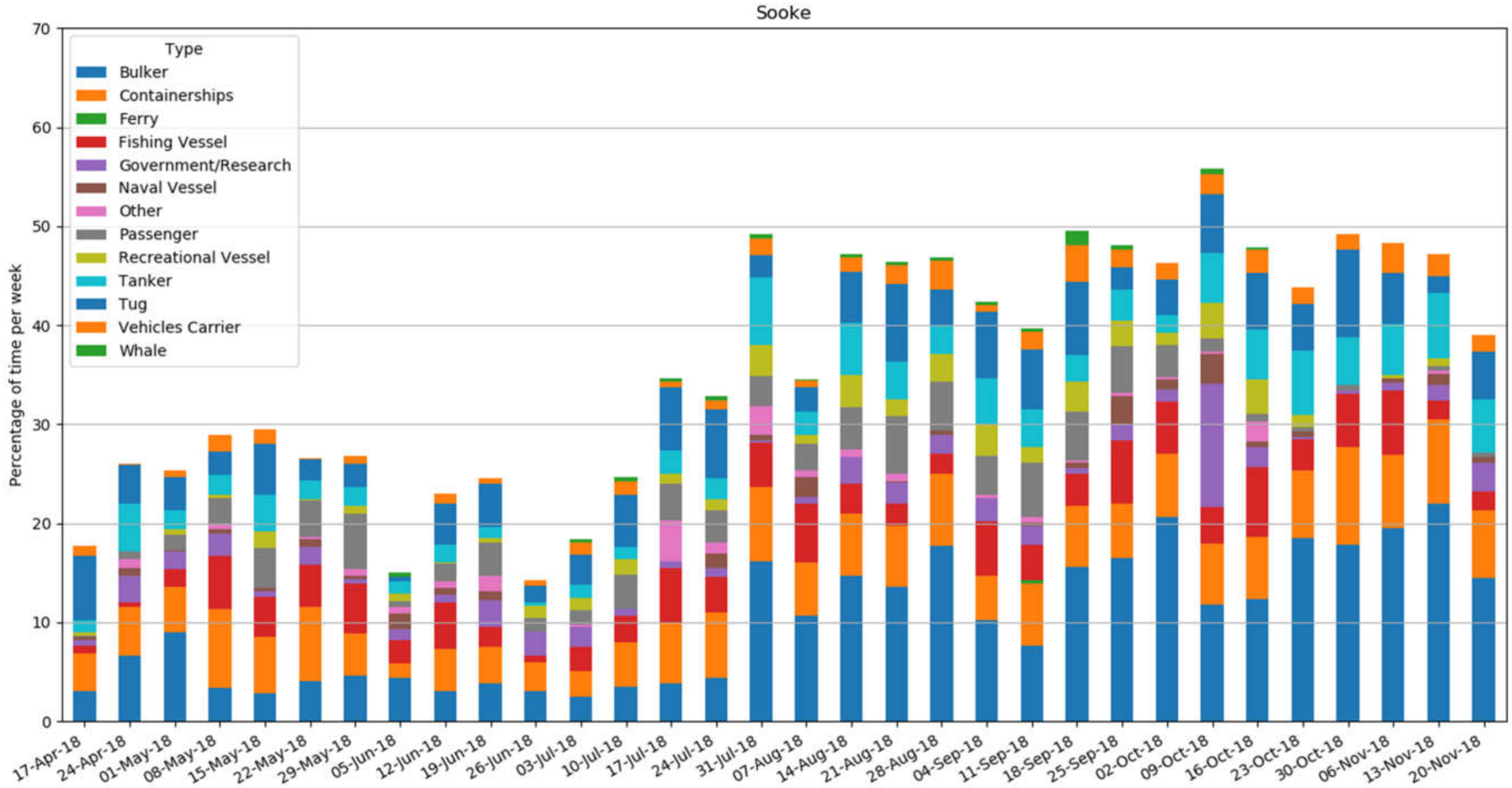

Figure 2c. Proportion of time vessels of given class are within a 20 km range to the Sooke mooring, within each 7-day period. (The order of the vessel types listed in the legend are from the bottom up in the figure.)

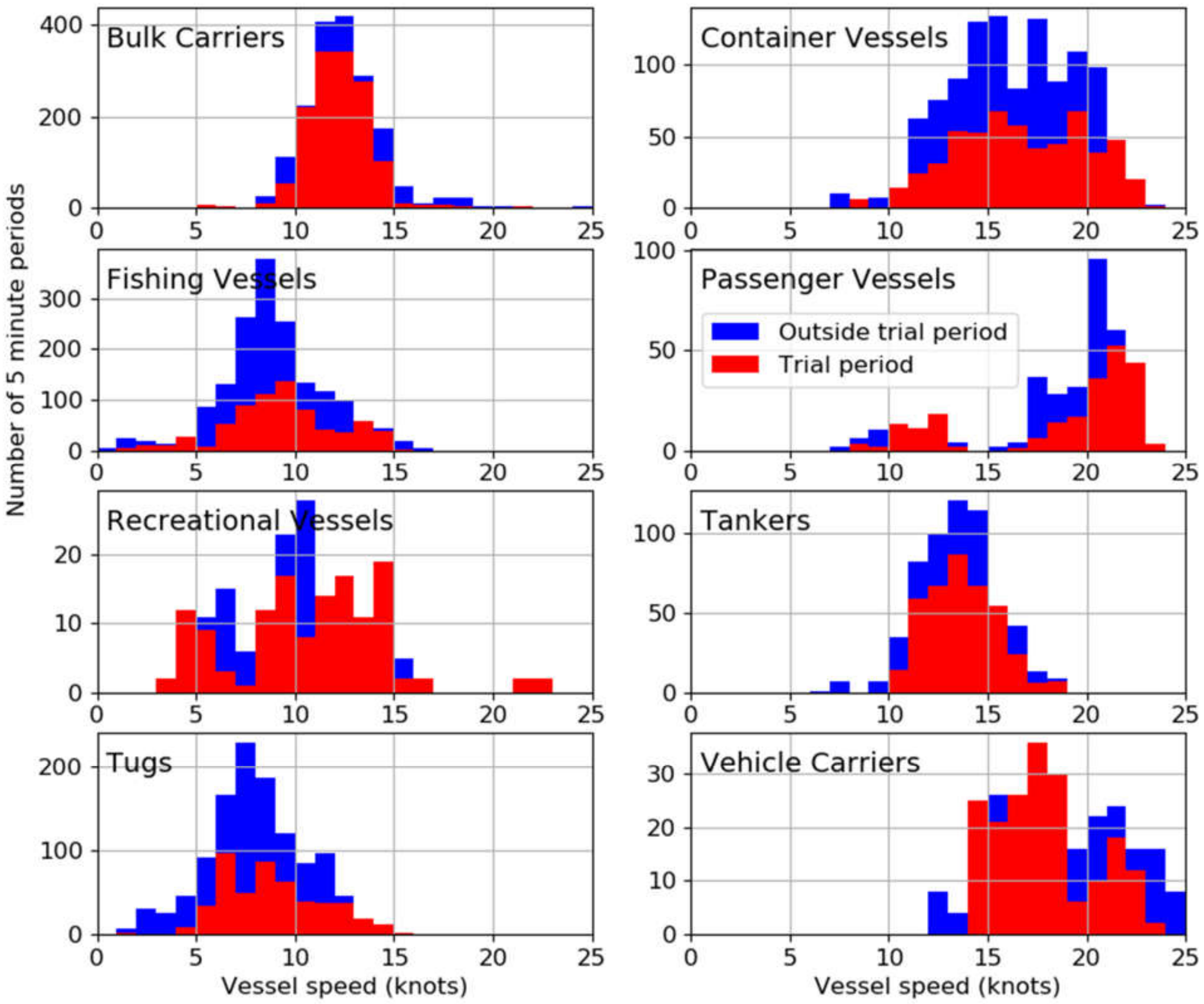

Figure 3. Distribution of vessel speeds for some of the vessel classes defined in the AIS data set for periods outside the lateral displacement trial (blue) and during the trial (red).

The minimum distance within a five minute period is a measure of how close any vessel got to the locations of the three hydrophones. These data were divided into pre-trial (April 16th – August 18th), trial (August 22nd – November 1st), and post-trial (November 1st – November 30th) periods and used to calculate probability density functions of closest approach for each of these periods for classes of vessels. The higher the probability the higher was the likelihood that a given vessel was travelling at a given distance away from a given hydrophone when it reached its closest approach.

The tracks from vessels equipped with Class B AIS transceivers (recreational and small commercial vessels) did not show any differences between the trial and non-trial periods (not shown) and were therefore not included in the subsequent analysis.

Figures 4, 5 and 6 show these probability density distributions for the three hydrophone locations for all Class A vessels (upper left panels) and for different vessel classes as identified in each panel. The maximum range considered here was chosen to be 11,000 m to include the main inbound shipping lane. The probability densities shown in the figures have been normalized so that the overall area under each curve adds up to 1.

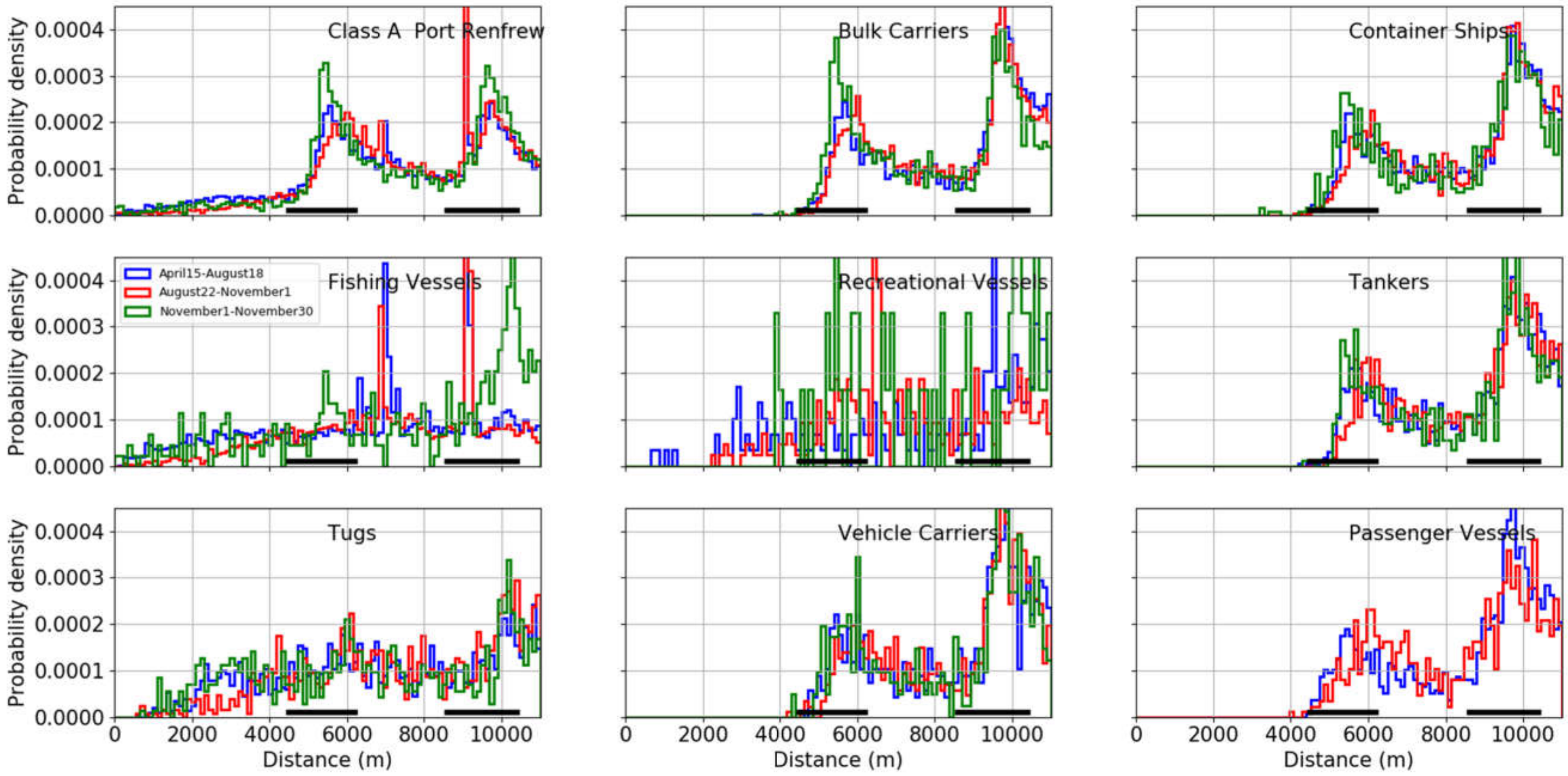

Figure 4. Probability distributions of AIS Class-A equipped vessel distances within 5 minute periods before the trial (blue), during the trial (red) and following the trial (green) for the **Port Renfrew** location. Upper left panel represents all vessel classes while the other panels represent classes as identified in each panel. Solid black horizontal lines identify ranges to outbound and inbound shipping lanes as obtained from local charts.

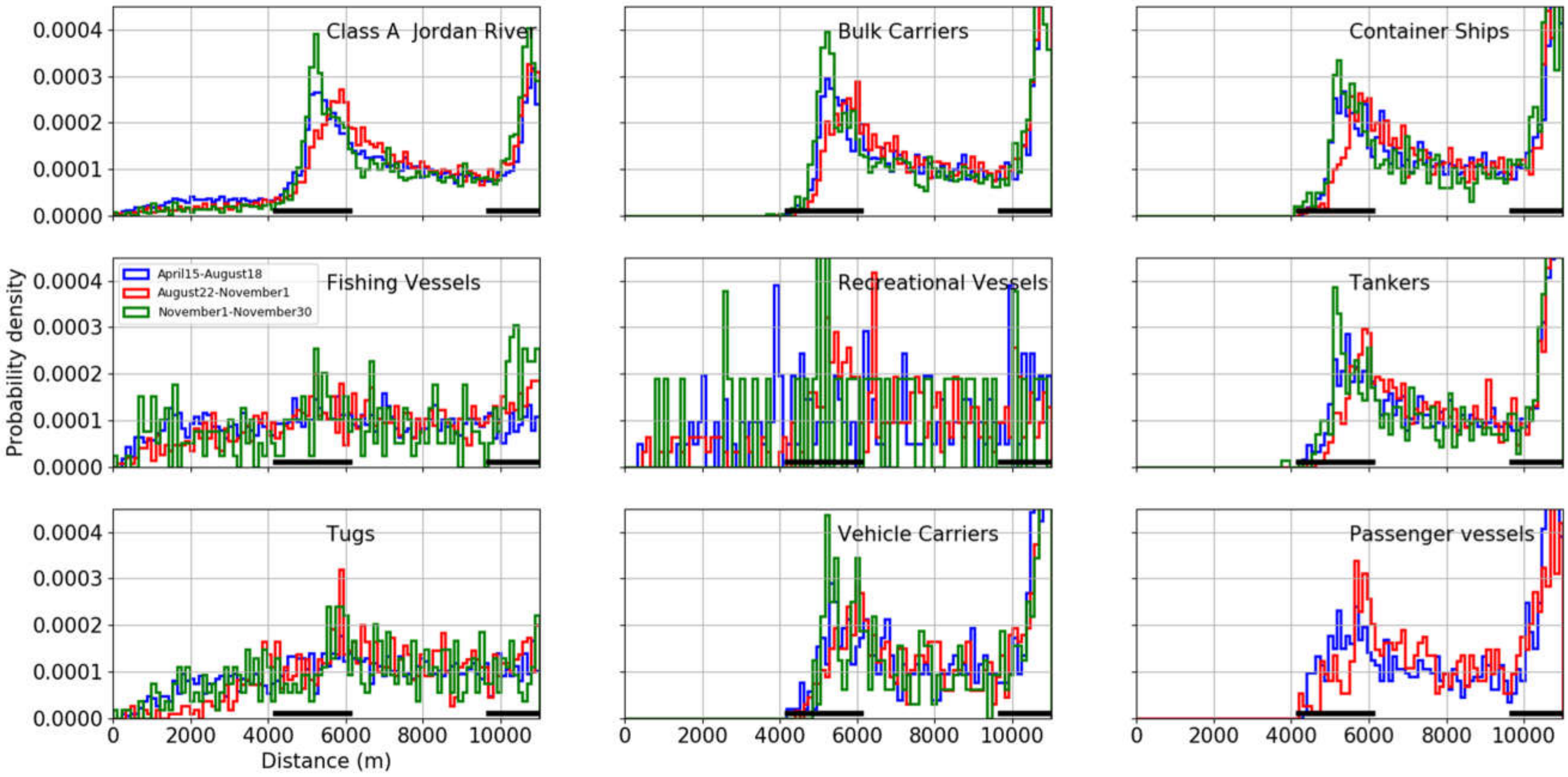

Figure 5. Probability distributions of AIS Class-A equipped minimum vessel distances within 5 minute periods before the trial (blue), during the trial (red) and following the trial (green) for the **Jordan River** location. Upper left panel represents all vessel classes while the other panels represent classes as identified in each panel. Solid black horizontal lines identify ranges to outbound and inbound shipping lanes as defined from local charts.

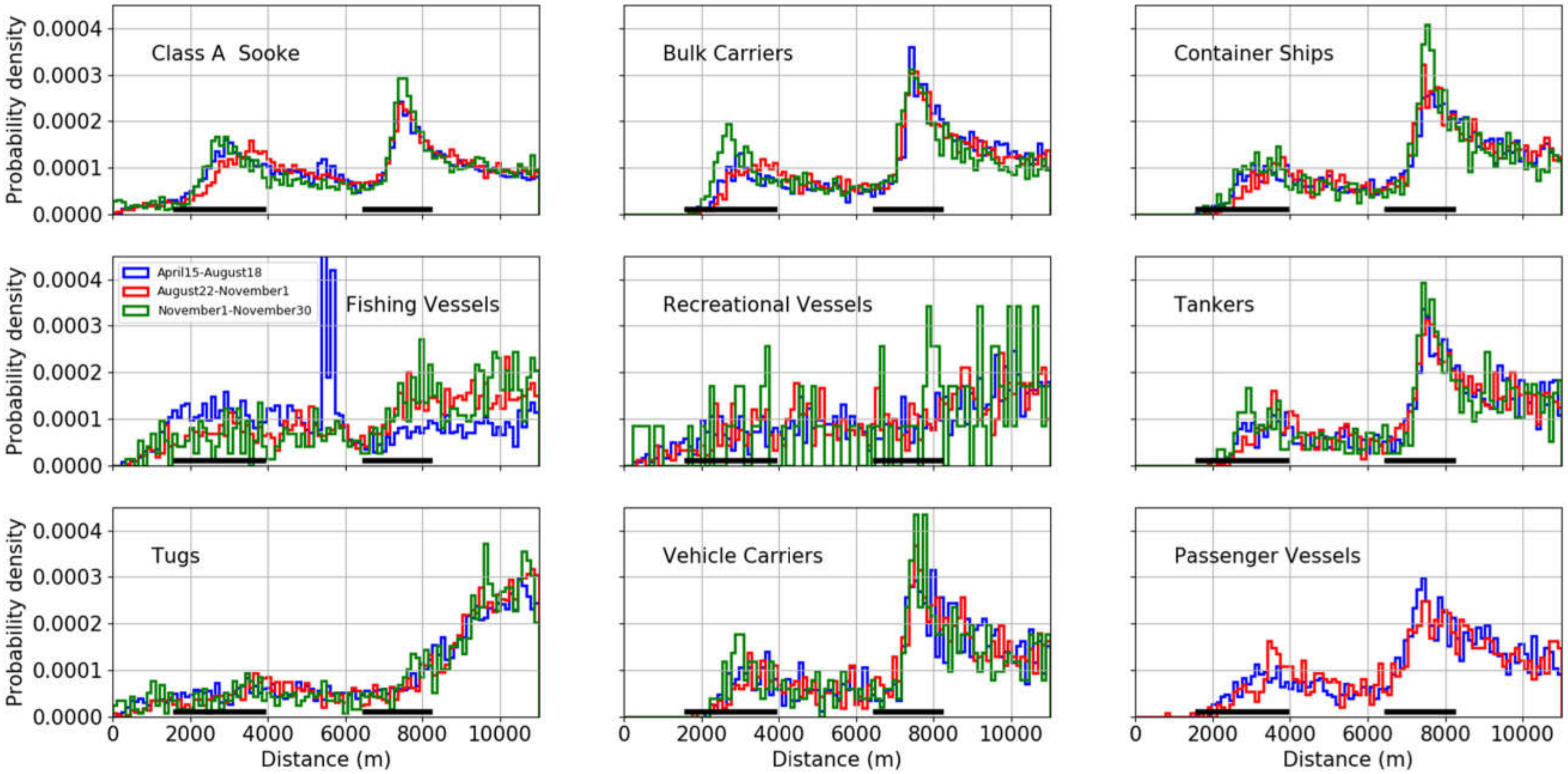

Figure 6. Probability distributions of AIS Class-A equipped minimum vessel distances within 5 minute periods before the trial (blue), during the trial (red) and following the trial (green) for the **Sooke** location. Upper left panel represents all vessel classes while the other panels represent classes as identified in each panel. Solid black horizontal lines identify ranges to outbound and inbound shipping lanes as obtained from local charts.

