Evaluation of the efficacy of the Juan de Fuca lateral displacement trial and Swiftsure Bank plus Swanson Channel Interim Sanctuary Zones, 2019

Svein Vagle

Ocean Sciences Division
Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, BC

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EVALUATION OF THE EFFICACY OF THE JUAN DE FUCA LATERAL DISPLACEMENT TRIAL AND SWIFTSURE BANK PLUS SWANSON CHANNEL INTERIM SANCTUARY ZONES, 2019

by

Svein Vagle

Ocean Sciences Division
Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, BC, V8L

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ABSTRACT

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In 2019, the ECHO Program coordinated the implementation of a voluntary inshore lateral displacement trial in the Strait of Juan de Fuca, with support from Transport Canada, Canadian and U.S. coast guards, Fisheries and Oceans Canada, and Canadian and U.S. marine transportation industries. The overall purpose of the trial was to reduce underwater noise from tugs in a known southern resident killer whales feeding area. This lateral displacement of vessel traffic was in place between June 17 and October 31, 2019. By shifting their routes southward individual tugs were observed to decrease their noise impact on the Jordan River SRKW feeding area by between 6 and 11 dB, depending on the frequency band being considered. By moving their routes to more than 3 km from the feeding areas most of the tugs will contribute minimally to the over all soundscape in these areas. However, since tugs make up a small proportion of the vessel traffic in the Strait of Juan de Fuca, this cannot account for the observed overall reduction in broad-band (10-100,000 Hz) noise of 3.6 dB in the feeding area. Rather, analysis of the ship transit data indicates that the reduction was due to a reduction in overall ship traffic during the period of the study.

A second mitigation measure was to implement interim whale sanctuary zones in key foraging areas on Swiftsure Bank and in Swanson Channel, off North Pender Island between June 1 and October 31, 2019. At the Swiftsure Bank mooring, which was just south of the interim sanctuary zone, the broadband (10-100,000 Hz) noise reduction was 1.1 dB, while no such reduction was observed in Swanson Channel. As with the results in the Strait of Juan de Fuca the noise reduction on Swiftsure Bank is attributed to a decline in ship traffic during the study. Analysis of available vessel track data indicated that in both sanctuary zones there was poor compliance with the request to avoid these areas.

RÉSUMÉ

Vagle, S. 2020. Evaluation of the efficacy of the Juan de Fuca lateral displacement trial and Swiftsure Bank plus Swanson Channel interim sanctuary zones, 2019. Can. Tech. Rep. Hydrogr. Ocean Sci. 332: vi + 60 p.

En 2019, le programme ECHO a coordonné l'essai de la mise en application d'une mesure volontaire de déplacement latéral du trafic en zone côtière dans le détroit de Juan de Fuca, avec la collaboration de Transports Canada, des Gardes côtières canadienne et américaine, de Pêches et Océans Canada, ainsi que des acteurs de l'industrie maritime au Canada et aux États-Unis. L'objectif général de cette mesure était de réduire les émissions de bruit sous-marin des remorqueurs à l'intérieur de ce qui est reconnu comme étant des aires d'alimentation des épaulards résidents du sud. Cette mesure exigeant le déplacement latéral du trafic maritime était en place du 17 juin au 31 octobre 2019. En exigeant un déplacement des itinéraires vers le sud, on a observé une diminution oscillant entre 6 et 11 dB du bruit qu'engendre chaque remorqueur dans l'aire d'alimentation des épaulards résidents du sud de la rivière Jordan, selon la bande de fréquence prise en compte. En déplaçant leur itinéraire de manière à s'éloigner à plus de 3 km des aires d'alimentation, la plupart des remorqueurs réduiront le plus possible leur incidence sur le paysage sonore dans ces zones. Cependant, puisque ces remorqueurs ne représentent qu'une petite partie du trafic maritime dans le détroit de Juan de Fuca, ils ne peuvent être responsables de la réduction globale du bruit à large bande (de 10 à 100 000 Hz) de 3,6 dB constatée dans l'aire d'alimentation. Une analyse des données sur les passages de bâtiments révèle plutôt que la réduction serait attribuable à une réduction du trafic maritime global durant la période visée par l'étude.

Une deuxième mesure d'atténuation consistait à mettre en place des zones de refuge provisoires pour les baleines dans les principales aires d'alimentation sur le banc Swiftsure et dans le chenal Swanson, au large de l'île Pender Nord, entre le 1er juin et le 31 octobre 2019. Aux amarres du banc Swiftsure, juste au sud de la zone de refuge provisoire, le niveau de bruit à large bande (de 10 à 100 000 Hz) a été réduit de 1,1 dB, alors qu'aucune réduction n'a été observée dans le chenal Swanson. À l'instar des résultats liés au détroit de Juan de Fuca, la réduction du bruit sur le banc Swiftsure est attribuable à une diminution du trafic maritime pendant la période visée par l'étude. Une analyse des données de surveillance des bâtiments disponibles a révélé que, dans bien des cas, on n'avait pas évité de naviguer dans les deux zones de refuge tel qu'il avait été demandé.

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

DST: Daylight savings time (UTC-7 hours)

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

Hz: Hertz

ISZ: Interim sanctuary zone

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

TSS: Traffic separation scheme

1 EXECUTIVE SUMMARY

In May 2019, the Government of Canada announced enhanced measures to protect the endangered Southern Resident Killer Whales (SRKW), intended to build upon earlier initiatives. These measures included (1) a lateral displacement trial in the Strait of Juan de Fuca, shifting inbound vessel traffic to avoid critical habitat, and (2) interim sanctuary zones (ISZs) intended to exclude vessels at Swiftsure Bank and off the South-west coast of North Pender Island, in Swanson Channel, and South of Saturna Island. Both measures aimed to address underwater noise and physical disturbance from vessels.

In the lateral displacement trial, all tugs and barges transiting in the Canadian inshore area of the Strait of Juan de Fuca were requested to move south of the known SRKW feeding area in the period between June 17 and October 31, 2019. The whale sanctuaries were implemented in several areas, including key foraging areas at Swiftsure Bank and in Swanson Channel, off North Pender Island between June 1 and October 31, 2019.

The impact of these measures was assessed through passive acoustic recordings from a number of bottom-mounted moorings deployed by the Department of Fisheries and Oceans (DFO). In this study we used acoustic data from 3 passive acoustic monitoring moorings deployed on Swiftsure Bank, in the Strait of Juan de Fuca at Jordan River, and in the ISZ in Swanson Channel to monitor the soundscape in important SRKW foraging areas in a portion of their critical habitat. No DFO recorders were deployed in the Saturna Island ISZ in 2019, so this area will not be discussed any further in this report. Hydrophone data from April 1 to June 16 and between November 1 and 30 were used as a baseline data set for the lateral displacement analysis, while for the ISZ zones analysis, April 1 to June 1 and November

1 to 30 were used as baseline data. However, the Swanson Channel recorder was first deployed on August 16, so no data are available prior to this date. Vessel transit data was derived from Automatic Identification System (AIS) reports.