T

There are two broad peaks associated with the dominant distances to the inbound and outbound shipping lanes for most of the vessel classes. As expected, the locations and widths of these distributions align well with the established shipping corridors in this area (Black horizontal lines in Figs. 4-6). However, these results also show that generally the vessels of different classes follow fairly narrow corridors within these lanes. As expected, there are no significant differences between the trial and non-trial periods with regards to travel in the inbound lane (Distances between ~8000 m and 11,000 m from the mooring locations). The data also show very limited differences between pre- and post-trial tracks, as identified by small differences between the blue and green curves in Figs. 4-6. However, the distribution of distances away from the mooring sites do differ between the trial period and the periods before and after (red curves in Figs. 4-6). Differences are obvious when all Class-A vessels are grouped together and for bulk carriers, container vessels, tankers, tugs, and passenger vessels. However, there were few vehicle carriers passing these sites during this study and therefore not statistically significant. This vessel type has therefore not been included in further analysis. Fishing vessels and recreational vessels are not following the shipping lanes and have therefore also been removed from further analysis. In addition, the number of cruise ships (Passenger class) was so low in November that no information can be gained for these vessels following the trial period (lack of green curve in Figs. 4-6).

The narrow-range peaks in the overall Class-A outbound lane data at Port Renfrew at around 6800 m are due to fishing vessels travelling along repeat tracks sometime between April 16th and November 30th (see the Fishing vessel panel in Fig. 4).

The most probable ranges for each significant vessel class, prior to, during, and after the trial, as obtained from Figs. 4-6 for the three sites are summarized in Table 2.

Table 2. Mean ranges between mooring and vessels in outbound shipping lane in Strait of Juan de Fuca prior to the lateral displacement trial, during the trial, and after the trial period was over. NA indicates that distances could not be defined.

SRKW critical habitat	Vessel class	Pre-trial mean distance (m)	During trial mean distance (m)	Post-trial mean distance (m)
Port Renfrew	All Class A	5515	5950	5430
Port Renfrew	Bulk carriers	5615	5900	5410
Port Renfrew	Container ships	5485	5944	5427
Port Renfrew	Tankers	5743	5915	5542
Port Renfrew	Tugs	2815	4165	2990
Port Renfrew	Cruise ships	5427	6060	NA
Jordan River	All Class A	5256	5888	5256
Jordan River	Bulk carriers	5270	5787	5270
Jordan River	Container ships	5341	5772	5197
Jordan River	Tankers	5341	5887	5312
Jordan River	Tugs	2010	3906	2125
Jordan River	Cruise ships	5398	5800	NA
Sooke	All Class A	2930	3533	2700
Sooke	Bulk carriers	2914	3345	2656
Sooke	Container ships	3043	3560	3014
Sooke	Tankers	3072	3588	2870
Sooke	Tugs	NA	NA	NA
Sooke	Cruise ships	3072	3417	NA

Using the most probable distances prior to and during the lateral displacement trial, the most probable vessel tracks for all Class-A vessels are shown in Fig. 7. The results show that on average the lateral displacement trial resulted in outbound AIS equipped Class-A vessels travelling approximately 435, 630, and 600 m further south than prior to the trial period at Port Renfrew, Jordan River and Sooke, respectively (Table 2, Fig. 7). For tugs, which tend to travel closer to the Vancouver Island coast, the shifts southward during the trial were significantly greater, with 1350 and 1896 m, at Port Renfrew and Jordan River, respectively. (No significant changes in tug tracks were observed at the Sooke location.)

Here it is worth noting that the trial area started west of Sooke (Fig. 1). However, the data suggest that the deep-sea vessels moved their tracks southward east of Sooke, and therefore before the suggested starting location, while tugs more closely followed the request from ECHO.

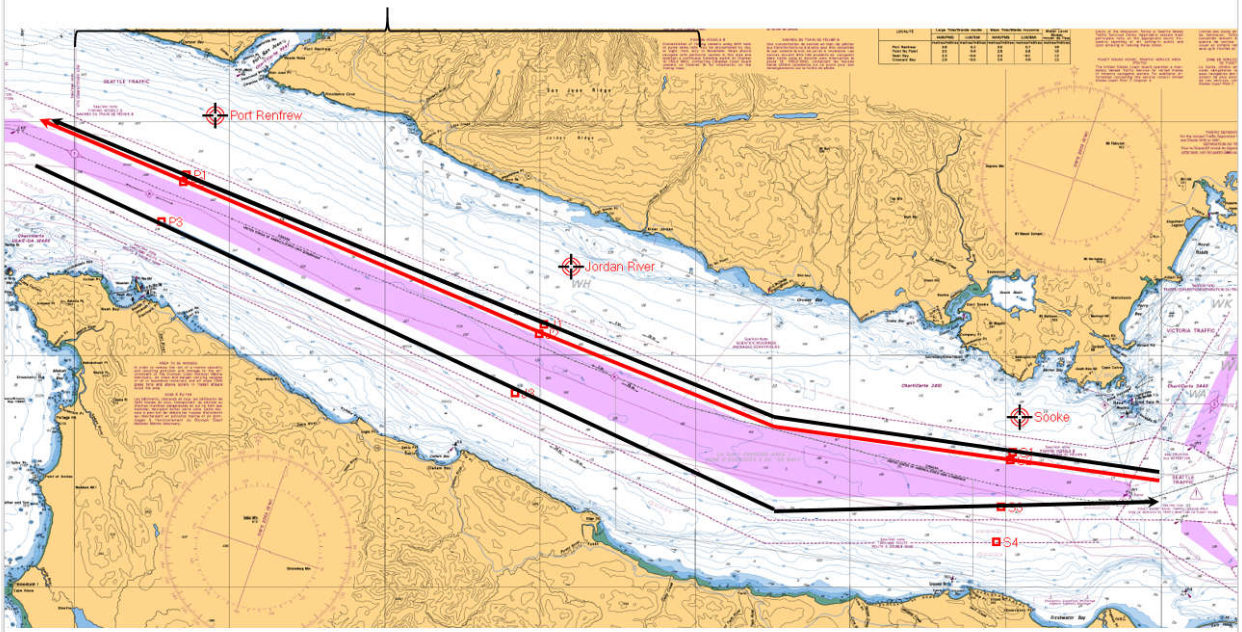

Figure 7. Strait of Juan de Fuca showing shipping lanes with the most probable shipping tracks for all Class-A commercial vessels. Black solid lines indicate the inbound and outbound shipping tracks prior to the trial and the red solid line shows the mostly used track during the trial period as obtained from the data shown in Figs. 4-6 and in Table 2. The three mooring locations are also shown.

3.2 Water Properties

One of the variable parameters affecting the received noise level at any of the mooring sites is the speed of sound in the water column between a noise generating vessel and a given hydrophone. There are typically two scenarios with regards to the upper ocean sound speed characteristics in the Salish Sea associated with summer and winter. In the summer the sun and generally calmer conditions will warm the surface and therefore stratify the near surface layer creating a situation where the sound speed will be largest at the surface and decreasing with depth. In this case noise generated in the upper part of the water column will be refracted downwards and therefore reduce the horizontal range, near the surface, where this noise can be heard. However, it may lead to increased noise levels at depth in certain locations away from the noise source.

In the winter the air will be colder and therefore cool the near surface water. Combining this with mixing from windier conditions will cool a deepening layer near the surface. In the open ocean one would see a deepening mixed layer where the temperature, salinity, and therefore the sound speed would be more or less constant down to the bottom of this layer. In more sheltered water, where the wind is not able to mix the water as deep, one will often end up with a profile where the temperature, and therefore also the sound speed, are lowest near the surface and increasing with depth. This will result in a situation where the sound speed is increasing with depth and therefore noise generated in the upper layer will now be refracted upwards towards the surface. At the surface it will be reflected downwards and get trapped near the surface and will be able to travel significant distances.

Figure 8 shows temperature and salinity plotted against pressure (~depth in m) as measured at or near the three mooring locations during six servicing trips between February and December 2018. Also shown are the corresponding sound speed profiles as calculated from the temperature, salinity, and pressure data using the equation in Mackenzie (1981).

One can see that all three locations experience the two different scenarios described above by transitioning from winter conditions (noise trapped in near surface channel) to summer conditions (noise refracted downwards) and back to winter conditions. However, our observations (not shown) are showing that there is significant variability even within the same months, on tidal time scales (hours). It is therefore very difficult at this stage to be able to say whether the oceanographic conditions prior to and after the trial period, as compared to the conditions during the trial, are sufficiently different to influence the acoustical observations described in this report. There is an ongoing effort to investigate the variability in sound speed conditions and what role this might play in modulating the soundscape characteristics. But this is beyond the scope of this report.

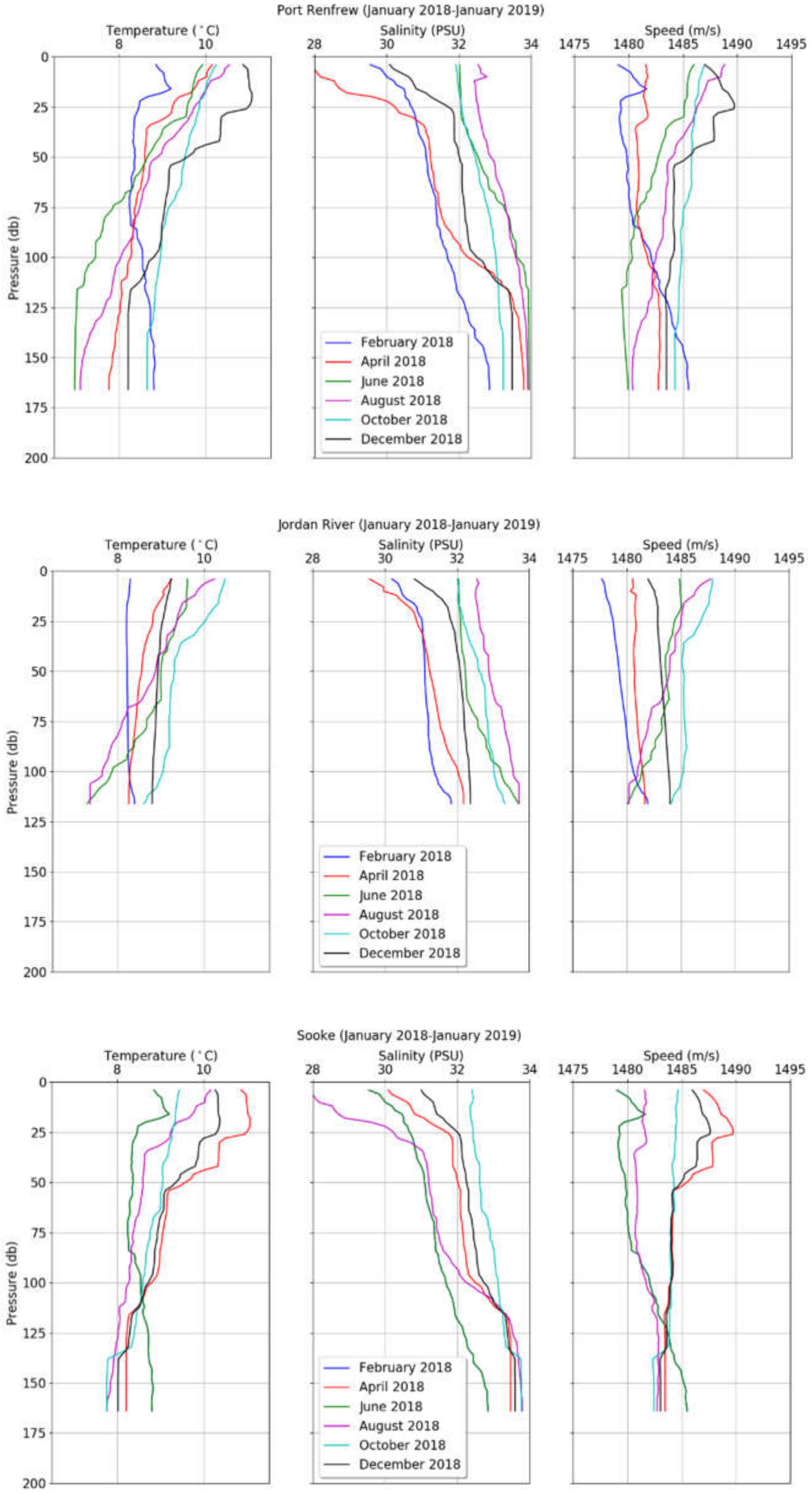

Figure 8. Temperature, salinity and sound speed as functions of pressure (~depth in m) at the three mooring sites: Port Renfrew (top), Jordan River (middle), and Sooke (bottom), during the months identified in the legends.

3.3 Passive Acoustic Monitoring (PAM) moorings

The Passive Acoustic Monitoring (PAM) moorings used in this study were specially designed to be small enough to be deployed and recovered from small chartered vessels, but solid enough to be deployed for extended periods in waters with significant current flows and at depths up to 300 m (Figure 9). The moorings are manufactured by Oceanetic Measurement Ltd. in Sidney, BC. The height of each mooring is approximately 2 m from the bottom of the anchor to the location of the hydrophone. Each mooring is equipped with dual acoustic releases for redundancy during recovery.

The two hydrophone systems along the official lateral displacement route (Jordan River, and Port Renfrew) were located approximately 5 km north of the outbound shipping lane at depths of 120 and 167 m, respectively (Figure 1, Table 1). The Sooke mooring was ~3 km north of the shipping lane in 168 m of water (Figure 1, Table 1).

These moorings were serviced between April 13th and 18th, between June 18th and 22nd, between August 15th and 21st, between October 10th and 16th, and between November 27th and December 2nd, 2018.

The sound recorders used were JASCO Applied Sciences AMAR G4 recorders equipped with GeoSpectrum Technologies M36-100 hydrophones. Each individual system was calibrated by the manufacturer before shipping and spot calibrated (at 250 Hz) prior to deployment. Data were digitized inside each AMAR G4 continuously at a sample-rate of 256 kHz with 24-bit resolution and stored on SD memory cards as wav files.

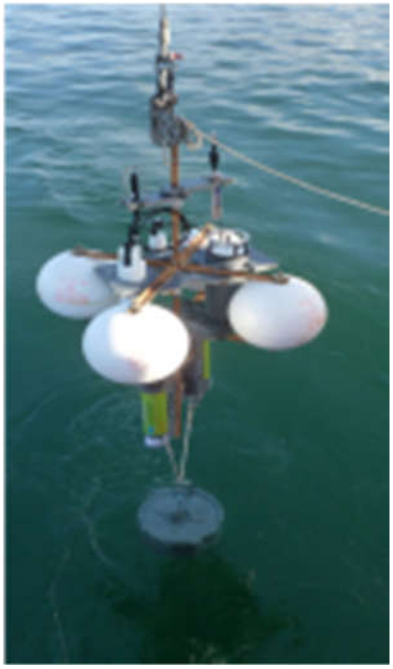

Figure 9. PAM mooring ready for deployment. The total height of the mooring is approximately 2 m.

The wav files were post-processed with custom Python scripts modified from Merchant et al. (2015) with a 1 second Hanning window, 50% overlap and Welch's averaging to generate 1 minute power spectra.

4 Results

4.1 Spectral Data at Port Renfrew, Jordan River and Sooke SRKW passive acoustic monitoring locations

The hydrophone data sets from April 16th to November 30th, 2018 are summarized in Fig. 10 where visual representations of the spectrum of acoustical frequencies of the hydrophone signals as they vary with time, or spectrograms, are shown when the Power Spectral Density (PSD) is averaged over 2 hours at the three passive acoustic monitoring locations. The lateral displacement trial period is indicated by the black rectangles. The figure shows that most of the energy in the noise field is at acoustical frequencies below about 300 Hz, and with rapid decrease as the frequency increases. It is worth noting the small 'specks' at 50 kHz, especially during the summer months, primarily at Sooke and Port Renfrew. These are associated with 50 kHz echo sounders on nearby vessels and will be discussed further later.

The analysis of standard metrics have been performed over lunar months to minimize the effect of low frequency flow noise due to tidal variability in current flow patterns past the hydrophones. Such analysis was recommended by the ECHO Program's Acoustic Technical Committee (ATC). Lunar months began and ended with each full moon. (The lunar months used here are listed in Table 3).

Table 3. Lunar months used in the present study. Months in bold covered the trial period.

Lunar Month	**Start time (UTC)**	**End Time (UTC)**
1	16 April 2018	15 May 2018
2	15 May 2018	13 June 2018
3	13 June 2018	12 July 2018
4	12 July 2018	11 August 2018
5	**11 August 2018**	**9 September 2018**
6	**9 September 2018**	**8 October 2018**
7	8 October 2018	7 November 2018
8	7 November 2018	6 December 2018

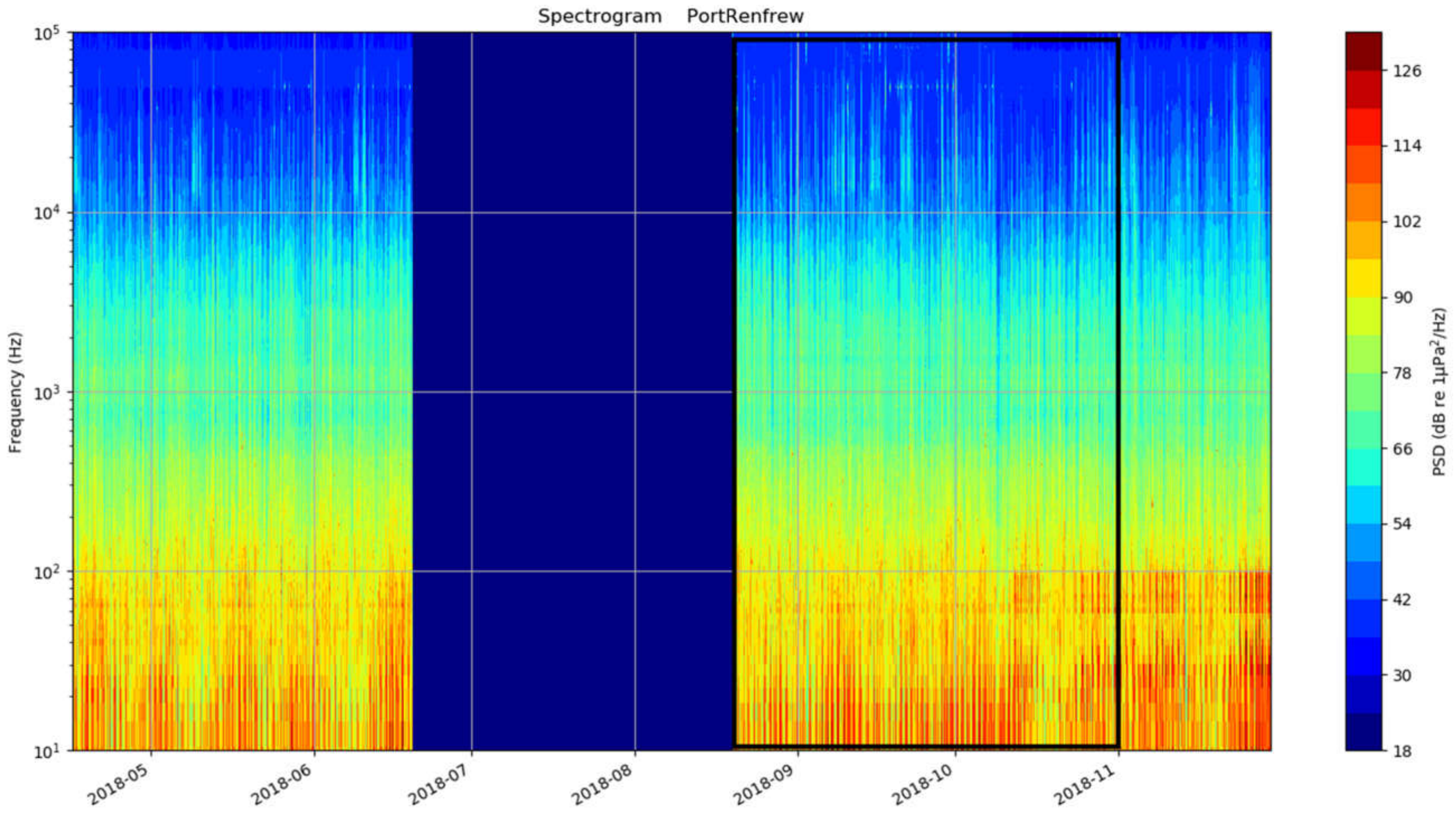

Figure 10a. Spectrogram plot for Port Renfrew) averaged over 2 hours covering the pre-trial period (April 16th – August 20th), the trial period (August 20th-October 31st) (black box) and the post-trial (November 1st-November 30th). (The recorder deployed between June and August failed shortly after deployment.)

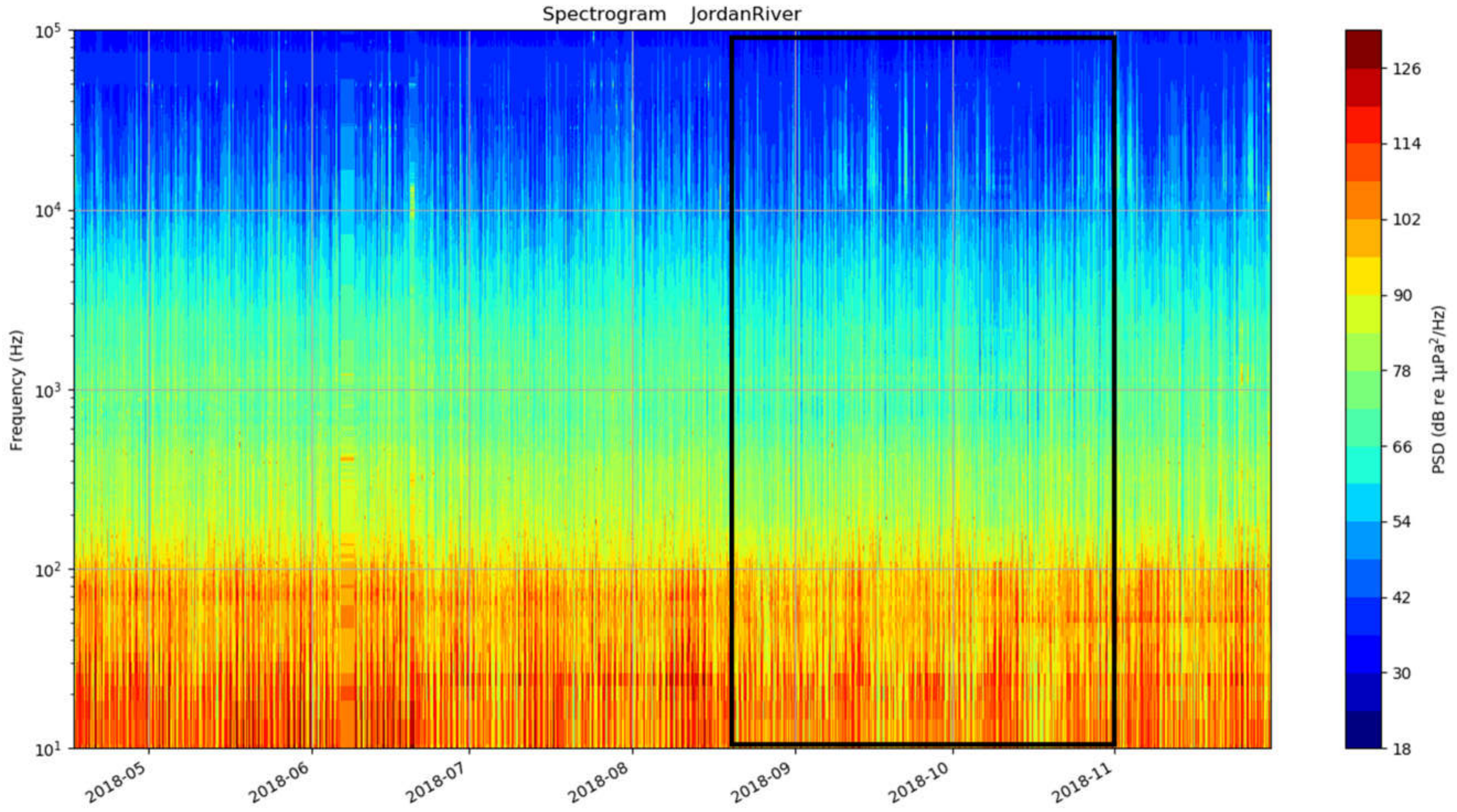

Figure 10b. Spectrogram plot for Jordan River averaged over 2 hours covering the pre-trial period (April 16th – August 20th), the trial period (August 20th-October 31st) (black box) and the post-trial (November 1st-November 30th).

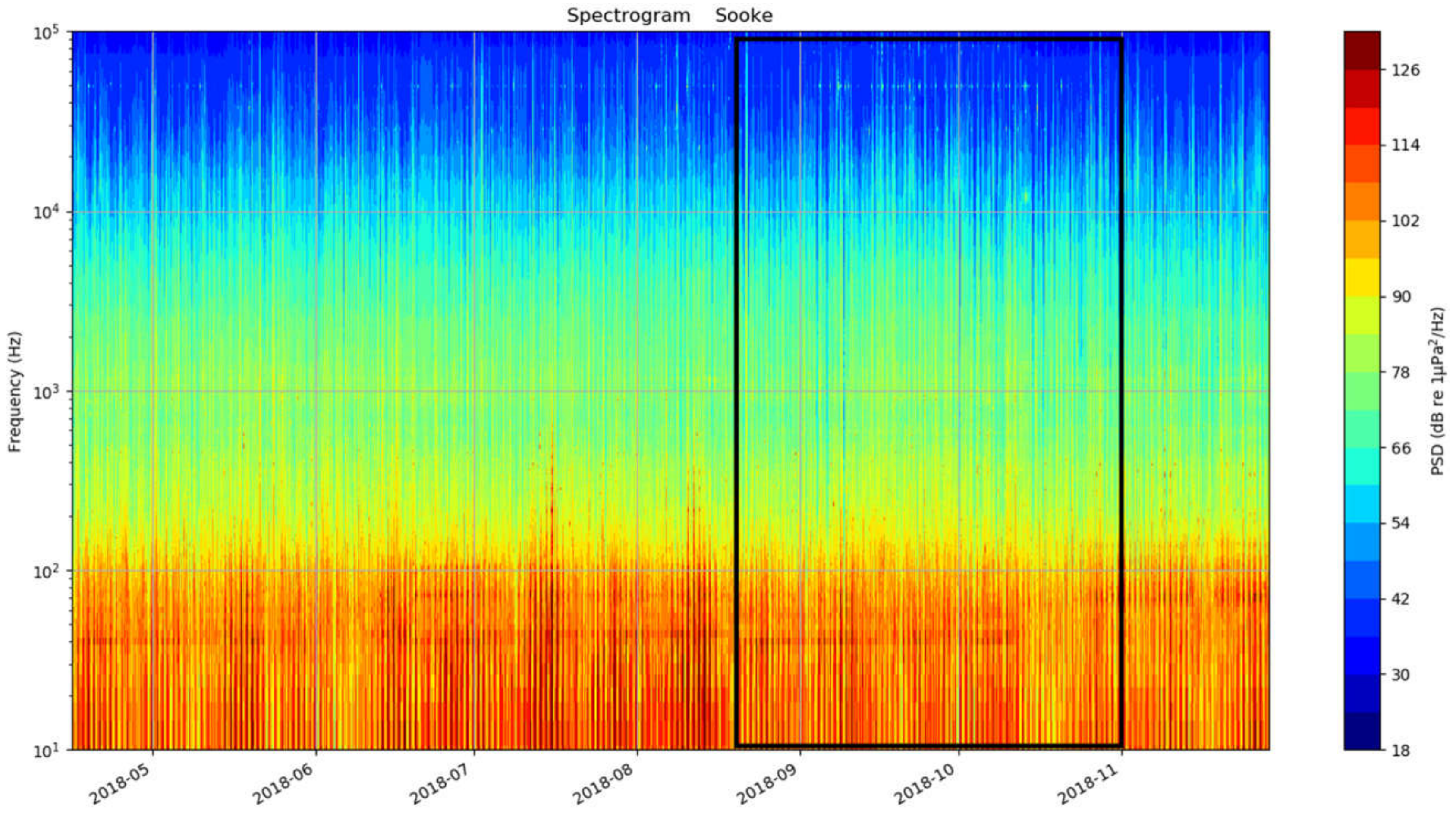

Figure 10c. Spectrogram plot for Sooke averaged over 2 hours covering the pre-trial period (April 16th – August 20th), the trial period (August 20th-October 31st) (black box) and the post-trial (November 1st-November 30th).

There are a number of ways to present in more detail the acoustical data summarized in Figure 10 from the three mooring locations within the lateral displacement region. The RMS mean (Leq) over a certain period is often a useful metric. However, this metric is strongly influenced by the highest sound levels.

In Figures 11-13 a number of potentially useful metrics are shown, including Leq, for 3 selected lunar months (months 2, 6 and 8 in Table 3). The different lines in these figures represent the different metrics over the whole lunar months depicted. The top and bottom thin black lines show the maximum and minimum PSD values as obtained from all the 1 minute spectral averages at all acoustical frequencies between 10 and 100,000 Hz for each lunar month. The monthly RMS mean (Leq) at each frequency are presented as the green line. The lunar month median values (L50) are shown as the heavy black line. In addition, the red lines (dashed at lower frequencies), from top to bottom, indicate the PSD that correspond to the 95th (L95) 75th (L75), 25th (L25), and 5th (L5) percentiles at each frequency. The percentiles indicate the values below which a given percentage of 1-minute PSDs falls. For example, L95 indicates that 95% of all PSDs are below this value at a given frequency.

A more detailed analysis of the sound level distribution is given by the spectral probability density where the empirical probability density of sound levels in each frequency band using all 1-minute PSDs is presented. In the figures, values that are given in red represent pairs of PSD and frequency that occur often during the lunar month, while dark blue pairs are rare. This presentation shows the modal structure and outlying data in the underlying distribution and can help to interpret the different metrics.

It is clear from the convergence of L5 and L25, and flattening of lines, above about 15 kHz that the instrument internal noise floor has been reached at these higher frequencies. Also, the empirical probability density shows a bimodal structure in PSD at frequencies below ~30 Hz. Figure 11 is a good example to show that Leq can be strongly influenced by a few high sound levels. In November-December Leq was above L95 at frequencies above 700 Hz.

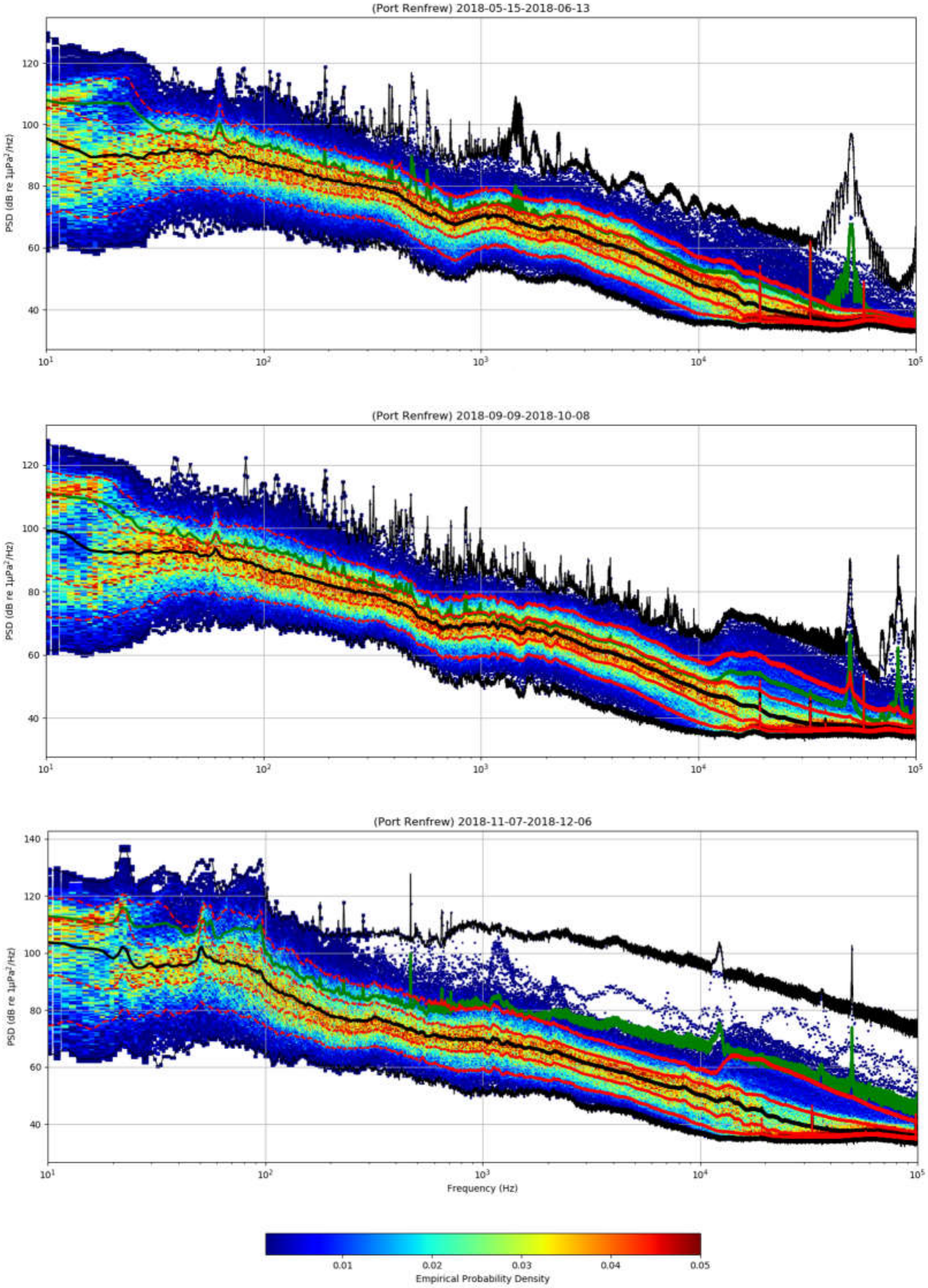

Figure 11. Power spectral density levels (PSD) for **Port Renfrew** (for description see text). Lunar month 2 prior to trial (upper panel), month 6 during the trial (middle panel), and month 8 after the trial (lower panel).

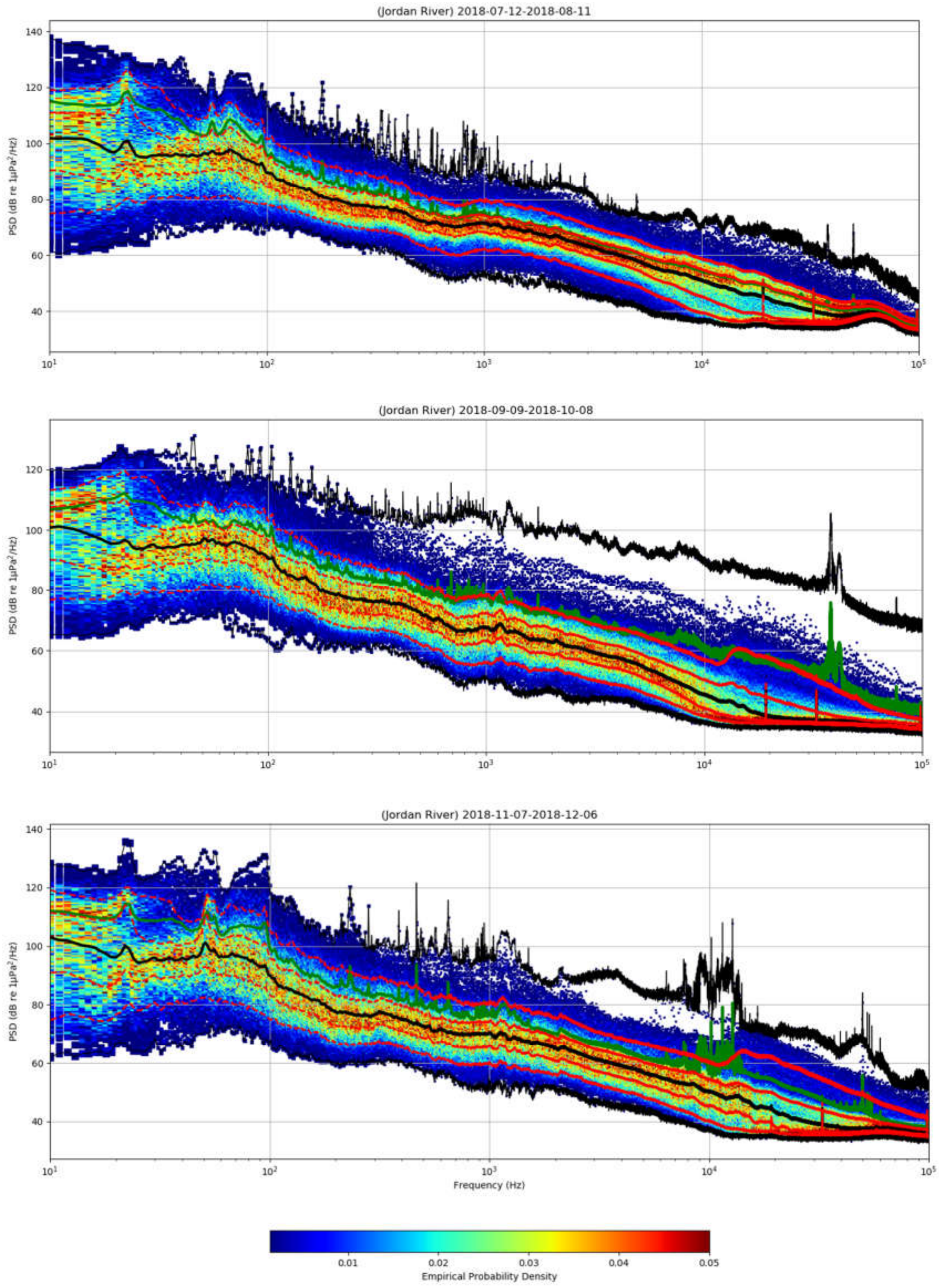

Figure 12. Power spectral density levels (PSD) for **Jordan River** (for description see text). Lunar month 2 prior to trial (upper panel), month 6 during the trial (middle panel), and month 8 after the trial (lower panel).

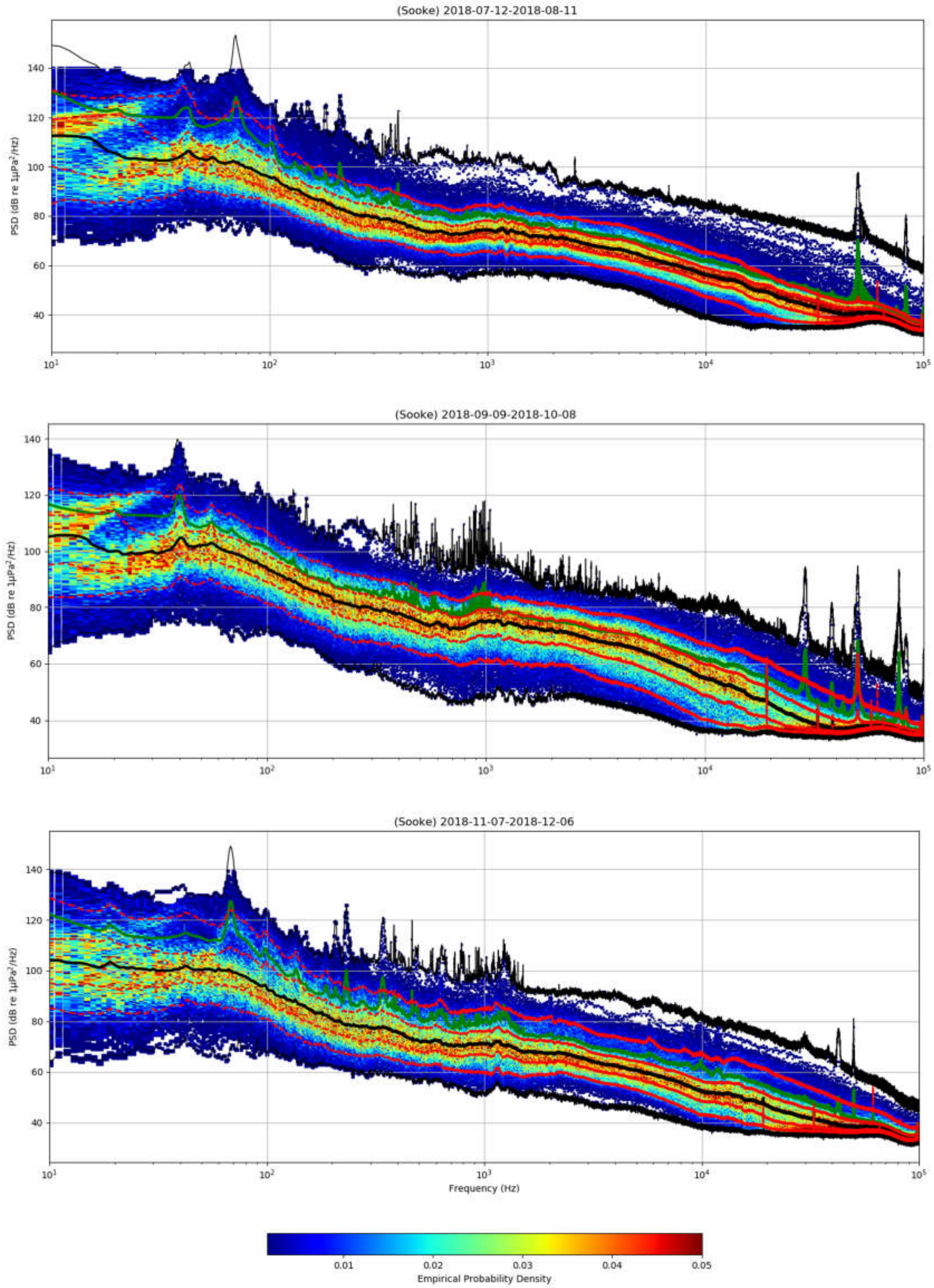

Figure 13. Power spectral density levels (PSD) for **Sooke** (for description see text). Lunar month 2 prior to trial (upper panel), month 6 during the trial (middle panel), and month 8 after the trial (lower panel).

To emphasize temporal and spatial variability in the noise field along the lateral displacement corridor, we focussed on the L5, L50 and L95 percentiles and plotted these metrics for all the available lunar months at each of the three mooring locations (Figure 14). The results show that there is little month to month variability in these percentiles at frequencies between 100 and 500 Hz, and between 5000 and 12,000 Hz at all 3 locations. Significant variability (up to 10dB) is observed at frequencies below 100 Hz, between 500 Hz and 5000 Hz, and, especially at Port Renfrew and Jordan River, at frequencies above approximately 12 kHz, during the summer months. This frequency dependence is likely due to differences in the noise generating mechanisms. For example, it is expected that propeller cavitation tends to dominate at low and very high frequencies, while general machinery noise dominates at middle frequencies. It is also well established that wind-dependent noise can dominate in the frequency band from about 300 Hz to tens of kHz (Wenz, 1962). The increase in the L95 values above 12 kHz observed at all three sights, but especially at the Port Renfrew and Jordan River locations during the summer months, is more difficult to explain. However, it might be associated with local presence of smaller non-AIS vessels travelling very close to the mooring locations during these periods. The 50 kHz signals from vessel sonars are clearly identifiable, especially at the Port Renfrew and Sooke locations.