Findings:

In the Strait of Juan de Fuca, the average distance between tugs and the important SRKW foraging area off Jordan River was 14 km. Only a small number of tugs were detected north of the outbound shipping lane.

A majority of the tugs transiting the Strait of Juan de Fuca, both inbound and outbound, travel south of the inbound deep-sea shipping lanes.

Tugs only represented 2-9% of the vessels travelling past the hydrophone mooring off Jordan River, and therefore only make a small contribution to the overall soundscape in the Strait of Juan de Fuca. However, transits of individual tugs close to the mooring (<4 km) were found to impact the local noise levels considerably. The displacement of these vessels significantly reduced the received noise levels, with some of the tugs identified as decreasing their band averaged Sound Pressure Level (SPL) by between 6 and 11 deciBels (dB), depending on the frequency band being considered. By moving their travelling routes to more than 3 km from the feeding areas, the noise levels from the tugs investigated in this study dropped below the ambient levels.

In the Strait of Juan de Fuca, the observed broad-band (10-100,000 Hz) noise reduction was 3.6dB during the study. There may be some contribution to this reduction from tugs moving further south. However, the study showed that most of this decrease was due to changes in the traffic pattern of deep-sea vessels.

South of ISZ at Swiftsure Bank the observed broad-band (10-100,000 Hz) noise reduction was 1.1 dB during the study, while no such reduction was observed within the Swanson Channel ISZ. The study showed that most of the observed decrease at Swiftsure Bank can be attributed to changes in the traffic pattern of deep-sea vessels.

Even though a number of non AIS equipped vessels were invariably missed in this study, the results of our AIS analysis show that there was poor compliance with the request to stay out of the two ISZs. Also, the mooring at Swiftsure Bank was located under the shipping lane and not in the ISZ. This might also explain why no significant effect on the soundscape was observed at this location. (A second mooring has since been deployed at Swiftsure Bank within the ISZ.)

However, by using the daily 95th percentile, the results suggest that in the Swanson Channel ISZ there was an observable reduction in the SPL, especially in the 15-100 kHz band, by up to 10 dB over the period from the middle of August to the end of October 2019. This implies that perhaps the vessels travelling through this area actually moved slightly further offshore.

2 INTRODUCTION

Shipping related underwater noise has the ability to interfere with marine mammals' ability to navigate, communicate and search for prey. Vessel noise is therefore considered to be one of the main stressors hindering the recovery of the threatened Southern Resident Killer Whale (SRKW) in the Salish Sea, off the West Coast of British Columbia and Northern Washington State. With increasing shipping in the area, significant effort is presently underway to implement mitigation techniques that can reduce the impact of the shipping noise on SRKW and other marine mammals and fish in this area.

SRKW are listed as Endangered under both the *Species at Risk Act* in Canada and the *Endangered Species Act* in the U.S. As of August 2019, the population has declined to 73 individuals. Over the last year, both countries' governments have continued to highlight the need to develop and implement measures to reduce underwater noise generated by ships.

In May 2019, the Government of Canada announced enhanced measures of protection for SRKW, to build upon earlier initiatives. These measures included a lateral displacement trial in the Strait of Juan de Fuca and the establishment of ISZs on Swiftsure Bank and off the South-west coast of North Pender Island, in Swanson Channel, to address underwater noise and physical disturbance from vessels.

In 2018, a similar voluntary lateral displacement trial was conducted to study how moving large commercial ships and inshore traffic, such as tugs and barges, further away from known whale feeding areas in the Strait of Juan de Fuca would affect the underwater noise levels in those areas. This trial was led by the Vancouver Fraser Port Authority's Enhancing Cetacean Habitat and Observation (ECHO) Program and Transport Canada, and was supported by U.S. Coast Guard, Fisheries and Oceans Canada, the Canadian and U.S. marine transportation industry, Indigenous individuals and environmental and conservation groups.

Analysis of underwater noise recordings in the Strait of Juan de Fuca following the 2018 study suggested that in areas important to SRKW the noise reductions achieved by moving the deep-sea vessel an average of 600 m further south in the outbound shipping lane; from approximately 5300 m to approximately 5900 m away from foraging areas, was insignificant. However, during this study tugs moved approximately 1900 m further south, allowing transits, on average to go from approximately 2000 m to approximately 3900 m away from critical areas. This resulted in frequency band cumulative function Sound Pressure Level (SPL) reductions of more than 4 dB, depending on the frequency bands considered (Vagle and Neves, 2019).

Based on the results from the 2018 trial, and in an effort to support ongoing whale recovery measures for the SRKW, the partners involved in the successful 2018 effort adapted and refined the approach in 2019 and ran a second voluntary displacement trial in 2019, including inshore traffic (i.e. tugs) only. In 2019 the trial took place between June 17 and October 31, 2019.

In 2018, 88 per cent of tugs and barges participated in the lateral displacement trial by spending all or part of their transit in the trial zone, located farther away from the whales' feeding areas in the Strait of Juan de Fuca. This high rate of participation resulted in a significant reduction in underwater noise in the area. In 2019, inshore tug and barge vessel traffic demonstrated a significant shift southward into the inshore trial zone and outbound shipping lane with 85 out of 122 (70%) vessels spending more than 75% of their transit in the inshore trial areas and 93 out of 122 (77%) vessels spending more than half their transit in the trial areas.

In 2019 the Government of Canada implemented whale sanctuaries in key foraging areas on Swiftsure Bank and off North Pender and Saturna Islands. These areas were off-limits to vessel traffic between June 1 and October 31, 2019. The timing and locations of these ISZs were designed to protect the whales during the season they are most frequently found in Canadian waters. The measures were intended to create spaces of refuge from vessel noise for the whales. The exclusion measures in these areas were implemented on an interim basis pending further feasibility assessment work on measures to reduce physical and acoustic disturbances.

Here we present results from the analysis of the three data sets to assess the impact of voluntary compliance to the request to move nearshore vessels further south in the Strait of Juan de Fuca, and away from a SRKW sensitive area, and to limit the presence of vessels in the two ISZs on Swiftsure Bank and in Swanson Channel.

3 METHODS

3.1. Passive acoustic recordings and mooring locations

Recordings for this study were made as part of a wider project under the Ocean Protection Plan-Marine Environmental Quality Program (OPP-MEQ). For this initiative DFO deployed 6 broad-band (10-100,000 Hz), continuously recording autonomous hydrophone systems at locations in the Salish Sea at Swiftsure Bank, off Port Renfrew, Jordan River and Sooke in the Strait of Juan de Fuca and in Haro Strait and Boundary Pass (Figure 1). Recordings have been continuous since February 2018. This monitoring program is SRKW centred, with recorder locations focused within SRKW critical habitat. Mooring deployment sites 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. In addition, a seventh hydrophone system was deployed in Swanson Channel to monitor the soundscape in the North Pender Island ISZ.