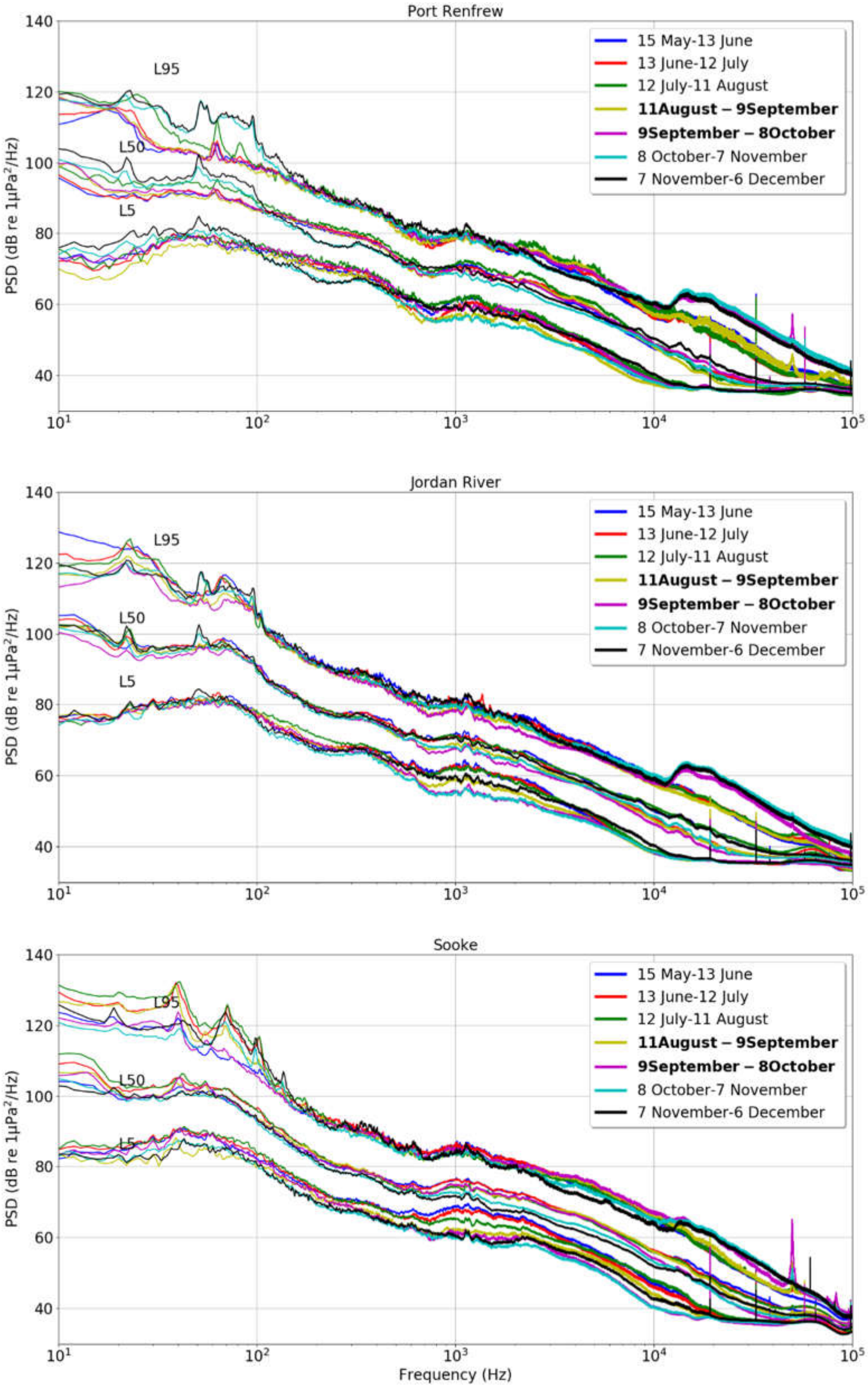

Figure 14. Lunar monthly percentiles (L95, L50, and L5) for 7 lunar months at the Port Renfrew (top panel), Jordan River (middle panel) and Sooke (lower panel) locations. (Bold faced months covered the lateral displacement period.)

In an attempt to try to put some light on the question about whether seasonal changes in water properties play any role in modulating the local soundscape characteristics in this portion of SRKW critical habitat, we calculated L5 at each location for each lunar month using only data from periods when the wind speed at Race Rocks Light station (Latitude 48.3°N Longitude 123.53°W; https://weather.gc.ca/past_conditions/index_e.html?station=wqk) was below 10 km/h to minimize wind generated noise. In addition, only data from slack tide periods were included to minimize low-frequency flow noise issues associated with water flowing past the hydrophones. Finally, we only included 1-minute averaged PSD when the nearest AIS equipped vessel was more than 20 km away, to minimize impact on noise levels by shipping. These results are shown in Figure 15.

The noise levels were generally lower at the Port Renfrew and Jordan River locations than at the Sooke location and the month to month variability at each location was low, typically within 2-3 dB. An exception was lunar month 3 (13 June – 12 July) at Jordan River which had L5 levels about 5 dB higher at frequencies below approximately 100 Hz. The source of this elevated noise level is not clear. The month to month variability was smallest at the Port Renfrew location for this period.

No seasonal patterns were observed in the L5 levels at these sites.

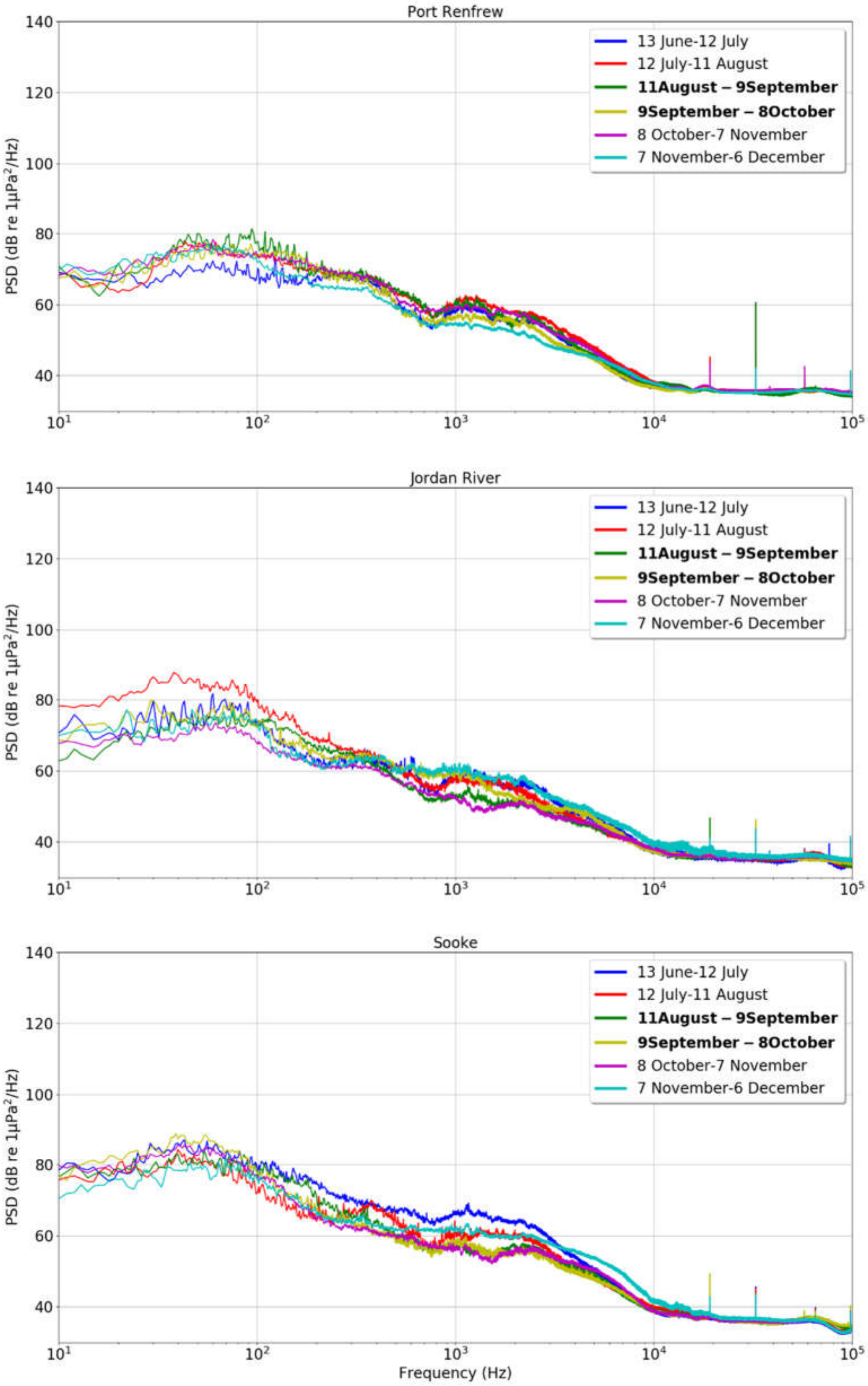

Figure 15. Lunar monthly L5 percentile data from periods with slack tide, Race Rocks winds < 10km h^{-1}, and AIS Type A vessels further away than 20 km at Port Renfrew (top panel), Jordan River (middle panel) and Sooke (lower panel).

Yet another way to represent the distribution of ambient sound during a lunar month by frequency is to depict percentiles of 1-minute 1/3 octave band levels as box and whisker plots for Port Renfrew, Jordan River and Sooke (Figures 16-18). Boxes are the L25 and L75 values and the horizontal black lines are the median values (L50). The whiskers extend outside the boxes to the highest and lowest observations that fall within 1.5 times the interquartile range (IQR). The IQR is the interquartile range measured from the 25th to the 75th percentile.

Upper panel is the lunar month closest to the trial period, before the actual trial, the middle panel is a lunar month during the trial, and the bottom panel is the lunar month following the trial.

The primary reason for including these figures in this report is to allow for future direct comparison with other studies in which the ambient noise levels are presented as 1/3 octave band levels.

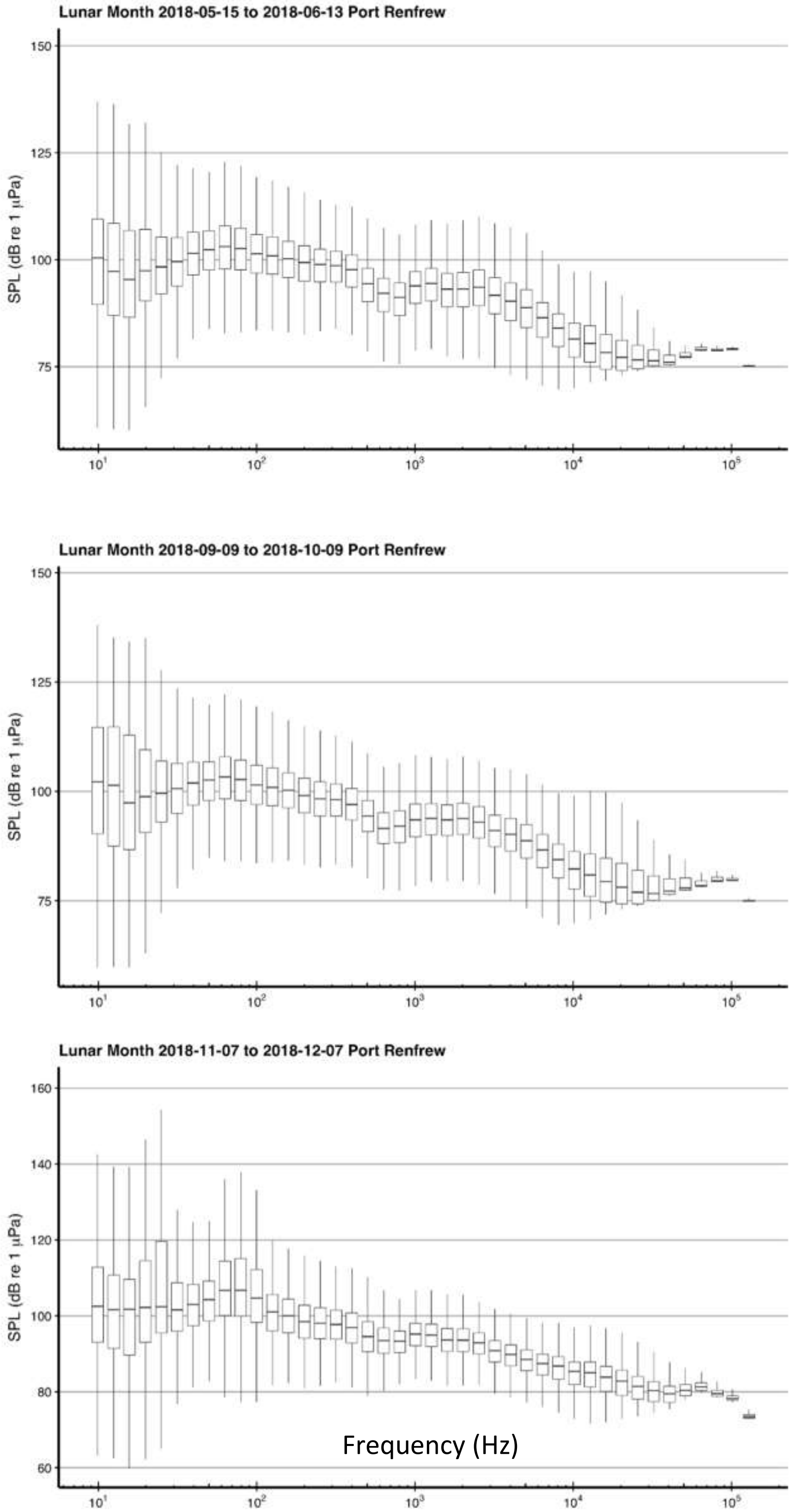

Figure 16. Representation of the distribution of ambient sound during lunar months by frequency for **Port Renfrew**. (See text for description of plots.) Upper panel is the lunar month closest to the trial period, before the actual trial, the middle panel is a lunar month during the trial, and the bottom panel is the lunar month following the trial.

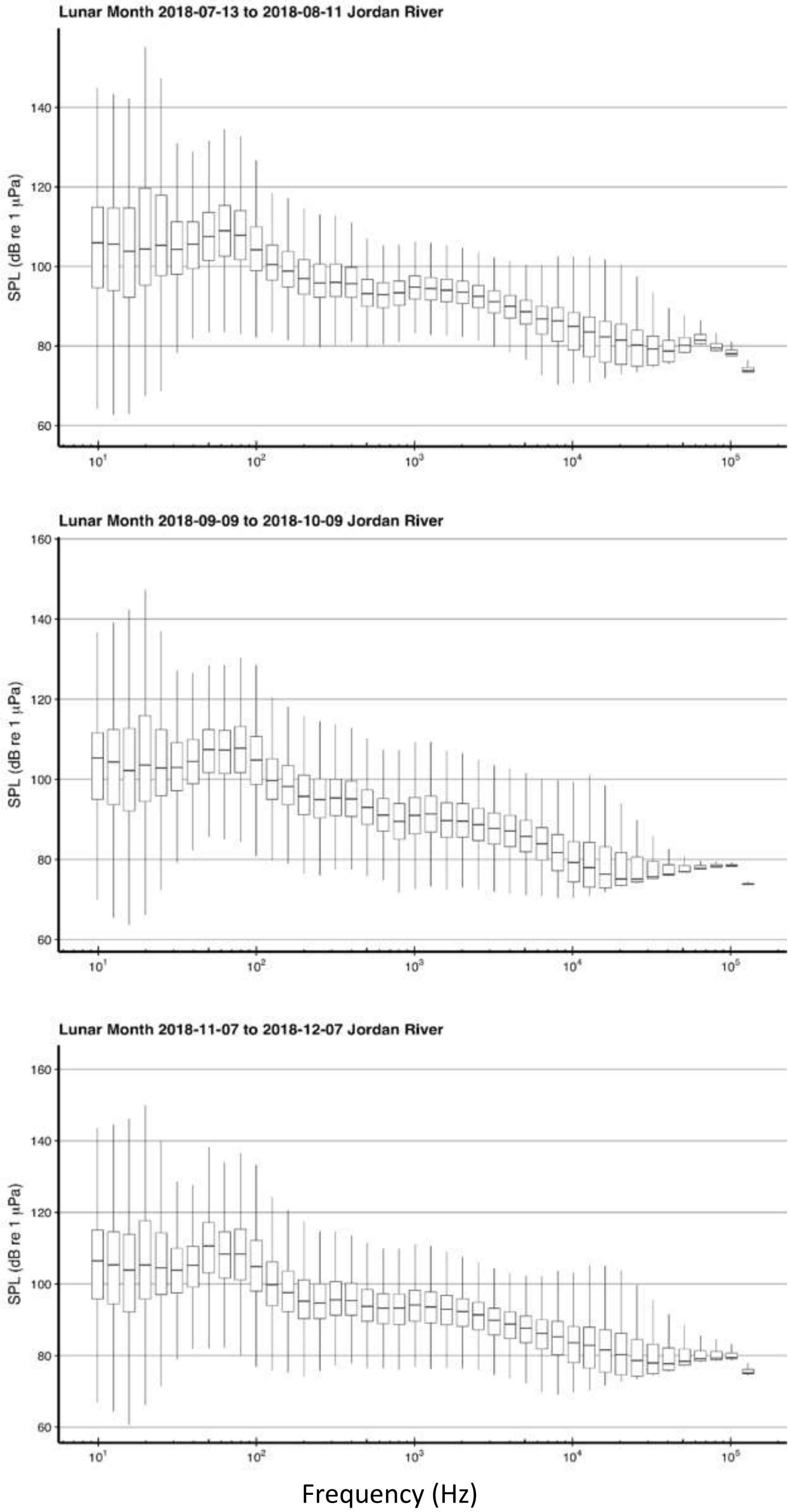

Figure 17. Representation of the distribution of ambient sound during lunar months by frequency for **Jordan River**. (See text for description of plots) Upper panel is the lunar month closest to the trial period, before the actual trial, the middle panel is a lunar month during the trial, and the bottom panel is the lunar month following the trial.

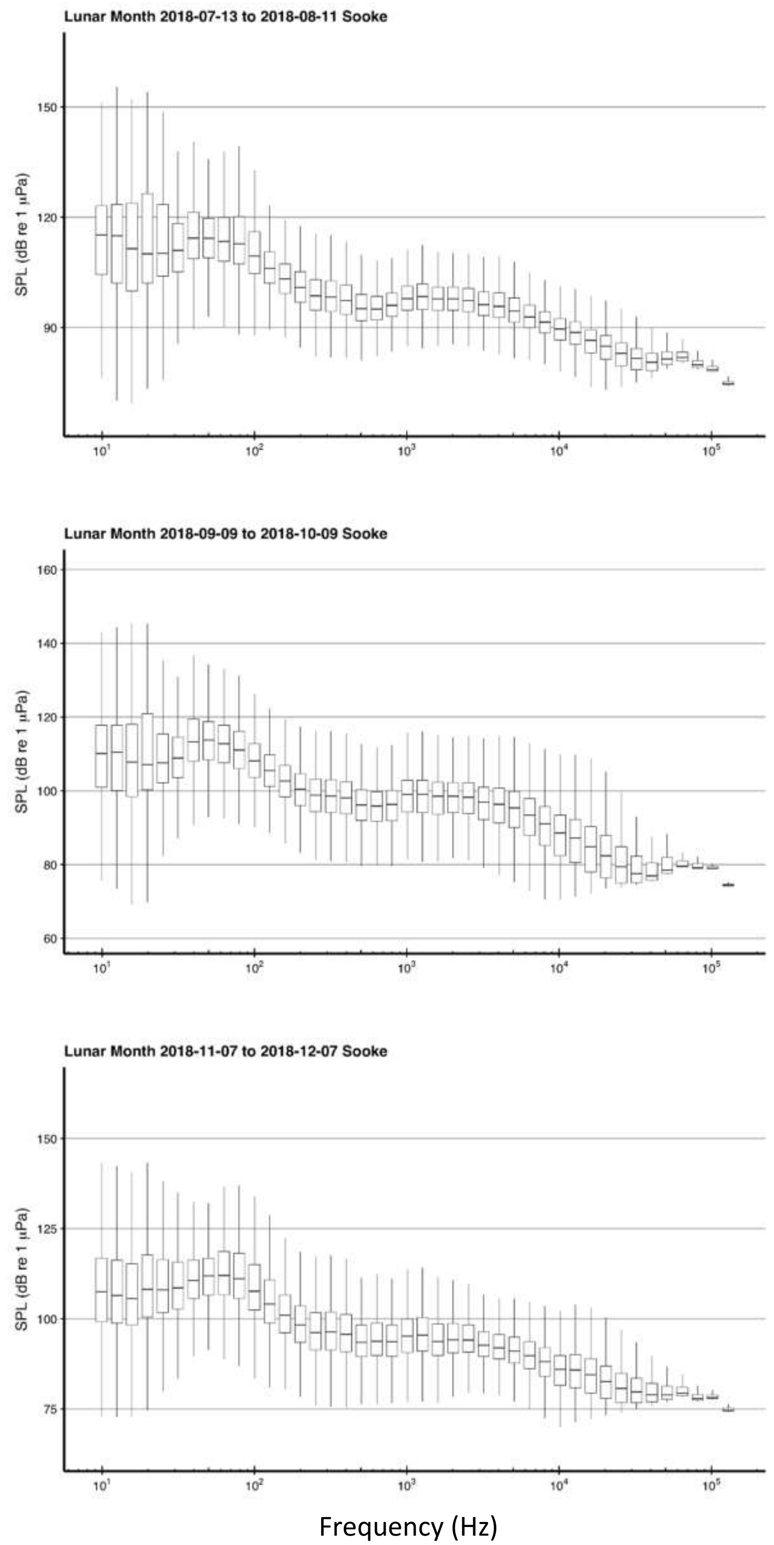

Figure 18. Representation of the distribution of ambient sound during lunar months by frequency for **Sooke**. (See text for description of plots) Upper panel is the lunar month closest to the trial period, before the actual trial, the middle panel is a lunar month during the trial, and the bottom panel is the lunar month following the trial.

4.2 Daily and Monthly Rhythm Plots

Rhythm plots on different time-scales can often reveal patterns associated with human activities, such as ferries, other scheduled vessel activity, fishing operations and pleasure craft use.

Figures 19-21 show daily rhythm plots (Median SPL across the lunar month for each hour of the day in local time) for the three Strait of Juan de Fuca locations during the lunar months considered here. The data are shown for relevant frequency bands, including bands important to SRKW.

Generally the band levels are similar across the three sites.

At Port Renfrew there was very little hourly variability during April and May, while in June there was significantly higher broad-band (10-100,000 Hz) noise between 20:00 and 02:00, i.e. at night (Figure 19). In August and September, and to a lesser degree in October, there was significantly increased noise levels in most bands between 04:00 and about 15:00. In November again the pattern was back to increased broad-band noise during night. At least part of the increased noise during daylight hours in the summer and autumn months is associated with increased number of recreational vessels fishing in the area.

No obvious hourly pattern in the noise field at Jordan River can be found in this data set. The Jordan River location is approximately 40 km from the nearest port and boat launch; limiting the number of recreational vessels visiting this area.

At the Sooke location there was less noise in most bands between approximately 03:00 and 16:00 than the rest of the day, during April to July. In August and September the pattern was similar to Port Renfrew with increased noise levels in most bands between 04:00 and about 15:00. The band levels for October and November are not shown because some presently unknown noise contaminated the data set.

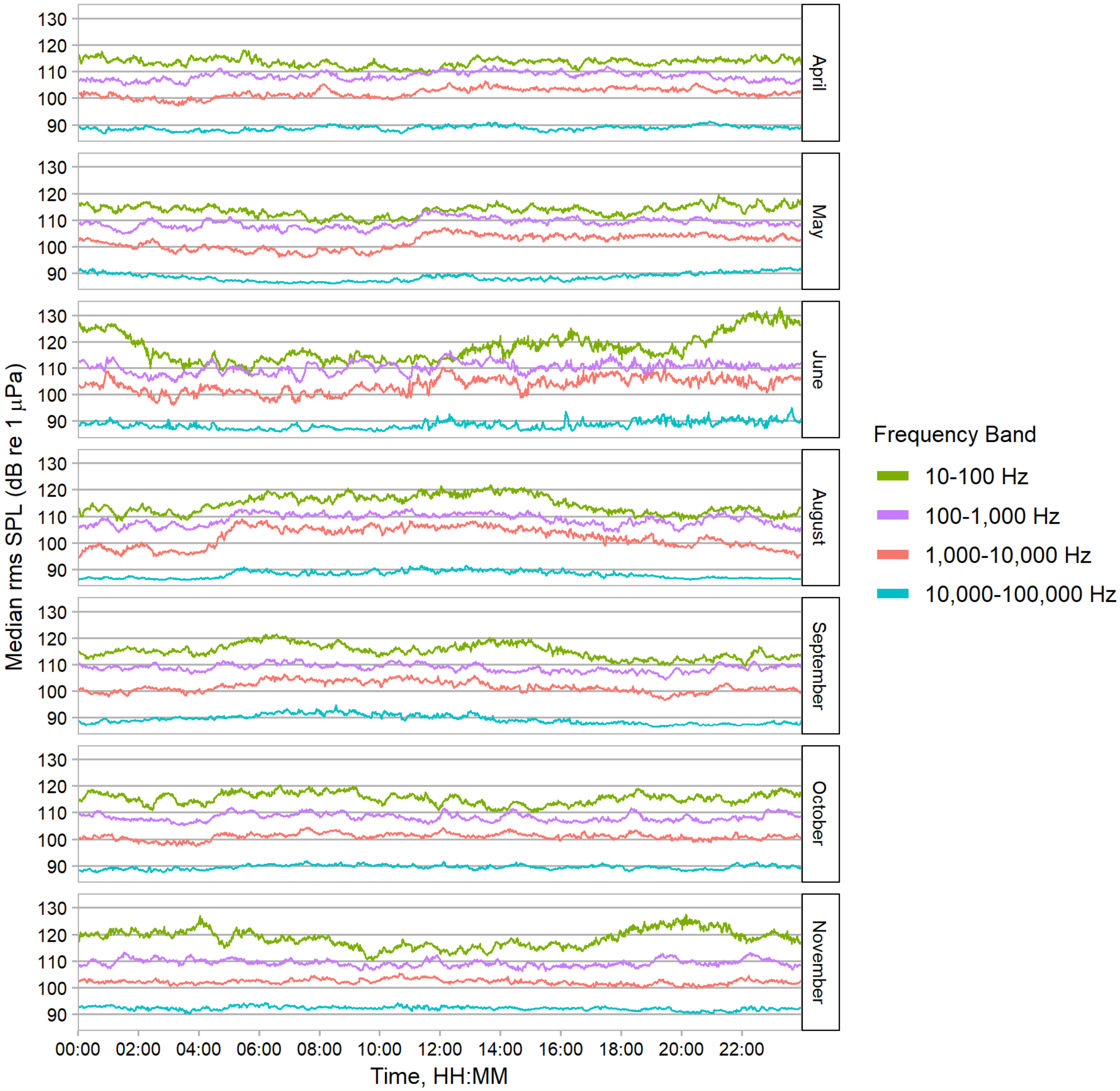

Figure 19a. Daily rhythm plot for each lunar month at **Port Renfrew** for frequency bands identified in legend.

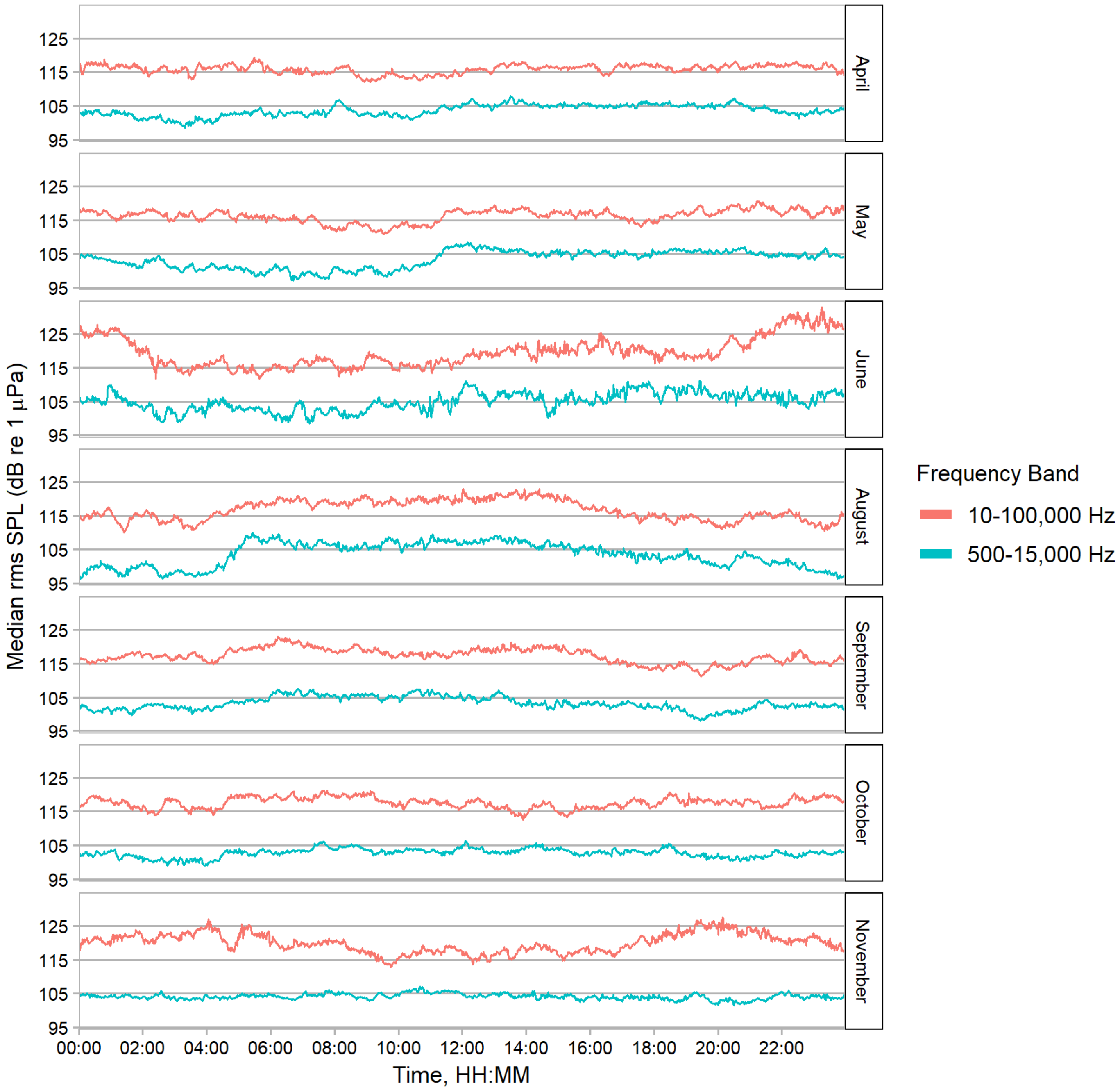

Figure 19b. Daily rhythm plot for each lunar month at **Port Renfrew** for frequency bands identified in legend.

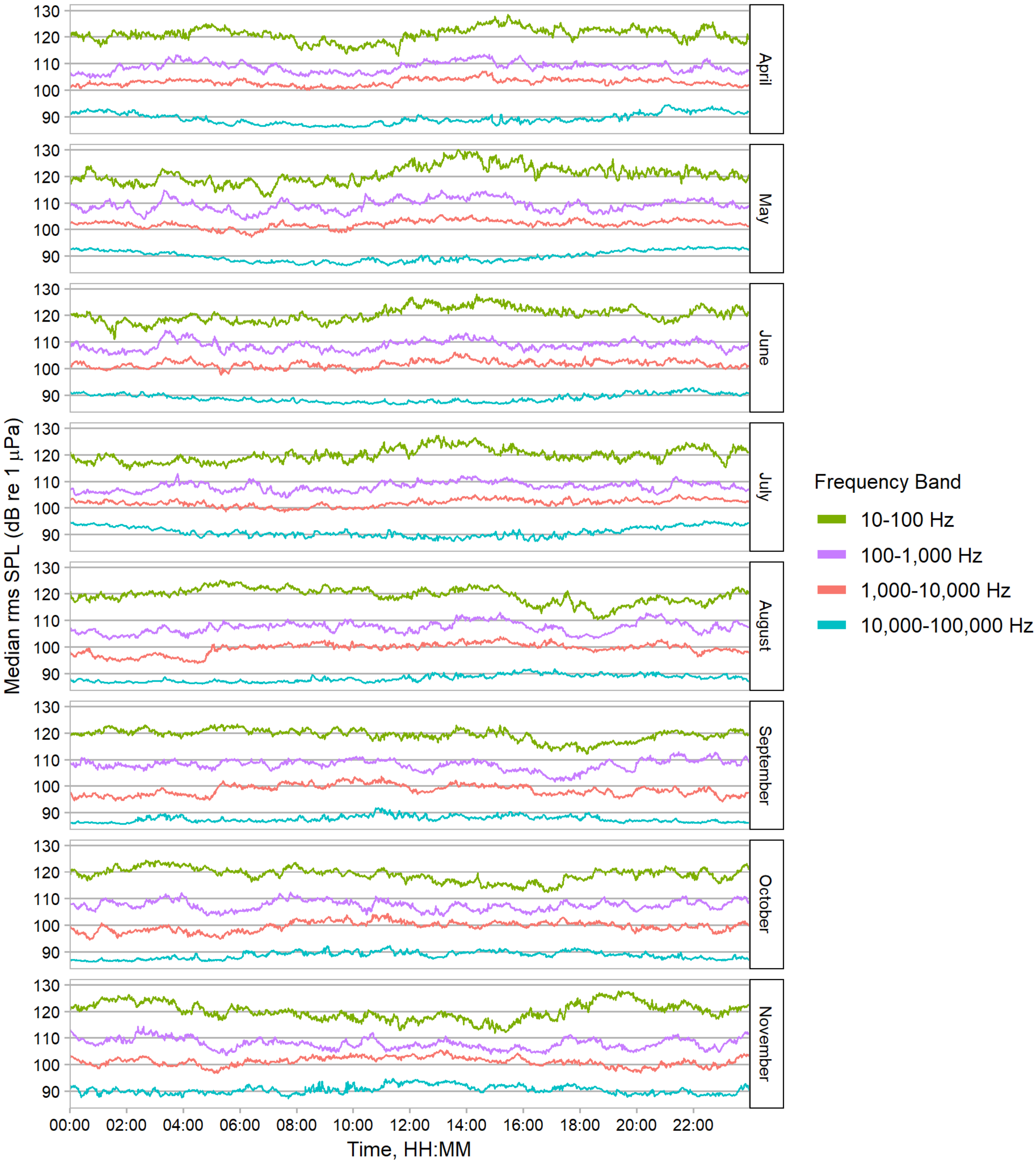

Figure 20a. Daily rhythm plot for each lunar month at **Jordan River** for frequency bands identified in legend.

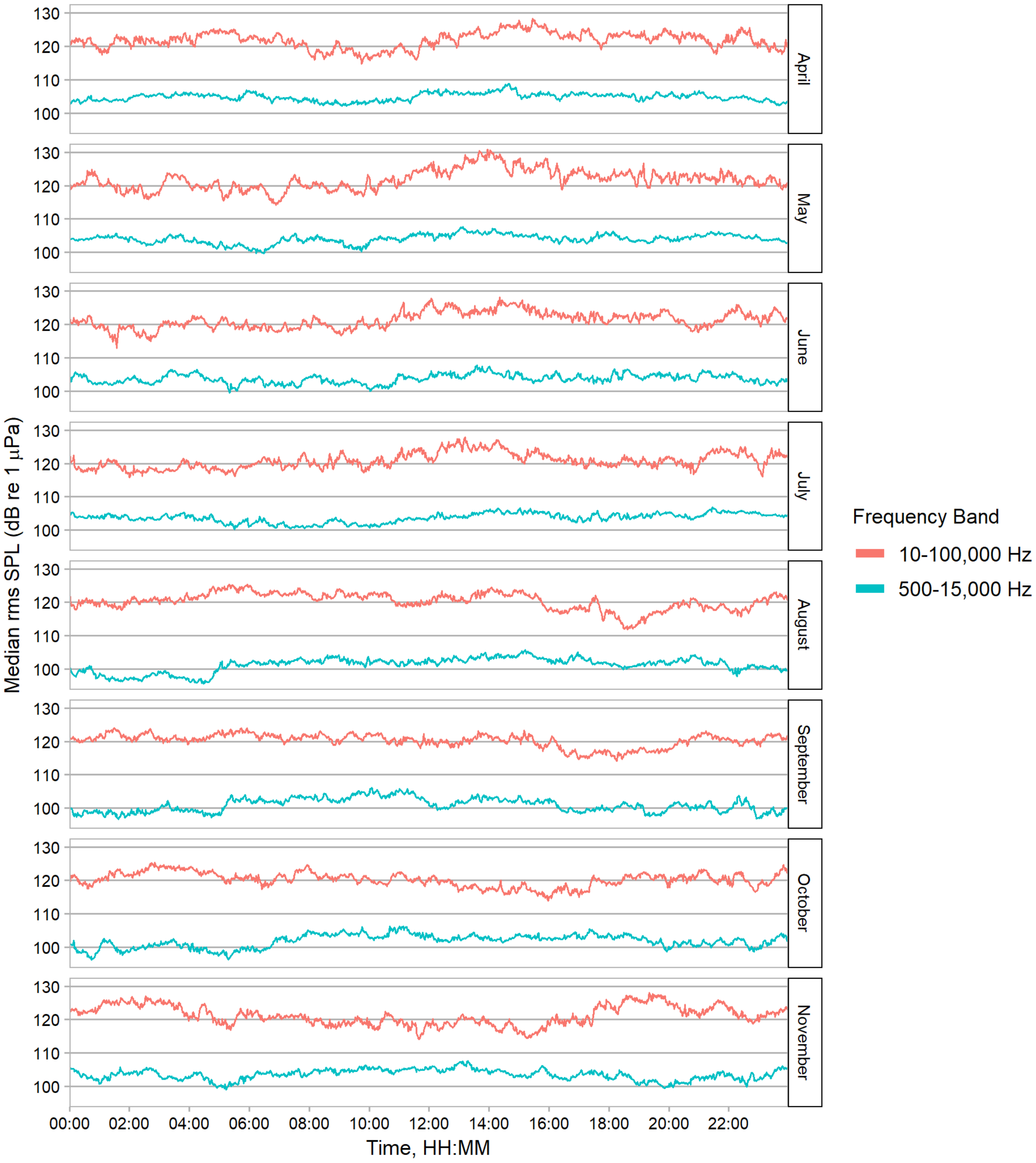

Figure 20b. Daily rhythm plot for each lunar month at **Jordan River** for frequency bands identified in legend.

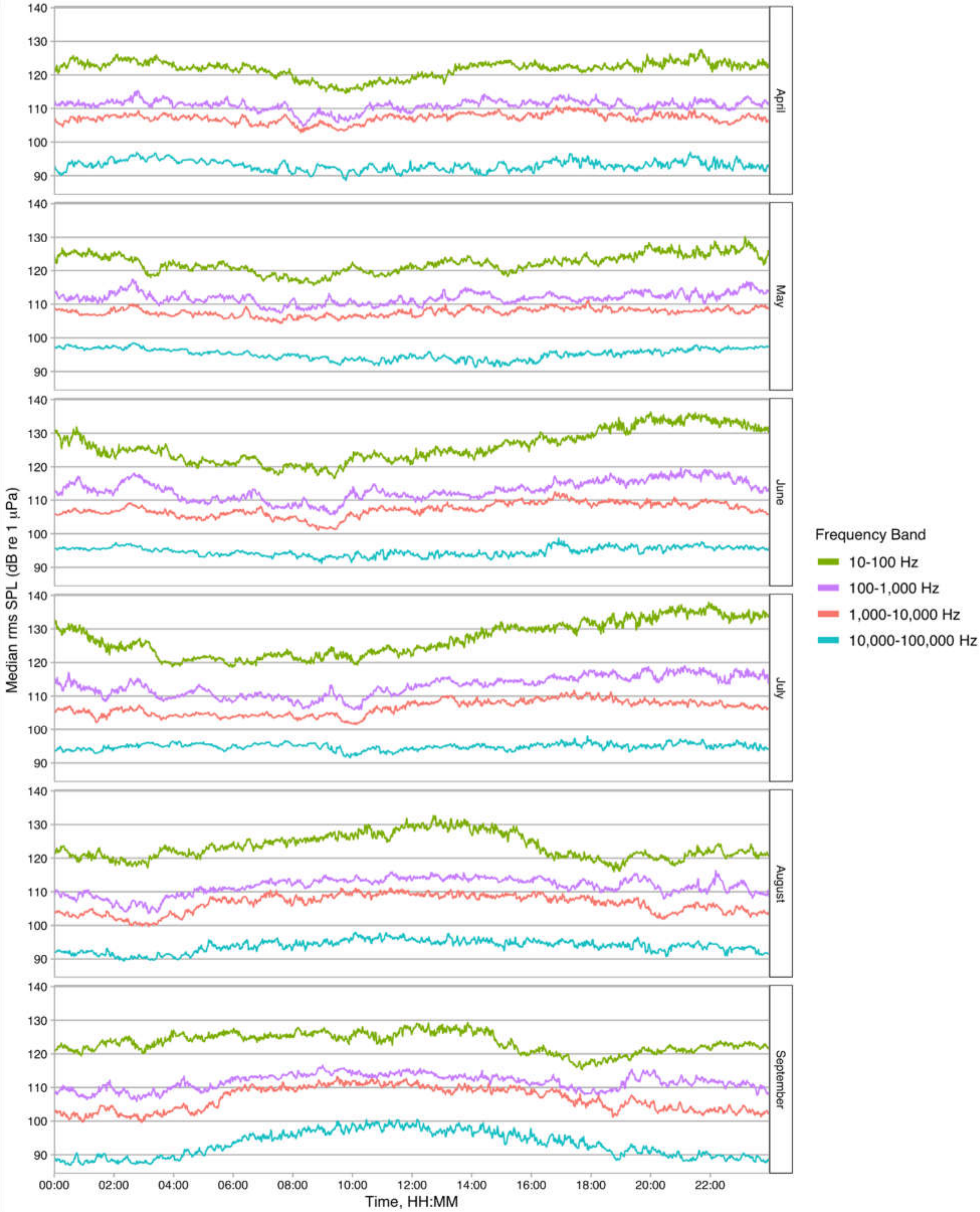

Figure 21a. Daily rhythm plot for lunar months at **Sooke** for frequency bands identified in legend.