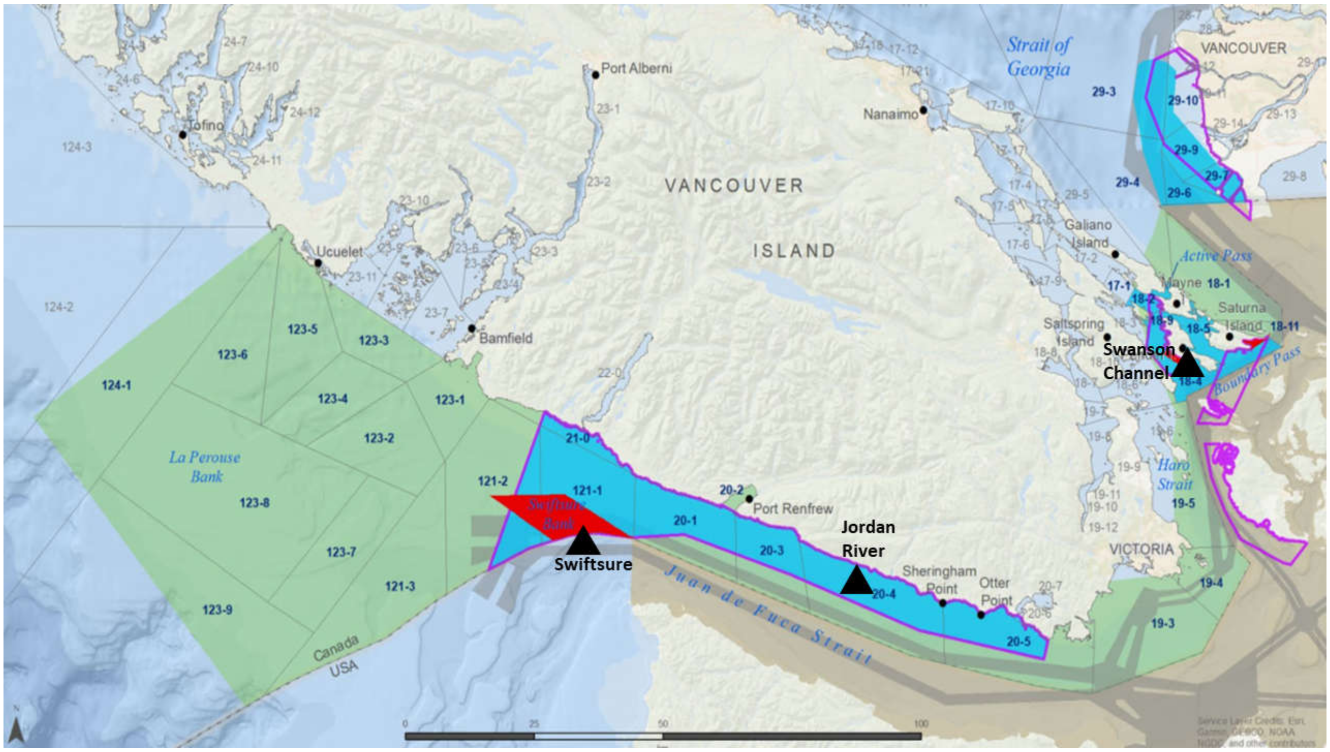

Figure 1. Salish Sea showing fishing areas, shipping lanes (grey areas), interim sanctuary zones (red) and the locations of the three (Swiftsure Bank, Jordan River and Swanson Channel) broad-band hydrophone moorings used in the present analysis (black filled triangles).

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 2). 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.

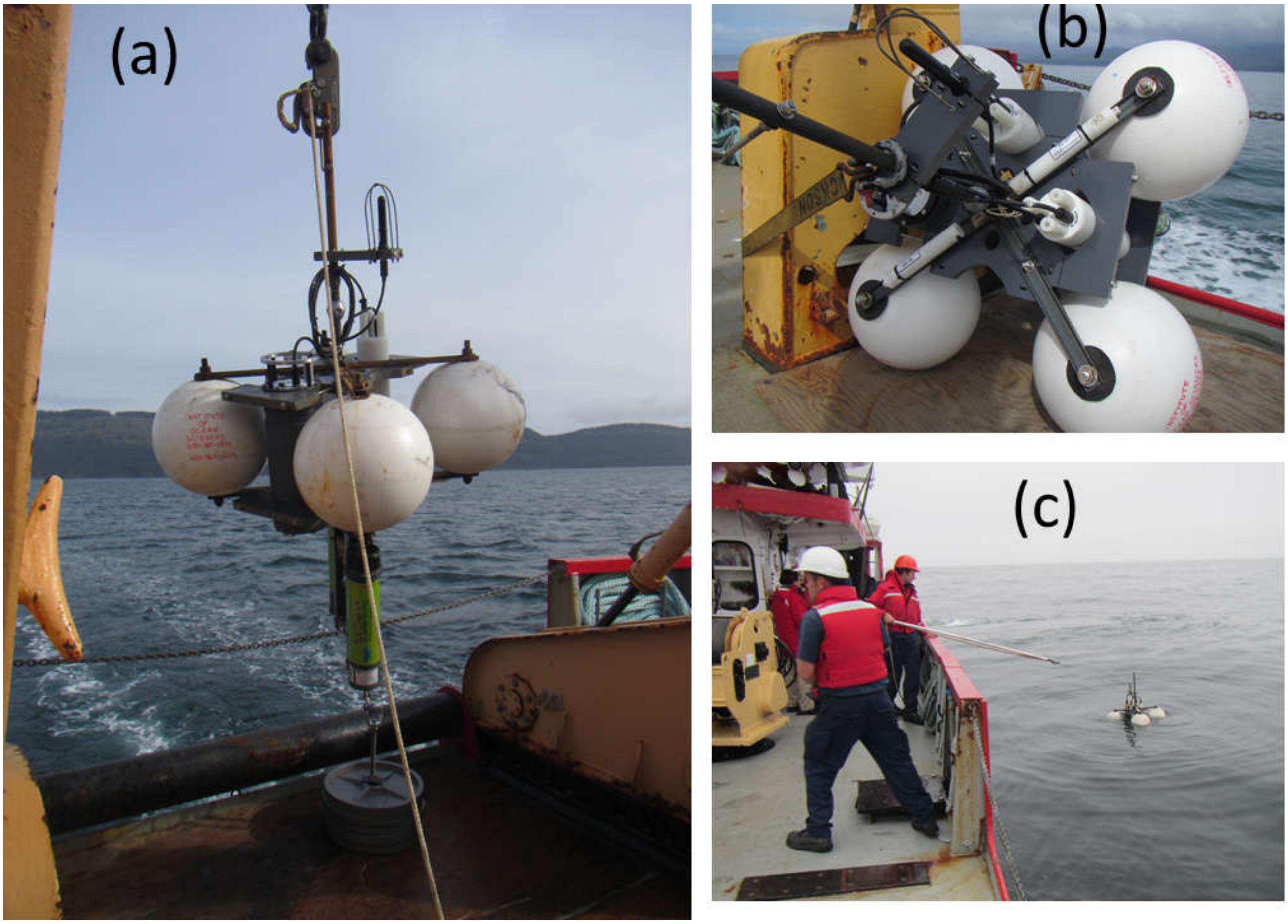

Figure 2. (a) PAM mooring ready for deployment on CCGS Vector. The total height of the mooring is approximately 2 m. (b) Top of mooring showing instrumentation. (c) Mooring being recovered after release from the sea floor.

The Swiftsure Bank hydrophone system was deployed under the outbound shipping lane, just south of the ISZ (Figure 1, Table 1), at a depth of 75 m with water depth of 77 m, while the system within the lateral displacement area, off Jordan River, was located approximately 5 km north of the outbound shipping lane at a depth of 118 m with a water depth of 120 m(Figures 1, Table 1). The Swanson Channel mooring was inside the sanctuary zone at a depth of 70 m in 72 m of water (Figure 1, Table 1).

These moorings were serviced in March, June, August and November 2019.

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.

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. From these spectra SPL measures were derived. Patterns in SPL levels frequency bands critical to SRKW critical frequency bands, and other ambient noise metrics were considered.

In this study, data from the Swiftsure, Jordan River and Swanson Channel recording systems will be included (Figure 1, Table 1). Recordings from Swiftsure Bank and Jordan River will inform the results of the lateral displacement, and Swiftsure Bank and Swanson Channel will be used to assess the efficacy of the ISZs. No DFO recorders were deployed in the Saturna Island ISZ in 2019, so this area will not be discussed any further in this report.

Table 1. Moorings deployed on Swiftsure Bank, off Jordan River in the Strait of Juan de Fuca and off North Pender Island in Swanson Channel.

Mooring	***Position***	***Water depth (m)***
Swiftsure Bank	48.515N 124.936W	77
Jordan River	48.397N 124.134W	120
Swanson Channel	48.7393N 123.257W	72

3.2 The 2019 inshore lateral displacement trial zone

During the period from June 17 to October 31, 2019, if it was safe and operationally feasible to do so, all tugs and barges transiting in the Canadian inshore area of the Strait of Juan de Fuca were requested to move south of the known SRKW feeding area and navigate through the inshore lateral displacement trial zone while maintaining a buffer distance of 1000 m from the traffic separation scheme (TSS). This zone was 1500 m wide and was defined to be between 123º 52'W and 124º 31' W, covering a distance of approximately 28 nm (52 km). The trial zone was located 1000 m north of the TSS in order to provide a safety buffer (Figure 3). Recordings were taken from the Jordan River mooring (Hydrophone 2, Figure 3).

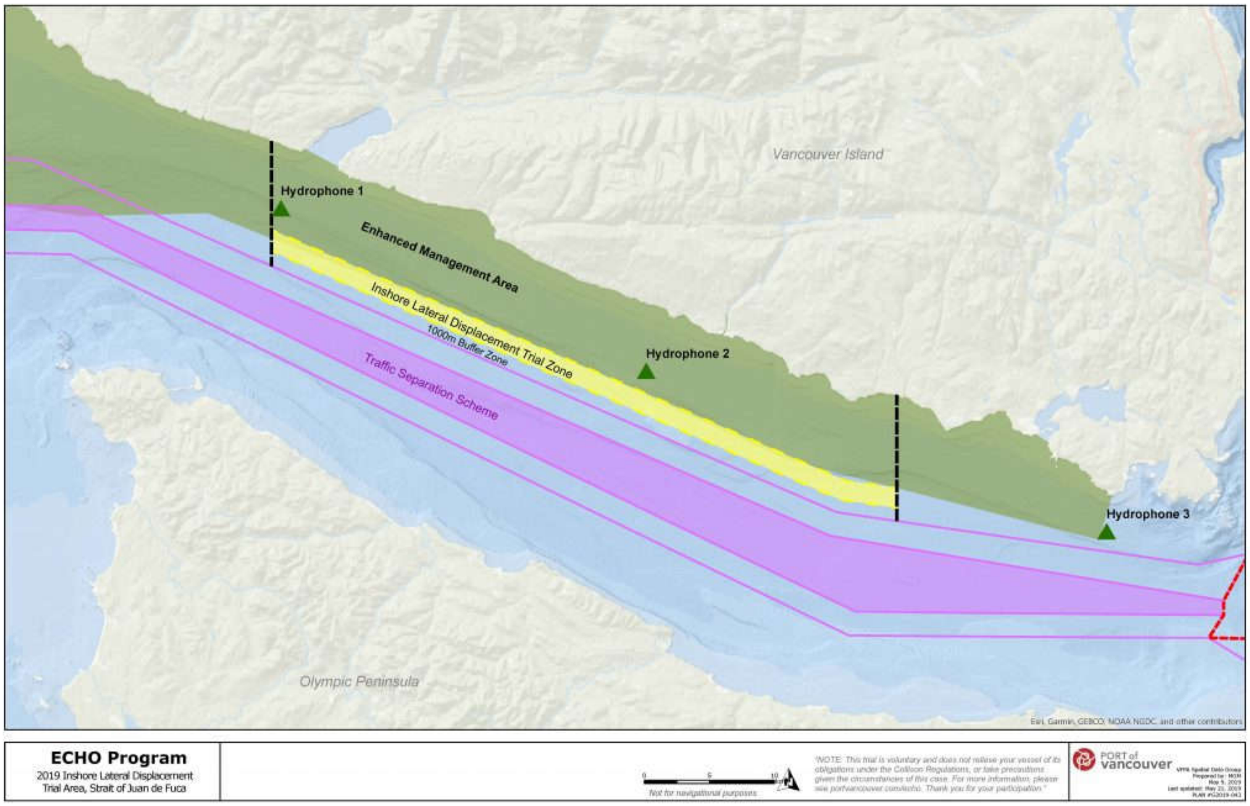

Figure 3. Strait of Juan de Fuca showing shipping lanes with the 28 nm between 123º 52'W and 124º 31' W (marked by black dashed line in outbound lane) where tugs were requested to transit in the Inshore Lateral Displacement Trial Zone (Yellow area) during the trial period between June 17 and October 31, 2019. The Department of Fisheries and Oceans hydrophone mooring used in this study is labelled as Hydrophone 2.

3.3 The ISZs at Swiftsure Bank and in Swanson Channel (North Pender Island)

To maximize protections in key SRKW foraging areas, ISZs were created off North Pender Island and on Swiftsure Bank (Figure 4). In addition to fishery closures, no vessel traffic was permitted in these areas from June 1 to October 31 2019, subject to certain exceptions for emergency and Indigenous vessels. The mooring on Swiftsure Bank was positioned just south of the ISZ (Figure 4a, Table 1). The Swanson Channel mooring was deployed August 16, 2019 to assess the ambient noise levels while the ISZ was in place (Figure 4b, Table 1).