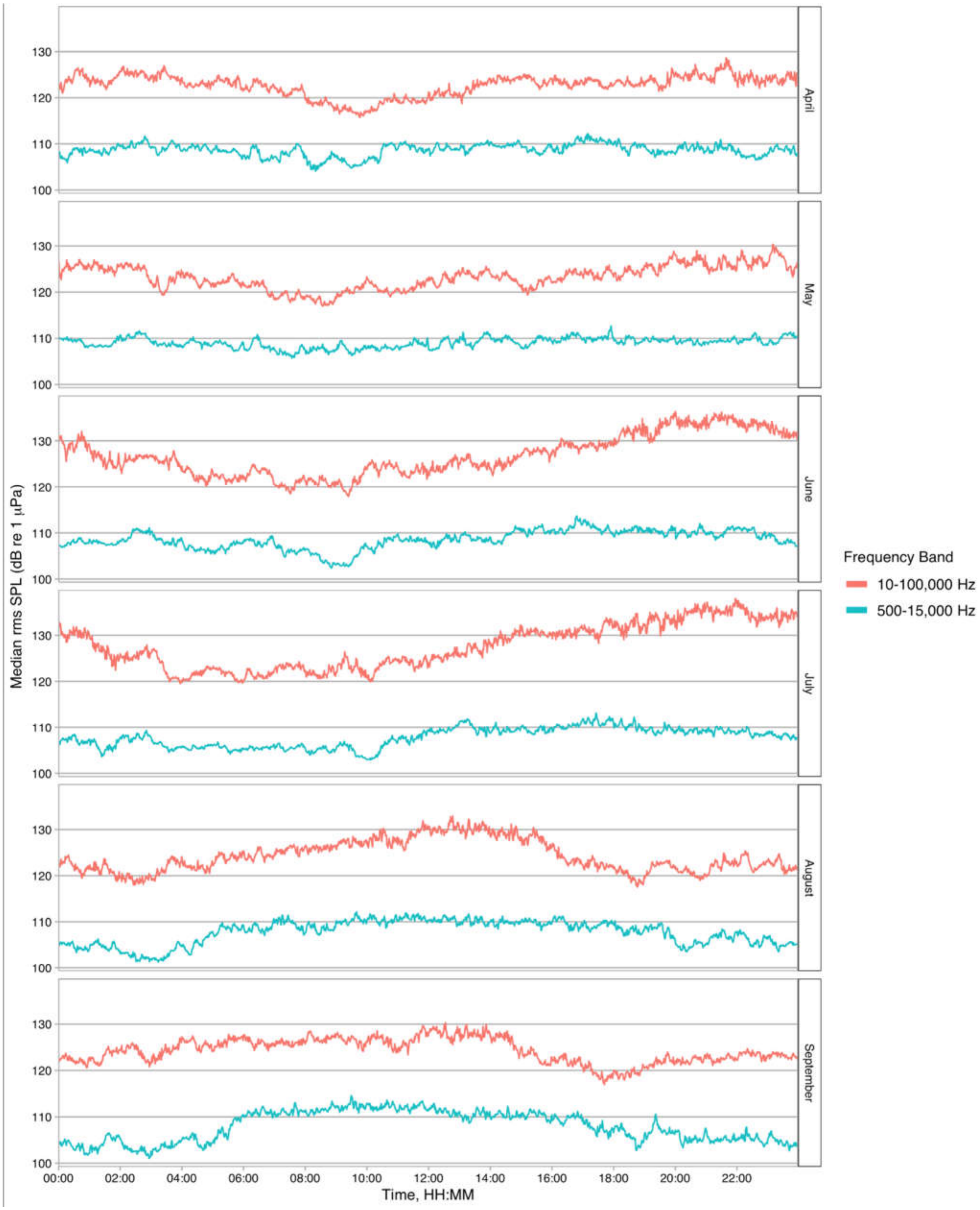

Figure 21b. Daily rhythm plot for lunar months at **Sooke** for frequency bands identified in legend.

Similarly, figures 22-24 show weekly rhythm plots (Median SPL across the lunar month for each day of the week) for the three Juan de Fuca locations during lunar months considered here. These data are also shown for relevant frequency bands, including bands important to SRKW.

The data clearly show passages of close-by larger vessels as manifested in the broad-band and lower frequency bands showing significant variability. No daily trends are obvious from these results.

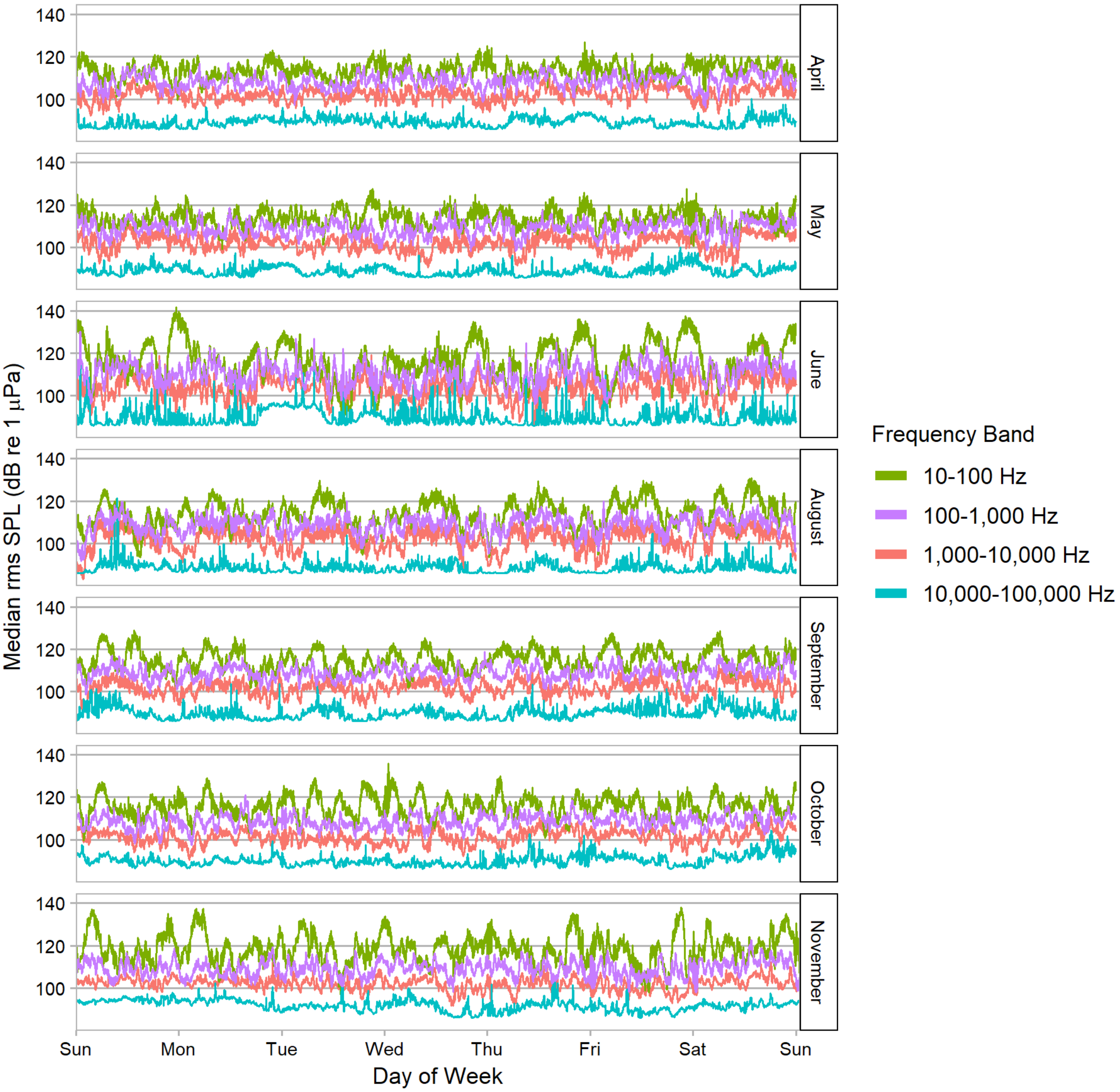

Figure 22a. Weekly rhythm plot for each lunar month at **Port Renfrew** for frequency bands identified in legend.

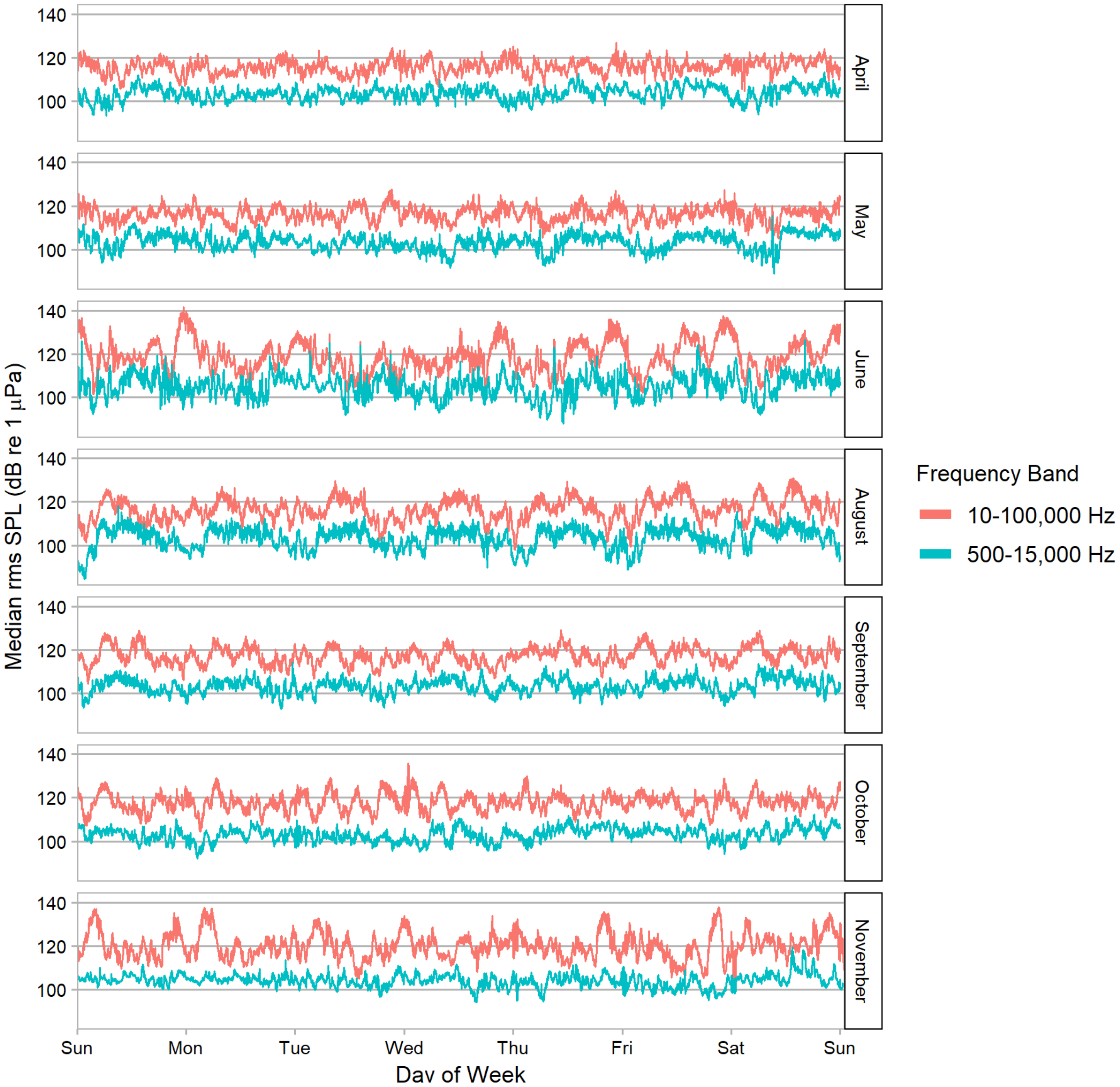

Figure 22b. Weekly rhythm plot for each lunar month at **Port Renfrew** for frequency bands identified in legend.

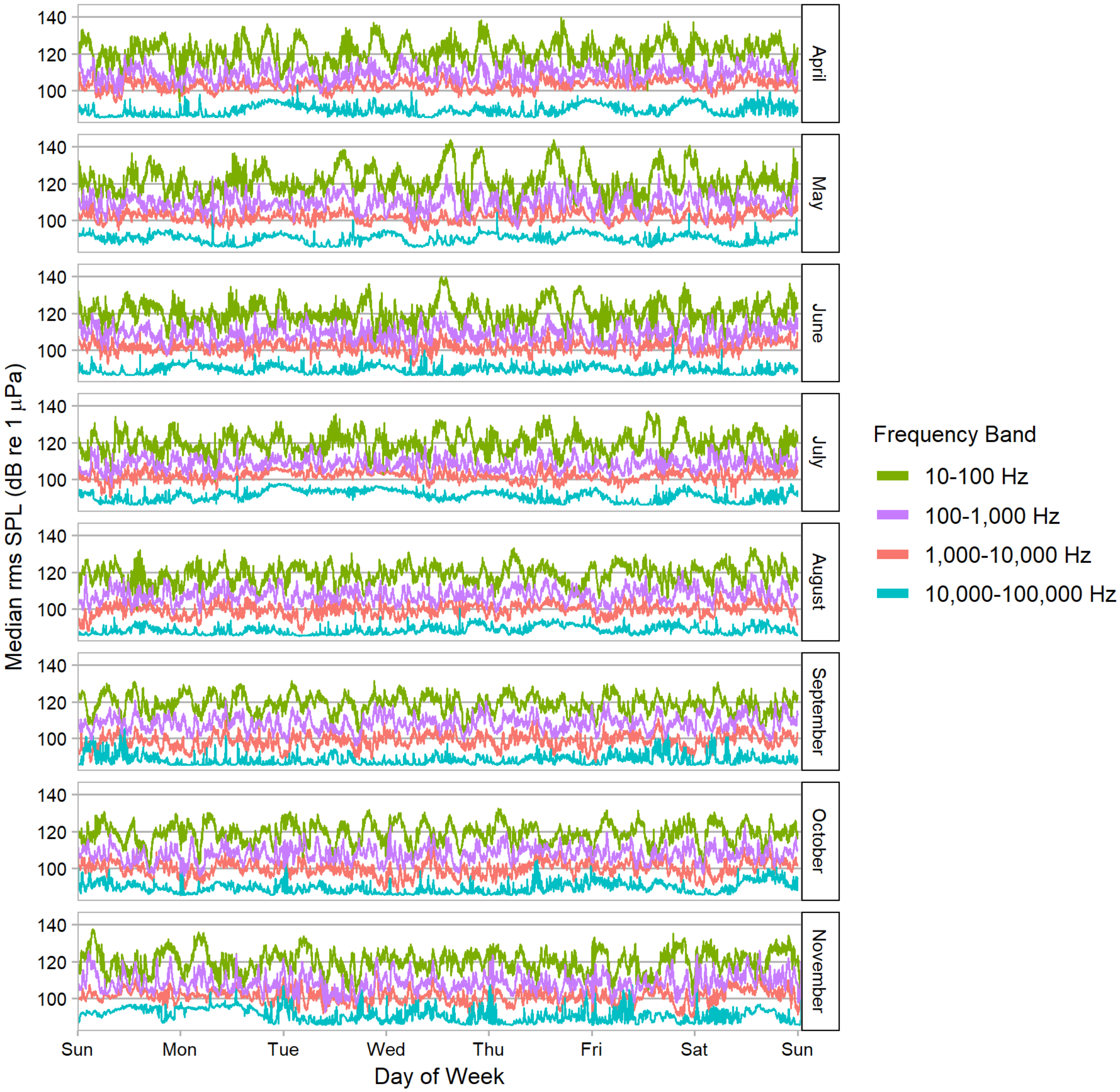

Figure 23a. Weekly rhythm plot for each lunar month at **Jordan River** for frequency bands identified in legend.

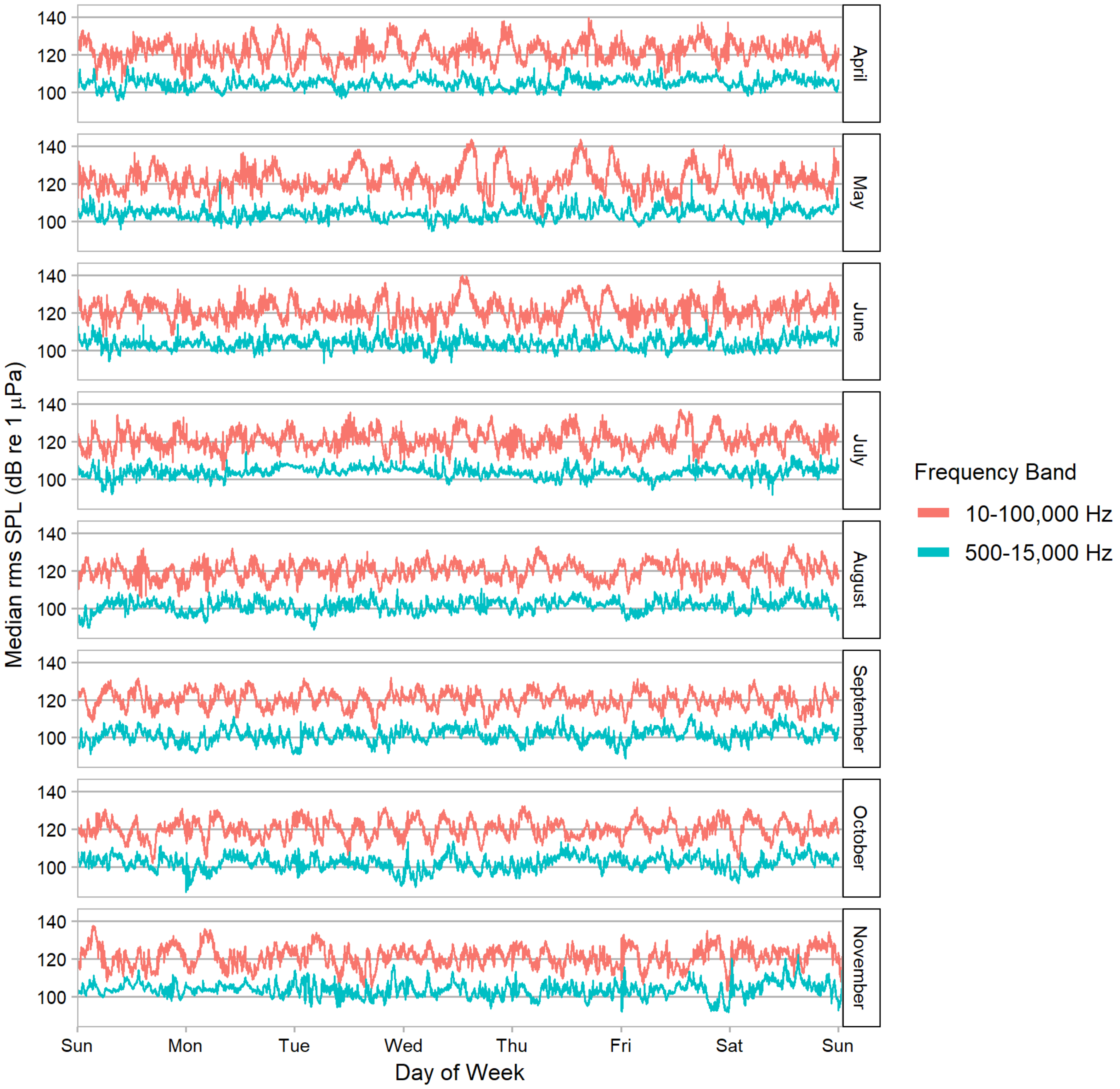

Figure 23b. Weekly rhythm plot for each lunar month at **Jordan River** for frequency bands identified in legend.

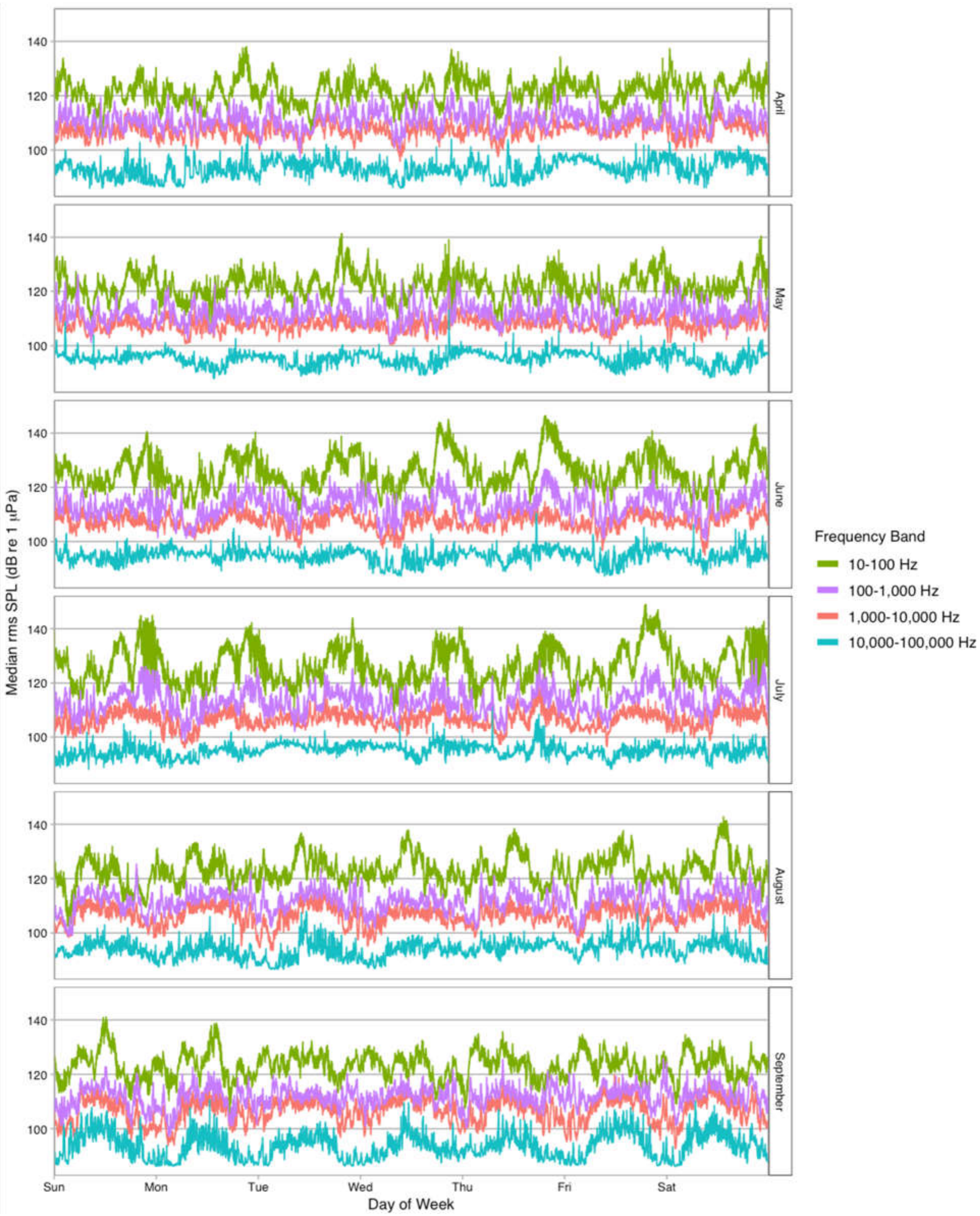

Figure 24a. Weekly rhythm plot for lunar months at **Sooke** for frequency bands identified in legend.