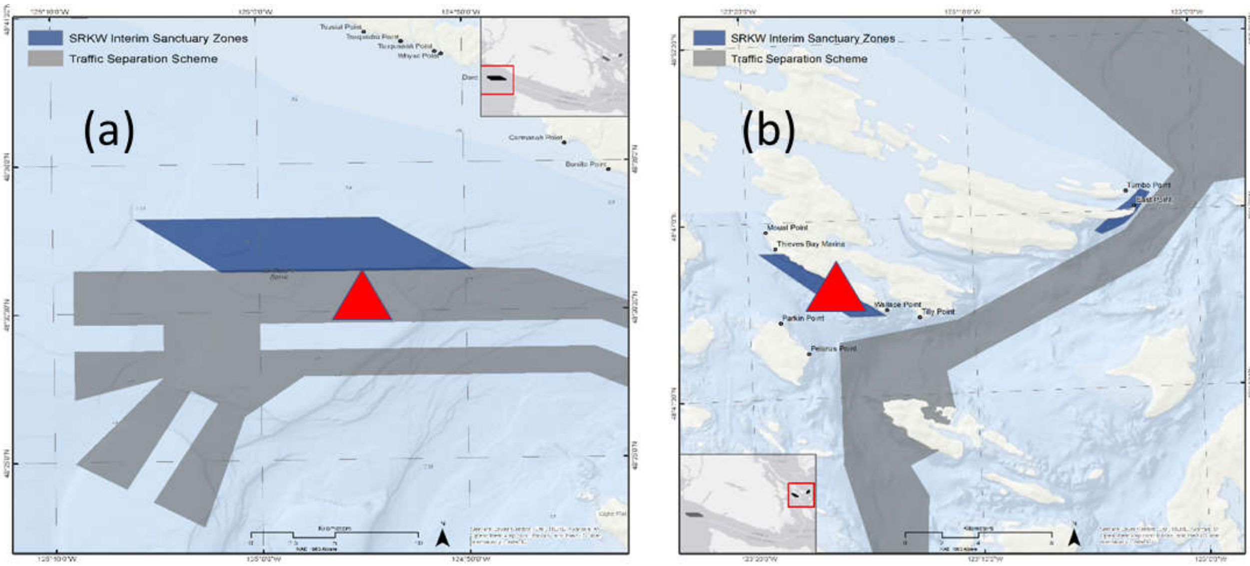

Figure 4. (a) Interim sanctuary zone at Swiftsure Bank (blue area) and location of DFO hydrophone mooring (red triangle). (b) Interim sanctuary zone in Swanson Channel, off North Pender Island (blue area) and the location of the DFO mooring in Swanson Channel (red triangle). These zones were in effect between June 1 and October 31, 2019.

The interim sanctuary zones (ISZs) were defined as:

The waters of Swiftsure Bank bounded by a line:

commencing at	48°34.000’N	125°06.000’W	;
then to	48°34.000’N	124°54.200’W	;
then to	48°32.100’N	124°49.518’W	;
then to	48°32.100’N	125°01.843’W	.

The waters off North Pender Island bounded by a line:

commencing at	48°44.166’N	123°13.900’W	;
then to	48°44.166’N	123°15.550’W	;
then to	48°46.050’N	123°19.516’W	;
then to	48°46.050’N	123°18.383’W	.

3.4 Passive acoustic analysis

Acoustic recordings were made at the mooring locations continuously up to 128 kHz. Not all of the acoustic data were considered in detail. Instead, analysis focused on evaluating the impact the measures in place would make in frequency ranges known to be used by SRKW. The frequency bands used in this analysis were taken from the results of an expert workshop in Vancouver 2017 which identified three principal impacts of underwater noise on SRKW (Heise et al. 2017). The first is behavioural disturbance, which may result from increased physiological stress, avoidance responses, and hearing sensitivity threshold shifts, and be observed as disruption of important activities such as resting and foraging. A metric defined to cover this disturbance was determined to be changes in the frequency range 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 the volume of water in which the whales can communicate effectively using the 0.5-15 kHz frequency band. 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. Changes and patterns in percentiles of unweighted sound pressure levels for these three bands were considered.

This study considered changes in the Sound Pressure Levels (SPL) of decade bands, which included: 10-100 Hz, 100-1,000 Hz, 1,000 -10,000 Hz, and 10,000 -100,000 Hz.

The lateral displacement trial was considered to have both control and test periods. The hydrophone data from the Jordan River mooring between April 1 and June 19 was considered as baseline data from before the trial, with data from the period between June 19 and October 31 considered the trial period data, and data collected between November 1 and November 25 (when the mooring were recovered and serviced) were considered baseline data post-trial. This approach was also taken for the two ISZs, whereby data between April 1 and June 1 were baseline pre-trial data, data from between June 1 and October 31 were trial data, and data between November 1 and November 25 were post-trial data.

In addition to the control pre-trial recordings, baseline ambient noise assessments were sought to be made. These would ideally be non modified reference data obtained at the same location as those being assessed, and during the same time of the year to allow for comparison while minimizing any effects of seasonal changes in water properties modulating the noise field. However, because no such data are available for the locations considered in this study, we made use of data sets from the same locations, but at times outside the trial periods.

During the analysis of the 2018 lateral displacement soundscape data Vagle and Neves (2019) investigated the ambient noise levels at each location. For each lunar month, recordings made during slack tide, when wind speed as less than 10 km/h (taken from Race Rocks Light Station, Latitude 48.3°N Longitude 123.53°W; https://weather.gc.ca/past_conditions/index_e.html?station=wqk), and there were no vessels noted within 20 km of the acoustic recorder were used to estimate a background noise baseline. These restrictions of the data were used to minimise flow, wind, and vessel noise in the recordings. From the periods when the conditions were satisfied, the 95th percentile of the Power Spectrum

Density (L95) was considered. Vagle and Neves (2019) found that the month to month variability at each location was low, and typically within 2-3 dB. Also, the analysis did not find any seasonal patterns in the L5 levels at these sites (Vagle and Neves, 2019). It is therefore assumed, from these results, that the data collected in this study in April, May and part of June can be compared with data collected in July, August, September and October. A baseline analysis of the Jordan River acoustic data was made using recordings made when the current speeds below 0.3 m/s. (measured at the Sooke mooring at 48.290 N, 123.654 W at a depth of 166 m (Hydrophone 3 in Figure 3)). No restrictions of current speed were used in the analysis of the Swanson Channel mooring data. Wind speed thresholds were also not used in the 2019 analysis.

The impact on the received noise levels from vessels as they transit past the mooring was assessed by fitting sound measures to a transmission loss model, as was done previously by Vagle and Neves (2019). The noise generated by a vessel will spread out as it travels from the source to the receiving hydrophone. The received level, RL, at the hydrophone 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:

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

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, vessel RLs were again calculated from the recordings made at the Jordan River mooring at the slack tide (when current was measured <0.3m/s at the Sooke mooring).

3.5 The AIS tracked vessels

In this study all available Class A and B Automatic Identification System (AIS) vessel information data were received from the Canadian Coast Guard for the relevant area in the Salish Sea for the period from April 1 to the end of November 2019. The Class A vessels are primarily larger commercial vessels, while the Class B vessels will primarily be pleasure crafts, but also consist of some fishing vessels and other smaller commercial vessels.

The AIS data were classified into 14 vessel categories; 13 Class A categories and all Class B vessels lumped together as the 14th category. In Class A: 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, 13) Others.

At both the Swiftsure Bank and Jordan River locations all vessels within 30 km of the mooring locations were included as possible contributors to the observed soundscape. For the mooring location within the sanctuary in Swanson Channel a radius of 30 km would include vessels behind islands and reefs and which would not be able to contribute to the observed soundscape. Therefore, at this location we defined a modified polygon, shown in Figure 5, from within which vessels were considered to contribute to the noise field.

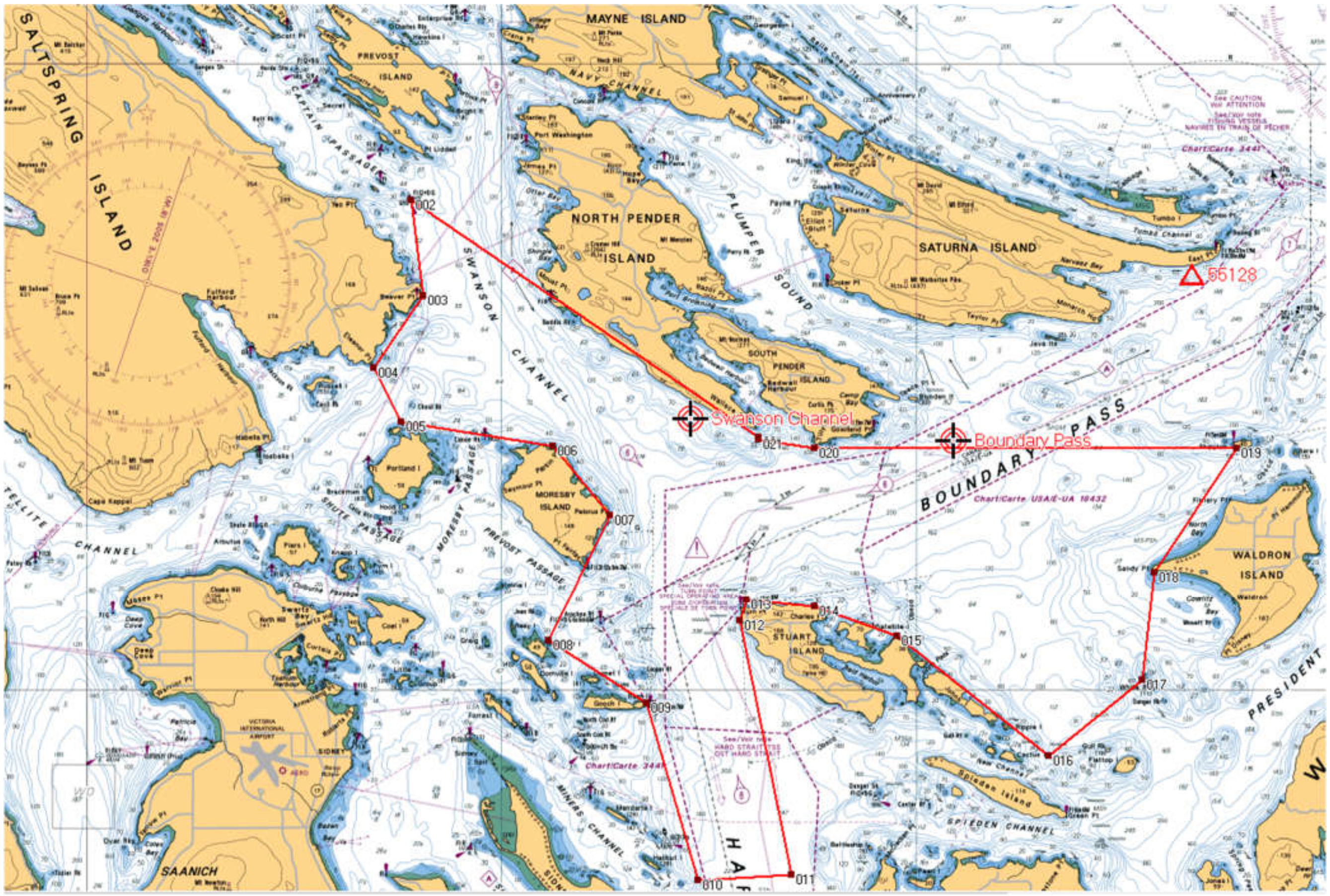

Figure 5. Polygon outlining the area used to define locations from which vessels may contribute to observed soundscape by the mooring in the sanctuary zone off North Pender Island (mooring marked as "Swanson Channel"). Also shown is mooring deployed in Boundary Pass as a part of the OPP-MEQ program.

For each of the mooring locations, the AIS data were used to derive the main contributors to the noise levels recorded. For comparison, Class B vessels and ferry and tug passages are shown, with all vessels in Class A classes 1, 2, 7, 9 and 11 labelled as 'Deep Sea' and depicted together, and all other classes considered together under 'Other' Contributions by each vessel class were calculated on a weekly basis for both pre-trial, trial and post-trial periods. Also, the distance for closest approach by each vessel type to the Jordan River mooring was calculated. This allowed us to consider which vessel type contributed most to the SPLs recorded, and the level of compliance of each vessel type to both the lateral displacement and ISZ measures. The AIS data were processed to determine the distances and vessel classes of the nearest vessels to the Jordan River hydrophone mooring within five-minute periods from April 1 to the end of November. Only Class A AIS data were used in this analysis. A focus to this analysis was the presence and proximity of tugs.

Cumulative time spent in the sanctuary zones for each vessel were also calculated from the AIS data from Swiftsure Bank and Swanson Channel. Again, for temporal comparison tug passages are shown, with all vessels in Class A classes 1, 2, 7, 9 and 11 depicted as 'Deep Sea' and all other classes aggregated together as 'Other'.

4 RESULTS

The AIS data showed that the vessel types contributing to the measured soundscape at the three different sites varied considerably between the locations. The composition of vessel traffic for each site is shown in Figure 6.

Both the Swiftsure Bank and Jordan River locations are dominated by the presence of 'Deep Sea' vessels. In addition, there were a few noted tugs, and a seasonal, relatively small number of Class-B vessels. In contrast, in Swanson Channel the Class-B vessels dominated most of the time; except late in the year. Here the number of tugs was relatively small, but consistent throughout the period, and 'Deep Sea' vessels and ferries contributed about the same percentages to the overall vessel presence (Figure 6).