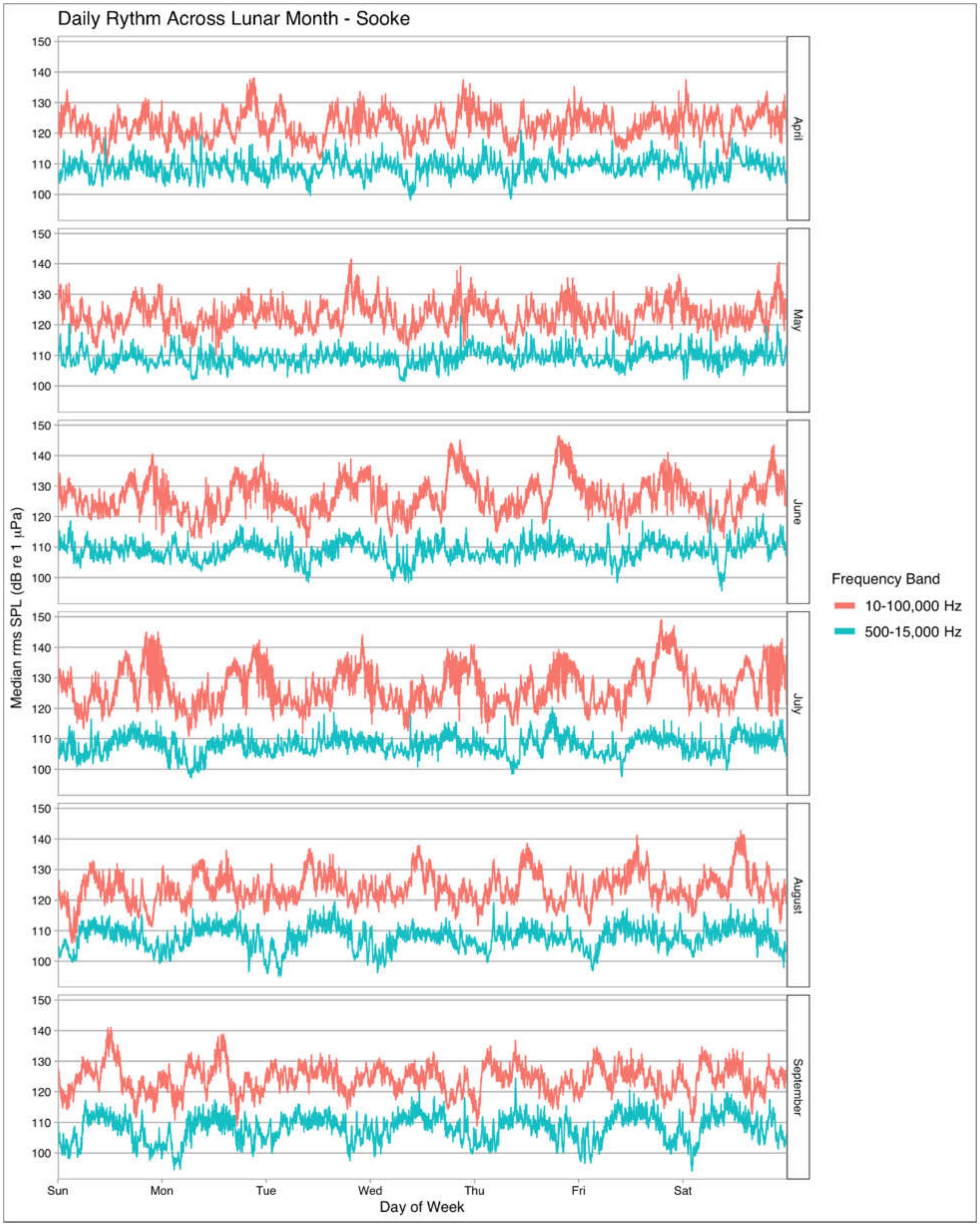

Figure 24b. Weekly rhythm plot for lunar months at **Sooke** for frequency bands identified in legend.

4.3 Comparisons of noise levels pre- and post-trial with noise levels during the lateral displacement trial period (August 20-October 31, 2018)

4.3.1 Overall underwater noise levels

To evaluate the effects on the noise levels at frequencies relevant to SRKW in the portion of their critical habitat that was monitored by our three hydrophone moorings, we compared the SPL in six different bands: 500-15,000 Hz, 10-100,000 Hz, 10-100 Hz, 100-1000 Hz and 10,000-100,000 Hz from the complete pre-trial period with all the available data from the trial and post-trial periods. The results are shown in Figure 25 and tabulated in Tables 4-6. In the data shown here all available data were used, including periods with high winds and strong tidal currents. The box plots are defined as before, with the solid horizontal lines in the middle of the boxes being the median (L50) values, and the boxes defined by L25 and L75. The whiskers extend outside the boxes to the highest and lowest observations that fall within 1.5 times the interquartile range (IQR). The IQR is the interquartile range measured from the 25th to the 75th percentile. The post-trial data from the Sooke location have not been included in these results due to some spurious, presently unknown, signals observed during this period.

At the Port Renfrew location there was a slight improvement (i.e. reduction) in SPL L50 in three of the six frequency bands considered (0.5 – 15 kHz, 0.1 – 1 kHz, and 1 – 10 kHz) of between 0.1 and 0.6 dB (Table 4). Similarly, at the Sooke location there was also improvement in SPL L50 in three of the six frequency bands (0.5 – 15 kHz, 0.01- 100 kHz, and 10 – 100 Hz) of between 1 and 4 dB (Table 6). In the other frequency bands there were observed **increases** in all SPL percentiles during the trial period at these two locations. The reasons for these increases have not been identified, but it is worth noting that the Sooke location is well outside the lateral displacement corridor (Figure 1) and at the Port Renfrew location, towards the end of the corridor, a number of the outbound vessels had already started to shift back towards the regular track lines.

Therefore, during the remainder of this report we will focus on the Jordan River data set, which is from the centre of the lateral displacement region and therefore should best represent the results of the lateral displacement trial.

At the Jordan River location all relevant metrics, in all frequency bands, indicated improved underwater noise conditions during the lateral displacement trial (Table 5). By assuming that the conditions pre- and post-trial were similar the band-level SPL noise reductions were lumped together as no-trial and trial periods in Table 7. These results show that L25, L50, L75 and Leq were all reduced by between 0.6 and 3.7 dB during the lateral displacement period in this portion of SRKW critical habitat.

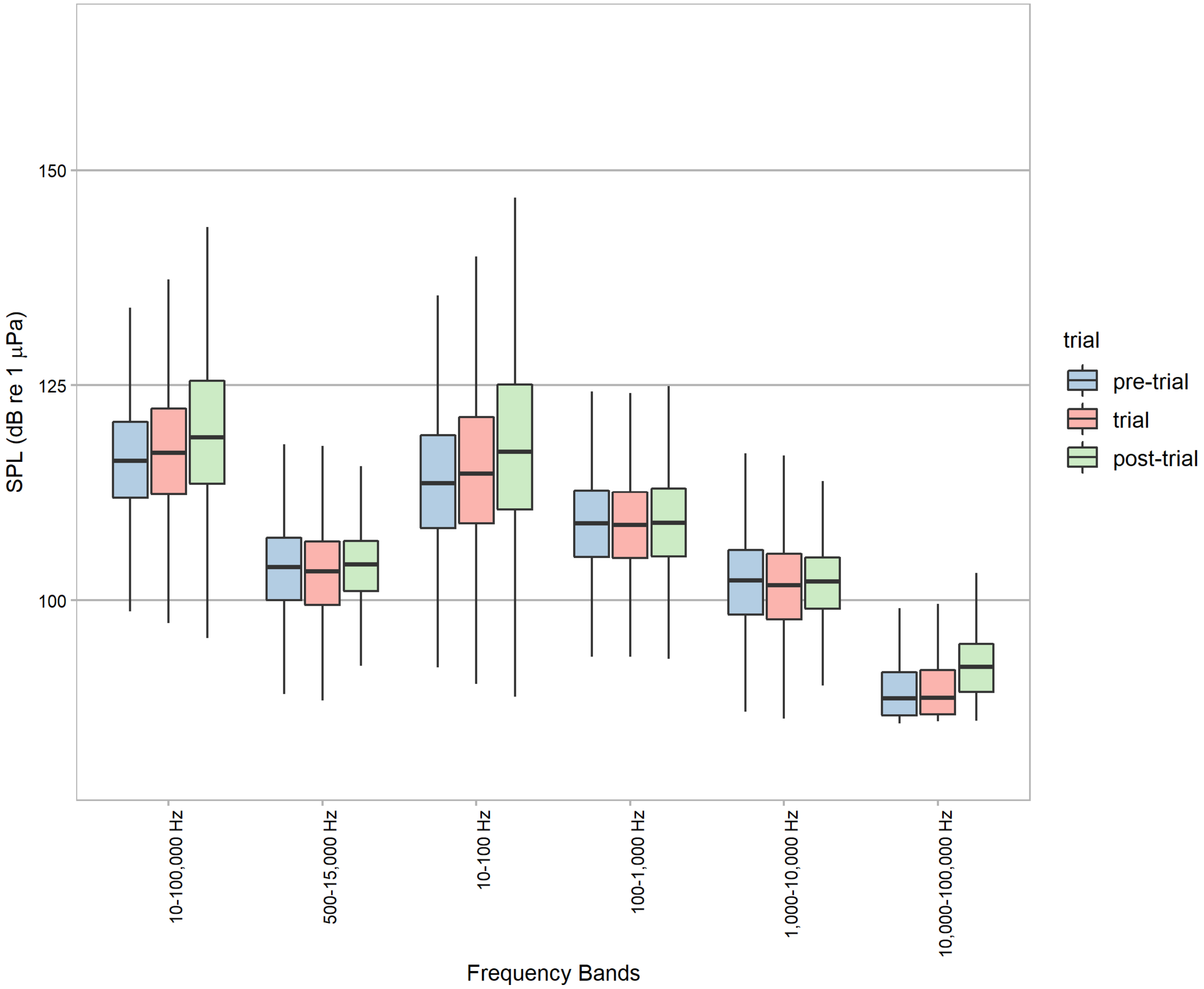

Figure 25a. **Port Renfrew** location. SPL boxplots for six frequency bands for the pre-trial period (Blue boxes), the trial period (Red boxes) and for the post-trial period (Green boxes). Values tabulated in Table *4*.

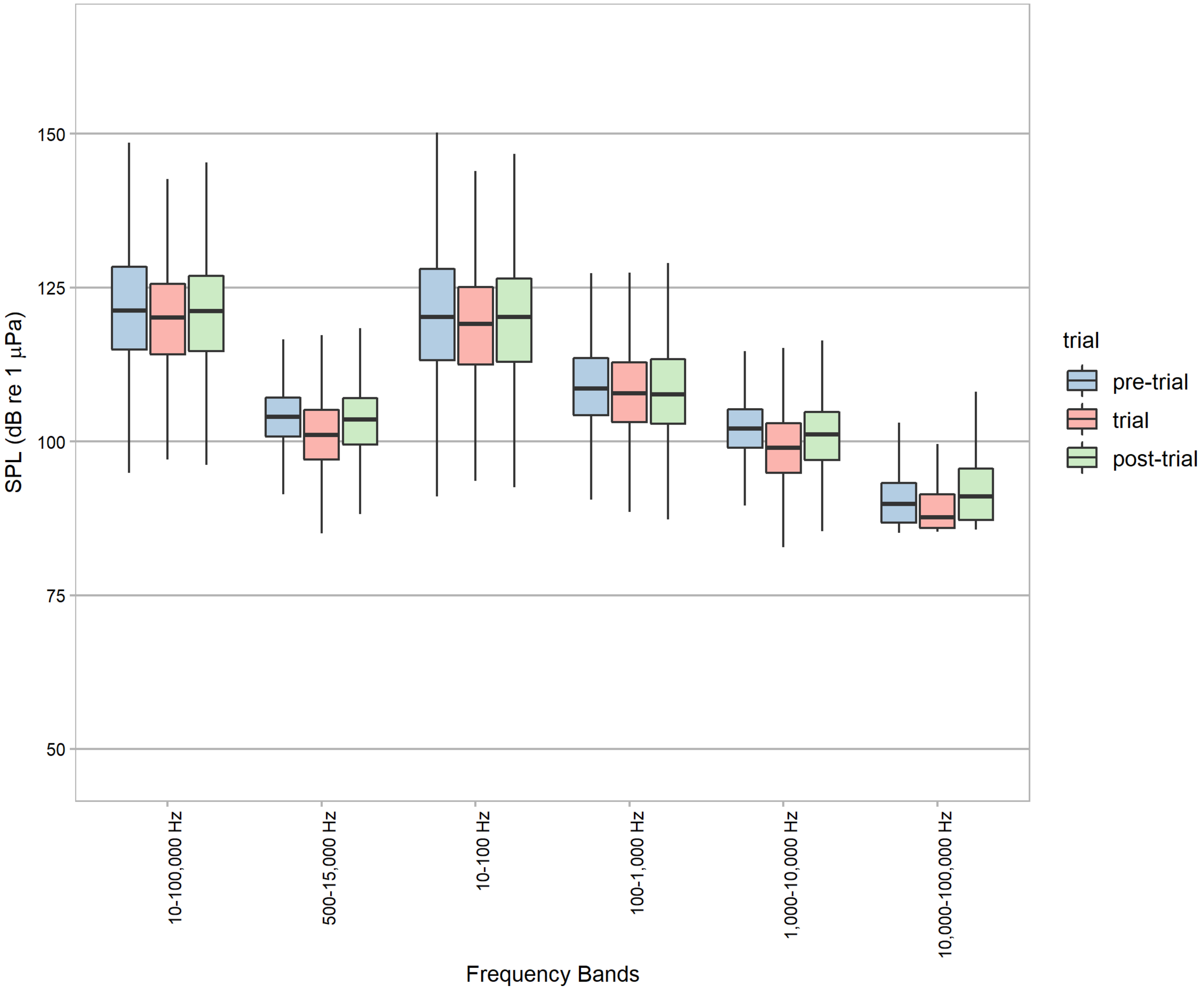

Figure 25b. **Jordan River** location. SPL boxplots for six frequency bands for the pre-trial period (Blue boxes), the trial period (Red boxes) and for the post-trial period (Green boxes). Values tabulated in Table 5.

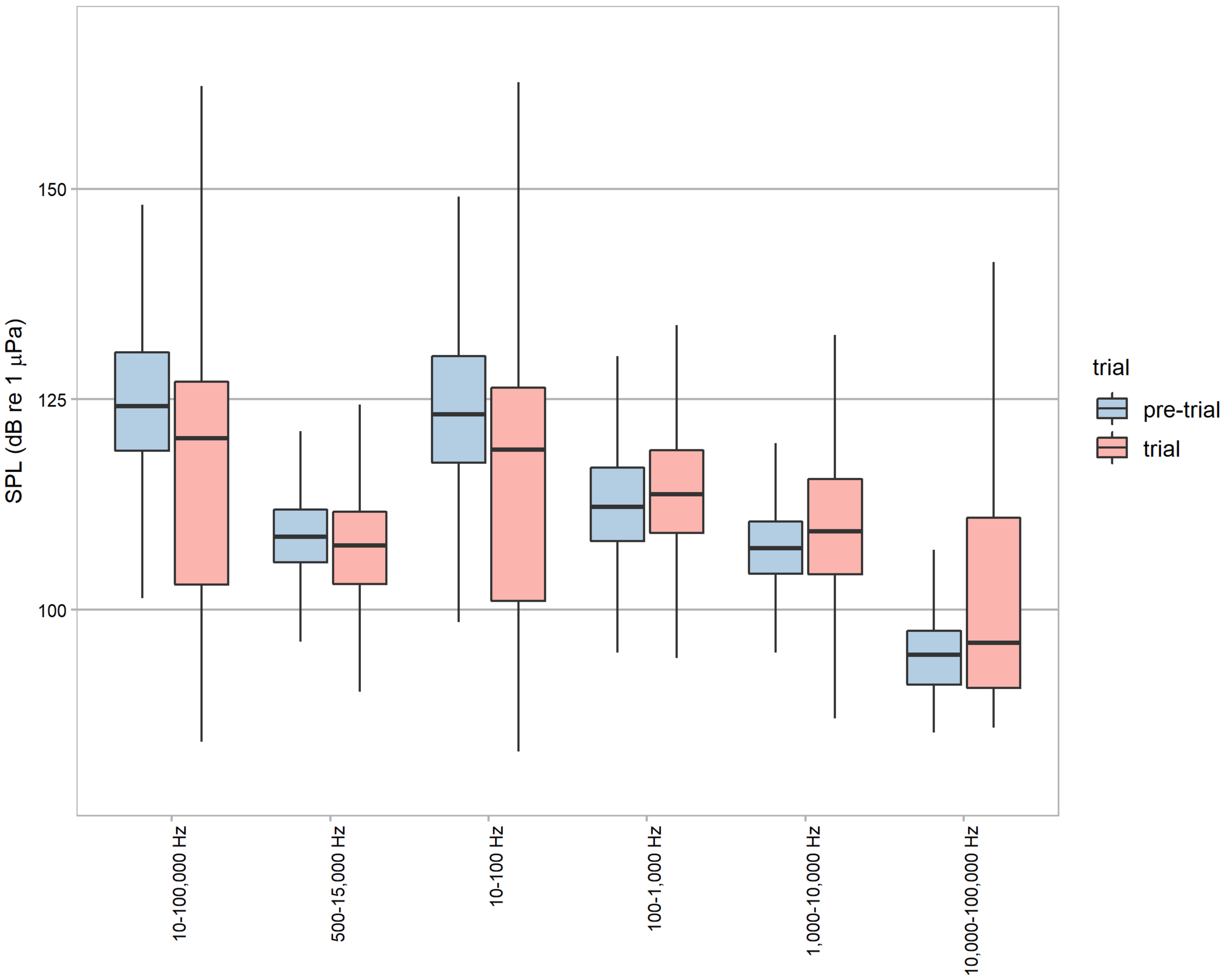

Figure 25c. **Sooke** location. SPL boxplots for six frequency bands for the pre-trial period (Blue boxes) and the trial period (Red boxes). Values tabulated in Table 6.

Table 4. **Port Renfrew** location. Tabulated values from Figure 25a. Values lower during the trial period are highlighted by being presented in bold face.

Pre-trial	**0.5-15kHz**	**0.01-100kHz**	**10-100Hz**	**0.1-1kHz**	**1-10kHz**	**10-100kHz**
Min.	86.3dB	94.5dB	85.8dB	88.3dB	85.0dB	85.7dB
75th percentile	100.0dB	111.9dB	108.4dB	105.0dB	98.3dB	86.6dB
Median	103.9dB	116.3dB	113.6dB	108.9dB	102.3dB	88.6dB
Mean	103.6dB	116.5dB	113.8dB	108.8dB	102.0dB	89.8dB
25th percentile	107.3dB	120.7dB	119.2dB	112.7dB	105.8dB	91.6dB
Max.	152.1dB	163.6dB	161.8dB	158.6dB	149.1dB	140.6dB
Trial						
Min.	**82.6dB**	**91.0dB**	**83.6dB**	**85.8dB**	**80.9dB**	85.9dB
75th percentile	**99.4dB**	113.3dB	108.9dB	**104.9dB**	**97.8dB**	86.8dB
Median	**103.3dB**	117.1dB	114.7dB	**108.8dB**	**101.7dB**	88.7dB
Mean	**103.0dB**	117.4dB	115.0dB	**108.7dB**	**101.5dB**	90.3dB
25th percentile	**106.8dB**	122.3dB	121.3dB	**112.6dB**	**105.4dB**	91.9dB
Max.	**155.8dB**	164.5dB	163.6dB	159.8dB	153.2dB	146.7dB
Post-trial						
Min.	86.2dB	93.4dB	81.9dB	88.0dB	84.4dB	86.0dB
75th percentile	101.1dB	113.6dB	110.6dB	105.1dB	99.0dB	89.4dB
Median	104.1dB	119.0dB	117.2dB	109.0dB	102.2dB	92.3dB
Mean	104.0dB	120.0dB	117.9dB	109.1dB	102.0dB	92.8dB
25th percentile	106.9dB	125.5dB	125.0dB	113.0dB	105.0dB	94.9dB
Max.	157.1dB	165.1dB	162.4dB	161.0dB	156.5dB	147.8dB

Table 5. **Jordan River** location. Tabulated values from Figure 25b. Values lower during the trial period are highlighted by being presented in bold face.