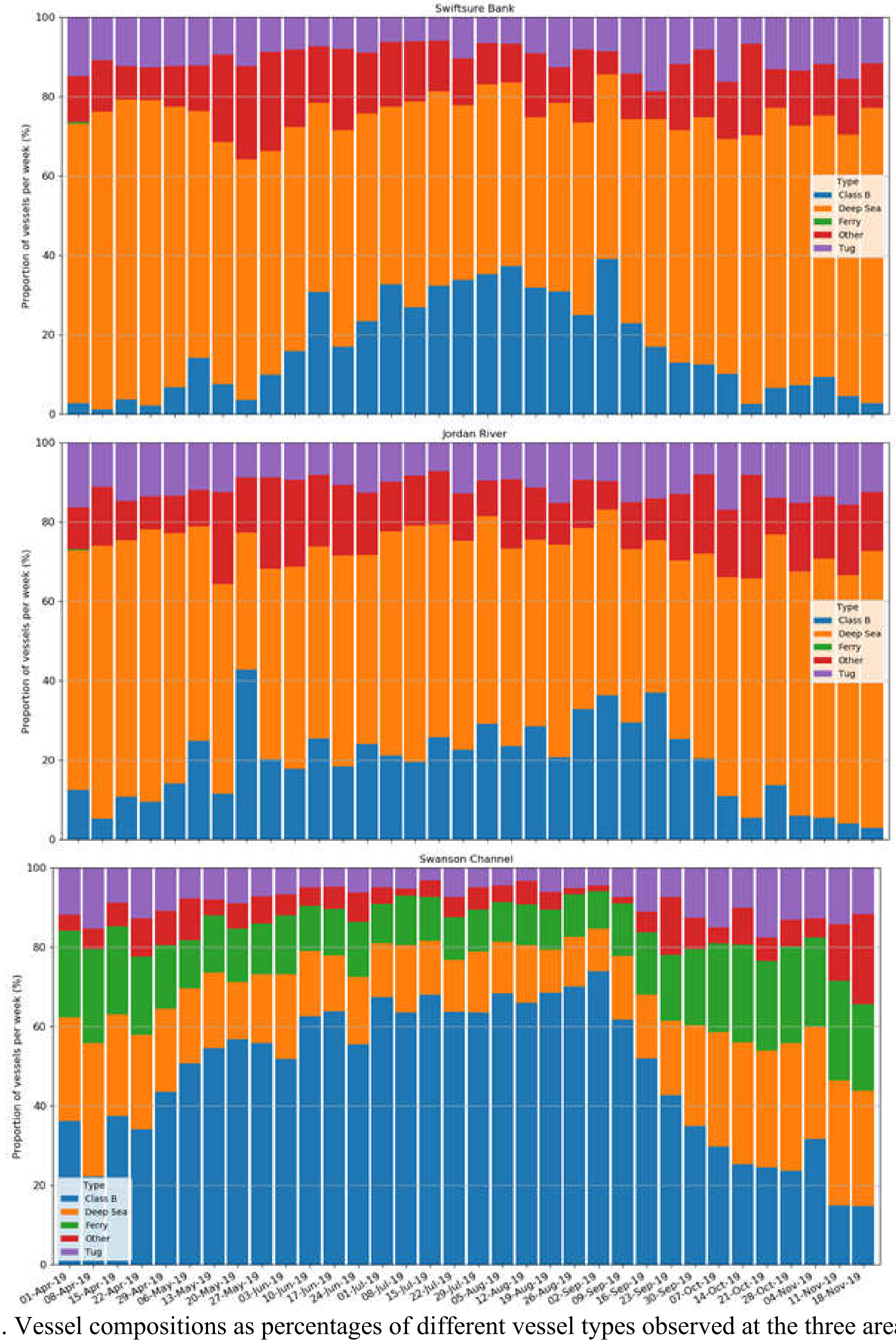

Figure 6. Vessel compositions as percentages of different vessel types observed at the three areas of interest, on a weekly basis. Upper panel is for Swiftsure Bank, while the middle panel is for Jordan River, and the lower panel is for Swanson Channel.

4.1 Lateral displacement trial in the Strait of Juan de Fuca 2019

4.1.1. Vessel presence and overall underwater noise levels at Jordan River

The percentage of time within all five-minute periods over a 7-day period between April 1 and November 30 when a vessel of a given class is closest to the Jordan River mooring and within 30 km of the mooring was determined from AIS data (Figure 7). The times in which vessels were within 30 km of the mooring varied between 24 and 60 % at this location.

From these data one can see that the percentage of time in which tugs were the closest vessels to the moorings within our defined five-minute intervals varied between a low of 2% to a maximum of 9%; which is a small proportion of the overall time. At this location the vessel traffic is dominated by bulk carriers.