Pre-trial	**0.5-15kHz**	**0.01-100kHz**	**10-100Hz**	**0.1-1kHz**	**1-10kHz**	**10-100kHz**
Min.	60.3dB	68.5dB	47.4dB	51.0dB	58.3dB	67.9dB
75th percentile	100.8dB	114.9dB	113.2dB	104.3dB	98.9dB	86.7dB
Median	104.0dB	121.3dB	120.2dB	108.6dB	102.1dB	89.9dB
Mean	104.1dB	121.7dB	120.4dB	109.0dB	102.2dB	90.5dB
25th percentile	107.1dB	128.4dB	128.0dB	113.5dB	105.2dB	93.2dB
Max.	158.9dB	164.3dB	162.9dB	159.2dB	158.7dB	148.9dB
Trial						
Min.	82.8dB	93.2dB	84.9dB	86.0dB	81.2dB	85.3dB
75th percentile	**97.1dB**	**114.1dB**	**112.5dB**	**103.1dB**	**94.9dB**	**85.9dB**
Median	**101.1dB**	**120.1dB**	**119.1dB**	**107.8dB**	**98.9dB**	**87.6dB**
Mean	**101.1dB**	**119.8dB**	**118.6dB**	**108.1dB**	**99.0dB**	**89.5dB**
25th percentile	**105.1dB**	**125.5dB**	**125.1dB**	**112.8dB**	**103.0dB**	**91.4dB**
Max.						
Post-trial						
Min.	85.7dB	91.9dB	81.8dB	86.7dB	83.5dB	85.7dB
75th percentile	99.5dB	114.6dB	112.9dB	102.9dB	97.0dB	87.2dB
Median	103.5dB	121.2dB	120.2dB	107.7dB	101.2dB	91.0dB
Mean	103.5dB	120.7dB	119.5dB	108.2dB	101.1dB	92.4dB
25th percentile	107.0dB	126.9dB	126.4dB	113.3dB	104.7dB	95.5dB
Max.						

Table 6. **Sooke** location. Tabulated values from Figure 25c. Values lower during the trial period are highlighted by being presented in bold face.

Pre-trial	**0.5-15kHz**	**0.01-100kHz**	**10-100Hz**	**0.1-1kHz**	**1-10kHz**	**10-100kHz**
Min.	85.2dB	95.5dB	90.4dB	86.6dB	84.0dB	85.5dB
75th percentile	105.6dB	118.9dB	117.5dB	108.1dB	104.2dB	91.1dB
Median	108.6dB	124.2dB	123.2dB	112.2dB	107.3dB	94.6dB
Mean	108.8dB	125.2dB	124.2dB	112.7dB	107.4dB	94.6dB
25th percentile	111.8dB	130.6dB	130.1dB	116.9dB	110.5dB	97.5dB
Max.	154.8dB	167.3dB	166.8dB	160.0dB	151.4dB	153.9dB
Trial						
Min.	**79.9dB**	**84.4dB**	**83.2dB**	**86.3dB**	**83.4dB**	86.0dB
75th percentile	**103.1dB**	**102.9dB**	**101.0dB**	109.1dB	104.2dB	**90.7dB**
Median	**107.6dB**	**120.4dB**	**119.0dB**	113.7dB	109.3dB	96.1dB
Mean	**107.2dB**	**115.3dB**	**114.3dB**	114.3dB	110.3dB	101.1dB
25th percentile	**111.6dB**	**127.1dB**	**126.4dB**	119.0dB	115.5dB	110.9dB
Max.	156.1dB	**165.0dB**	**162.6dB**	160.6dB	160.7dB	160.6dB

Table 7. **Jordan River** location. Pre- and post-trial periods have been combined into a no-trial period and compared to the trial period.

No-trial	**0.5-15kHz**	**0.01-100kHz**	**10-100Hz**	**0.1-1kHz**	**1-10kHz**	**10-100kHz**
Min.	60.3dB	68.5dB	47.4dB	51.0dB	58.3dB	67.9dB
75th percentile	100.6dB	114.8dB	113.1dB	104.0dB	98.6dB	86.8dB
Median	103.9dB	121.3dB	120.2dB	108.4dB	102.0dB	90.0dB
Mean	104.0dB	121.5dB	120.2dB	108.9dB	102.0dB	90.9dB
25th percentile	107.1dB	128.0dB	127.6dB	113.5dB	105.1dB	93.6dB
Max.	158.0dB	165.1dB	163.7dB	159.2dB	158.7dB	148.9dB
Trial						
Min.	82.8dB	93.2dB	84.9dB	86.0dB	81.2dB	85.3dB
75th percentile	97.1dB	114.1dB	112.5dB	103.1dB	94.9dB	85.9dB
Median	101.1dB	120.1dB	119.1dB	107.8dB	98.9dB	87.6dB
Mean	101.1dB	119.8dB	118.6dB	108.1dB	99.0dB	89.5dB
25th percentile	105.1dB	125.5dB	125.1dB	112.8dB	103.0dB	91.4dB
Max.	156.5dB	165.2dB	163.4dB	160.9dB	155.4dB	143.1dB
Trial minus No-trial						
75th percentile	**-3.5dB**	**-0.7dB**	**-0.6dB**	**-0.9dB**	**-3.7dB**	**-0.9dB**
Median	**-2.8dB**	**-1.2dB**	**-1.1dB**	**-0.6dB**	**-3.1dB**	**-1.4dB**
Mean	**-2.9dB**	**-1.7dB**	**-1.6dB**	**-0.8dB**	**-3.0dB**	**-1.4dB**
25th percentile	**-2.0dB**	**-2.5dB**	**-2.5dB**	**-0.7dB**	**-2.1dB**	**-2.2dB**

4.3.2 Vessel Class Noise Level reductions

The impact on the received noise levels from classes of vessels at a given location within SRKW critical habitat can be assessed by investigating the received noise levels as a function of range by combining the measured noise and the AIS vessel position and class data. The noise generated by a vessel will spread out as it travels between the vessel and the receiving hydrophone. The received level at the hydrophone, RL, will therefore be a function of the frequency dependent source level of the vessel, SL0, the frequency dependent losses A, and the range, r (m), via the sonar equation:

$$RL = SL0 - K*\log10(r) - A*(r/1000), \tag{1}$$

where K is a spreading loss coefficient. By knowing RL, r, and A it is possible to solve for SL0 and K. The frequency dependent absorption coefficient A was calculated using the Francois-Garrison equation (Francois and Garrison, 1982). In addition to the sound received from a given vessel, RL will also include natural sound, from wind and rain, possible flow noise due to tidal currents, and noise from other vessels within range. To minimize the possible effect of flow noise from tidal currents, the results below only include vessels from periods when the current speed was below 0.25 ms^{-1}; here defined as slack tide.

Two examples of this approach are shown in Figures 26 and 27, at the Jordan River location, for bulk-carriers and tugs, respectively. In Figure 26 the received noise levels within the three SRKW frequency bands: 10-100,000 Hz, 500-15,000 Hz and 15-100 kHz are shown for all the bulk-carriers observed during times satisfying the conditions outlined above. Blue dots represent the RL versus range for all bulk-carriers, while the red dots are from bulk-carriers during the lateral displacement trial only. The red solid lines are least-squares best fits of the model in equation 1 through these data. The blue lines show the SL and the dominant range prior to the trial, while the green lines show the corresponding level and range during the trial. (Ranges as obtained from Table 2). The lower panel (15-100 kHz band) has no fitted line, indicating that noise from bulk carriers could not be detected at frequencies above 15 kHz at this location.

The same results are shown for tugs in Figure 27. From the lower panel in Figure 27, it is clear that when the tugs were travelling further away than about 3,000 m from the mooring, they had no impact on noise levels above 15 kHz.

Using the same approach the best least-squares fits for SL0 and K, as well as the observed noise reduction for all vessel classes considered within the different frequency bands are summarized in Table 8. In cases where values are replaced by NA this implies that the vessels were too far away to contribute any sound within these frequency bands.

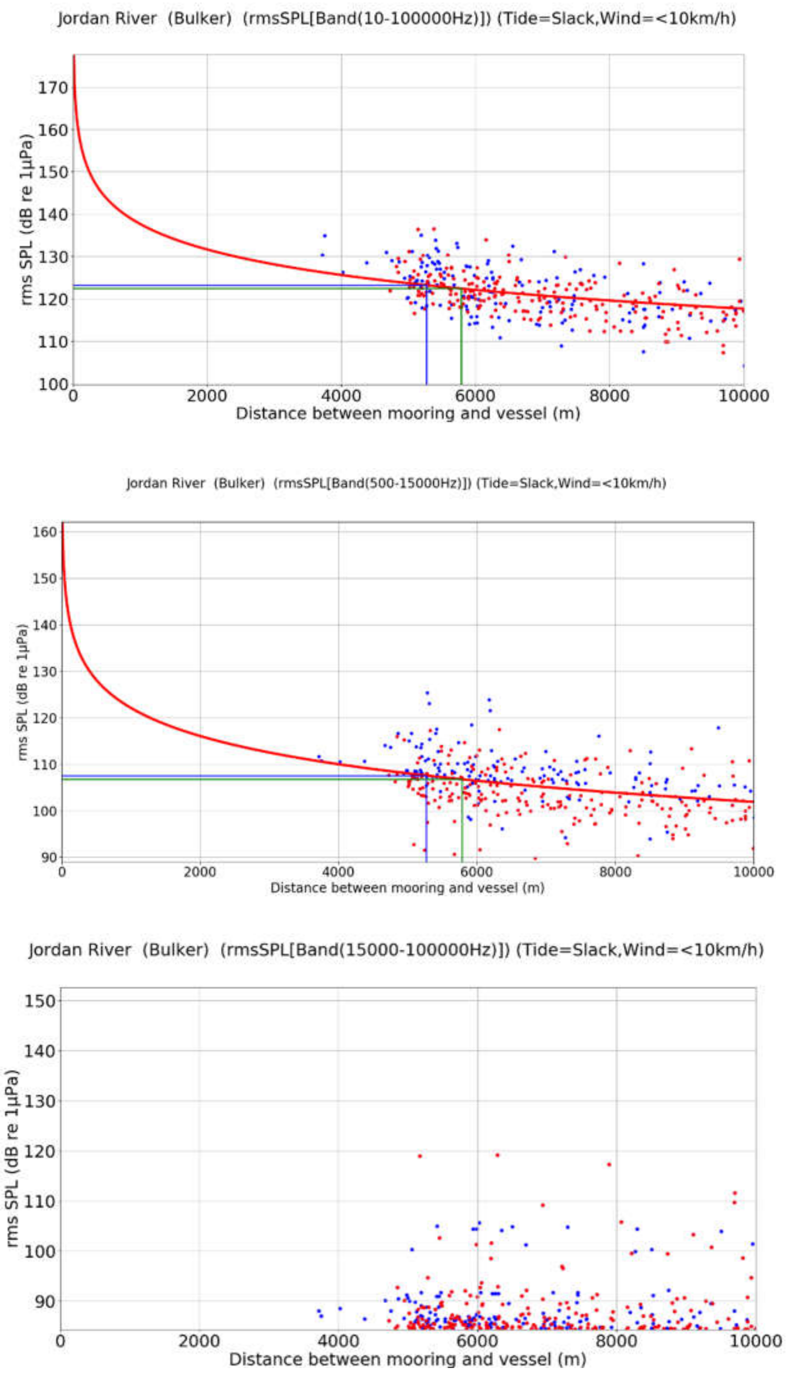

Figure 26. SL versus range for **bulk carriers** passing the Jordan River location. Blue dots are all vessels, while red dots are only vessel recorded during the trial period. Red solid lines are best fits to equation 1. Blue and green lines show the SL and ranges of vessels at the most common distances outside trial period and during the trial period, respectively, as obtained from Table 2. Upper panel covers the broad-band (SRKW disturbance) frequency band between 10 and 100,000 Hz, the middle panel covers the SRKW communication band (0.5-15kHz), while the lower panel covers the SRKW echo-location band (15-100kHz) Only data obtained during periods with slack tide and with windspeeds < 10km/h are shown.

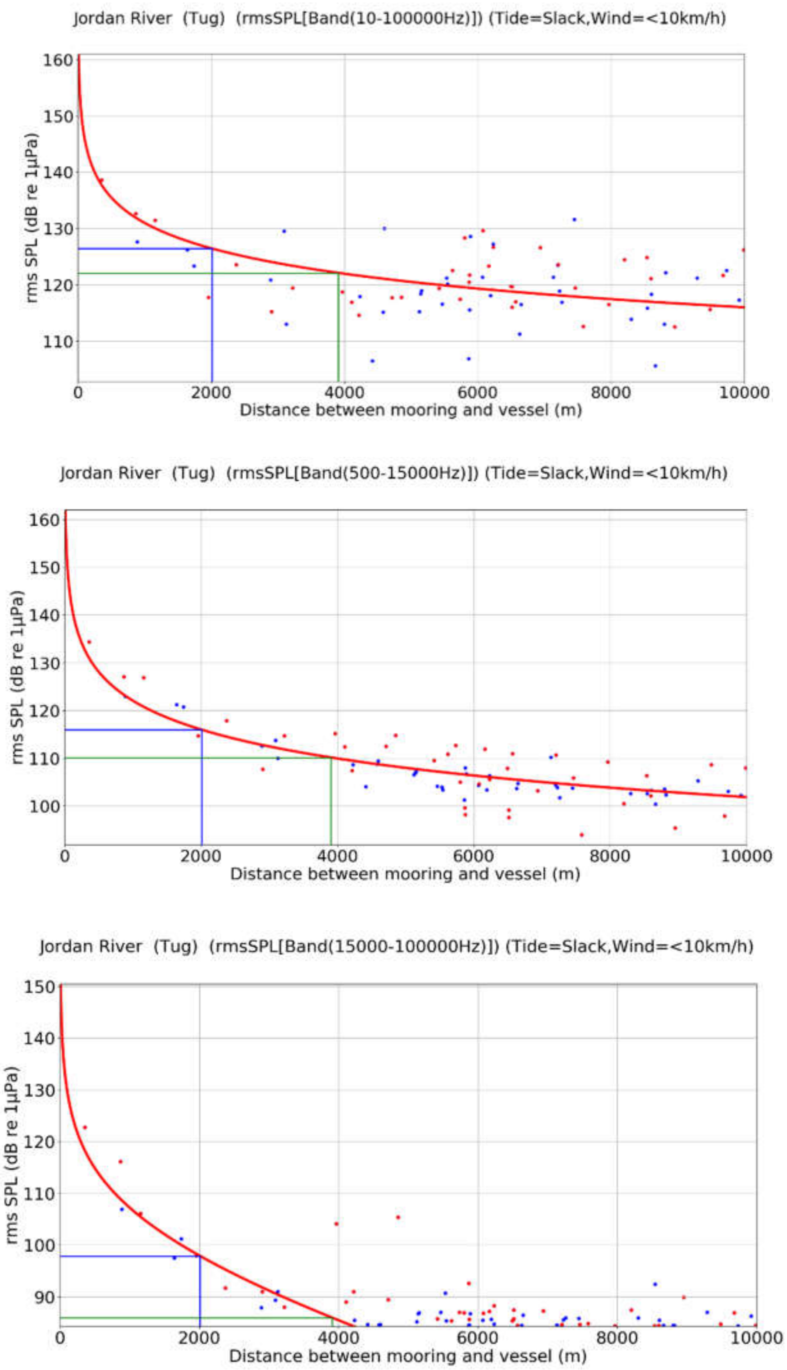

Figure 27. SL versus range for **tugs** passing the Jordan River location. Blue dots are all vessels, while red dots are only vessel recorded during the trial period. Red solid lines are best fits to equation 1. Blue and green lines show the SL and ranges of vessels at the most common distances outside trial period and during the trial period, respectively, as obtained from Table 2. Upper panel covers the broad-band (SRKW disturbance) frequency band between 10 and 100,000 Hz, the middle panel covers the SRKW communication band (0.5-15kHz), while the lower panel covers the SRKW echo-location band (15-100kHz) Only data obtained during periods with slack tide and with windspeeds < 10km/h are shown.

Table 8. Summary of best fits to range dependent SL model (Equation 1) for a range of vessel classes at different frequency bands.

Class/Band (Hz)	**SL0 (dB)**	**A (dB/km)**	**K**	**Pre-trial range (m)**	**Trial range (m)**	**Pre-trial SL (dB)**	**Trial SL (dB)**	**Noise reduction (dB)**
Bulk carriers								
500-15,000	182.14 ± 5	0.023	20	5270	5787	107.6	106.7	**-0.9**
10-100,000	197.65 ± 5	0.0035	20	5270	5787	123.2	122.4	**-0.8**
10-100	195.90 ± 7	8.81e-5	20	5270	5787	121.6	120.7	**-0.9**
15,000-100,000	NA	6.737	NA	5270	5787	NA	NA	**NA**
Tankers								
500-15,000	172.98 ± 5	0.023	16.8	5341	5887	110.1	109.4	**-0.7**
10-100,000	199.52 ± 3	0.0035	20	5341	5887	125.0	124.1	**-0.9**
10-100	198.36 ± 3	8.81e-5	20	5341	5887	123.8	123.0	**-0.8**
15,000-100,000	NA	6.737	NA	5341	5887	NA	NA	**NA**
Container ships								
500,15,000	184.03 ± 5	0.023	20	5341	5772	109.3	108.7	**-0.6**
10-100,000	199.60 ± 5	0.0035	20	5341	5772	125.0	124.4	**-0.6**
10-100	198.12 ± 5	8.81e-5	20	5341	5772	123.6	122.9	**-0.7**
15,000-100,000	NA	6.737	NA	5341	5887	NA	NA	**NA**
Cruise ships								
500,15,000	182.49 ± 3	0.023	20	5398	5800	107.7	107.1	**-0.6**
10-100,000	197.97 ± 3	0.0035	19.6	5398	5800	124.7	124.1	**-0.6**
10-100	192.12 ± 3	8.81e-5	18.6	5398	5800	122.8	122.2	**-0.6**
15,000-100,000	NA	6.737	NA	5341	5887	NA	NA	**NA**

Vehicle carriers								
500-15,000	183.08 ± 3	0.023	20	5256	5888	108.5	107.5	**-1.0**
10-100,000	197.57 ± 3	0.0035	20	5256	5888	123.3	122.3	**-1.0**
10-100	196.40 ± 3	8.81e-5	20	5256	5888	122.0	121.0	**-1.0**
15,000-100,000	NA	6.737	NA	5256	5888	NA	NA	**NA**
Tugs								
500-15,000	182.05 ± 6	0.023	20	2010	3906	115.9	110.1	**-5.8**
10-100,000	175.97 ± 7	0.0035	15	2010	3906	126.4	122.1	**-4.3**
10-100	173.76 ± 8	8.81e-5	15	2010	3906	124.2	119.9	**-4.3**
15,000-100,000	170.46 ± 3	6.737	20	2010	3906	97.9	85.9	**-11.9**

5 Discussion and Conclusions

The main results of the effect of the lateral displacement trial on the underwater noise levels in SRKW critical habitat in Strait of Juan de Fuca are summarized in Figure 25 and Tables 4-8 above.

Limited overall noise level reductions were observed at the Port Renfrew and Sooke locations, which were at each end of the lateral displacement corridor. At the Jordan River location, in the middle of the trial section, all identified metrics in all defined frequency bands indicated reduction in noise levels of between 0.6 and 3.7 dB from vessels that on average moved from a typical distance of 5300 m to a trial-period distance of 5900 m.

The results presented in Table 8 suggest that for most of the commercial vessel classes analyzed in this study, except tugs, the noise reduction as a result of displacing these vessels southward in the outbound shipping lane in the Strait of Juan de Fuca, varied between 0.6 and 1 dB as a result of travelling an average distance of 700 m further south in the shipping lane. These are all vessels which already travel relatively far south of these SRKW foraging areas (~5300 m prior to the trial to a trial distance of ~5900 m). A modest increase in their distance away from these areas will therefore have limited effects on the received noise levels at the lower frequencies. Also, because of the relatively large ranges, the high-frequency contribution, at frequencies above 15 kHz, from these vessels is minimal at all ranges observed (Figure 26, lower panel). Another observation from Figure 26 and Table 8 is that the observed variability in the inferred broad-band SPL from the observed bulk carriers reaches as high as ± 5dB.

A logical inference from these result is that even if one moved all the outbound bulk carriers southward to the middle of the present separation zone (7800 m), the present broad-band noise level from these vessels would only be reduced by 3 dB.

Where the results of this study show a significant improvement in the noise levels is with regards to the tugs. Depending on the frequency bands of interest, the noise levels from these vessels were reduced by between 4.3 and 11.9 dB (Table 8). The reason for this significant drop is the fact that these vessels tend to travel closer to these foraging areas during normal conditions (~2000 m) and moved a significant distance away during the trial (~3900 m). Also, because these vessels are closer overall, the noise reduction impact at the higher frequencies is much greater. The results shown in Figure 27, for example, indicate that at a distance of approximately 3,000 m from the monitoring location the noise contribution at frequencies above 15 kHz is negligible for these vessels.

This study showed that only the inshore lateral shift (primarily by tugs) resulted in significant noise reduction in the three important frequency bands for SRKW. The noise in the broad-band (10-100,000 Hz) disturbance band was reduced by 4.3 dB, while the noise in the communication band (500-15,000 Hz) was reduced by 5.8 dB and in the echo-location band (15,000 – 100,000 Hz) the noise level was reduced by as much as 11.9 dB.

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