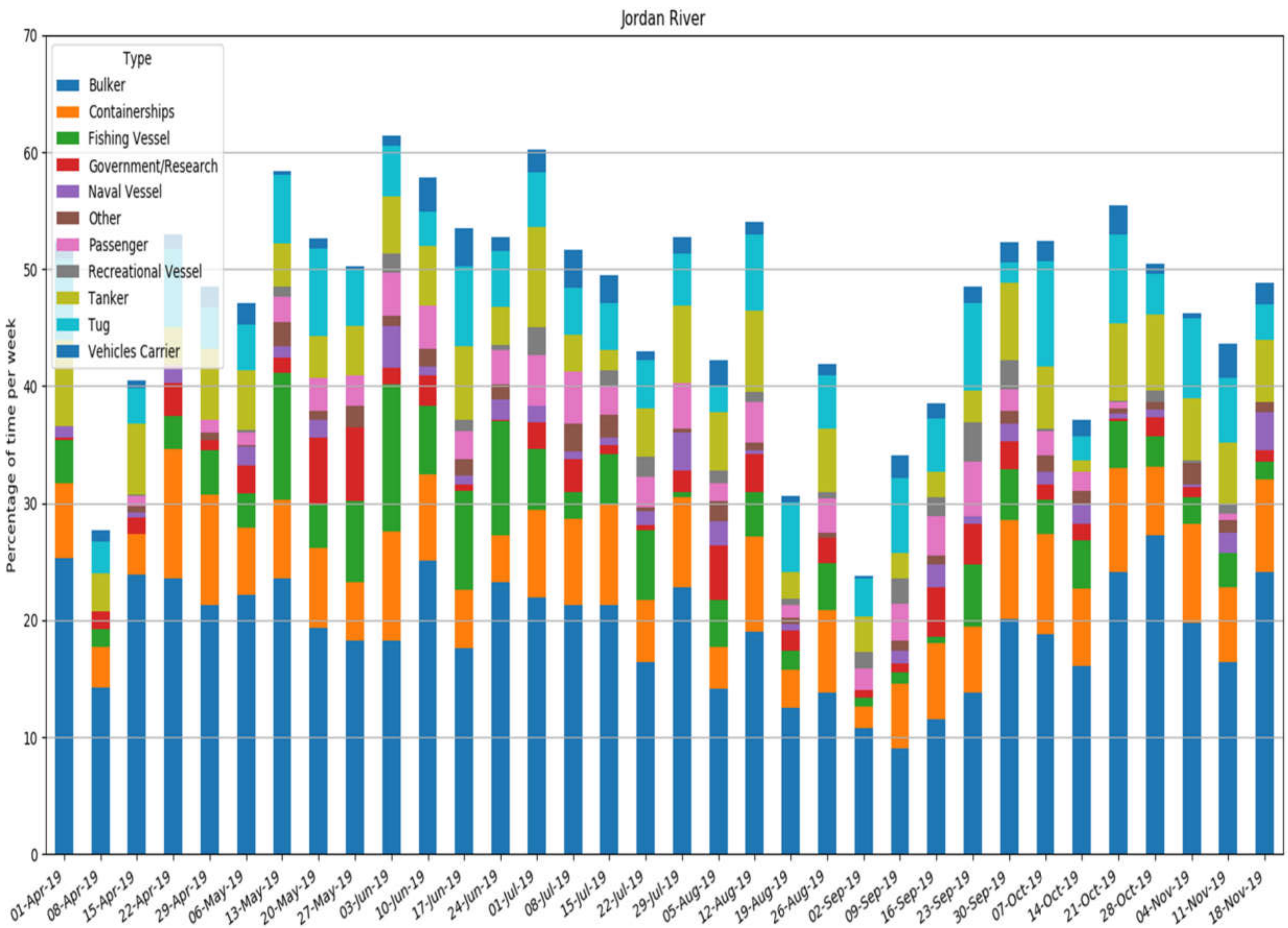

Figure 7. Proportion of time vessels of given class are within a 30 km range to the Jordan River mooring, within each 7-day period. (The order of the vessel types listed in the legend are from the bottom up in the figure.)

The minimum distance of each vessel type within each five-minute period was assessed. These data were divided into pre-trial (April 1 – June 17), trial (June 19 – November 1), and post-trial (November 1 – November 25) 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.

Figure 8 shows these probability density distributions for the Jordan River hydrophone location for all Class A vessels (upper panel) and for tugs (second panel). The maximum range considered here was chosen to be 16,000 m to include the main tug lanes south of the inbound shipping lane. The two lower panels only cover the range to 8,000 m to clearly show the probability density distributions near the mooring location. The probability densities shown in the figures have been normalized so that the over-all area under each curve adds up to 1.

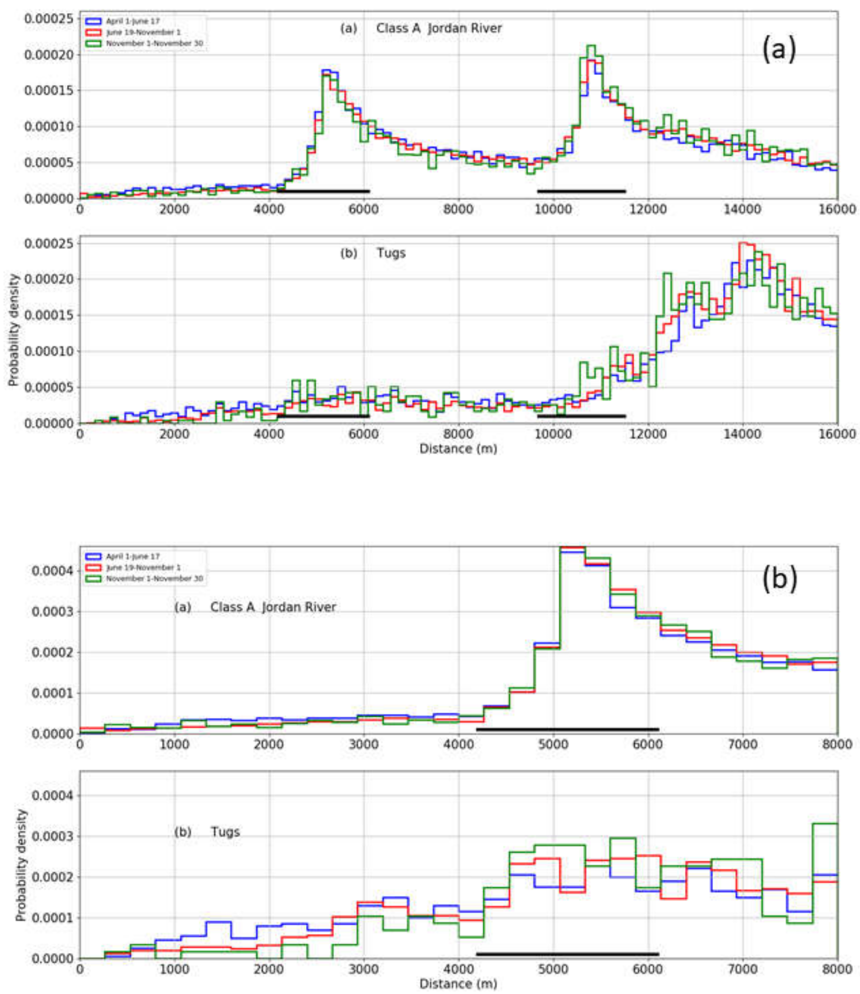

Figure 8. Probability distributions of AIS Class-A equipped vessel distances within 5-minute periods before the trial (blue), during the trial (red) and following the trial (green) for the Jordan River location. First and 3rd panels represent all vessel classes while the 2nd and 4th panels represent the tugs. Solid black horizontal lines identify ranges to outbound and inbound shipping lanes as obtained from local charts.

There are two broad peaks associated with the distances to the inbound and outbound shipping lanes that dominate the distributions when all AIS equipped Class A vessels are included (Figure 8, 1st panel). As expected, the locations and widths of these distributions aligned well with the established shipping corridors in this area (Black horizontal lines in Figure 8) and very few vessels are closer than 4500 m from the mooring. These results also showed no differences between the different pre-, post- and trial periods, as expected.

However, for the tugs the results showed that these vessels (both inbound and outbound) predominantly use the waters south of the inbound shipping lanes for all periods (Figure 8, 2nd panel). The passage of tugs is therefore more than 11 km away from the areas considered to be important to the SRKW. As expected, there are no significant differences between the trial and non-trial periods with regards to travel that far from the mooring, and well outside the voluntary lateral displacement zone.

Even within the lateral displacement zone (ranges <4,000 m) there are only subtle differences between the trial period and the pre- and post- periods (Figure 8, 3rd panel), with significant variability due to the low number of transects in this area.

The soundscape in the Strait of Juan de Fuca was dominated by deep-sea vessels, which were the most numerous vessel type in the outbound shipping lane (Figure 9). The distances to all deep-sea vessels within 30 km of the mooring at Jordan River each hour is shown in the upper panel in Figure 9, while the number of vessels of each category, per hour, are shown in the lower panel. There are several important findings shown in this figure: 1) The number of deep-sea vessels is much greater than for tugs; 2) The dominant outbound and inbound shipping lanes are apparent as two horizontal, mostly blue bands, at about 5 and 11 km; 3) The number of vessels, mostly tugs, closer to the mooring than 4-5 km, is small and not significantly different between the pre-trial and post-trial periods and the trial period.

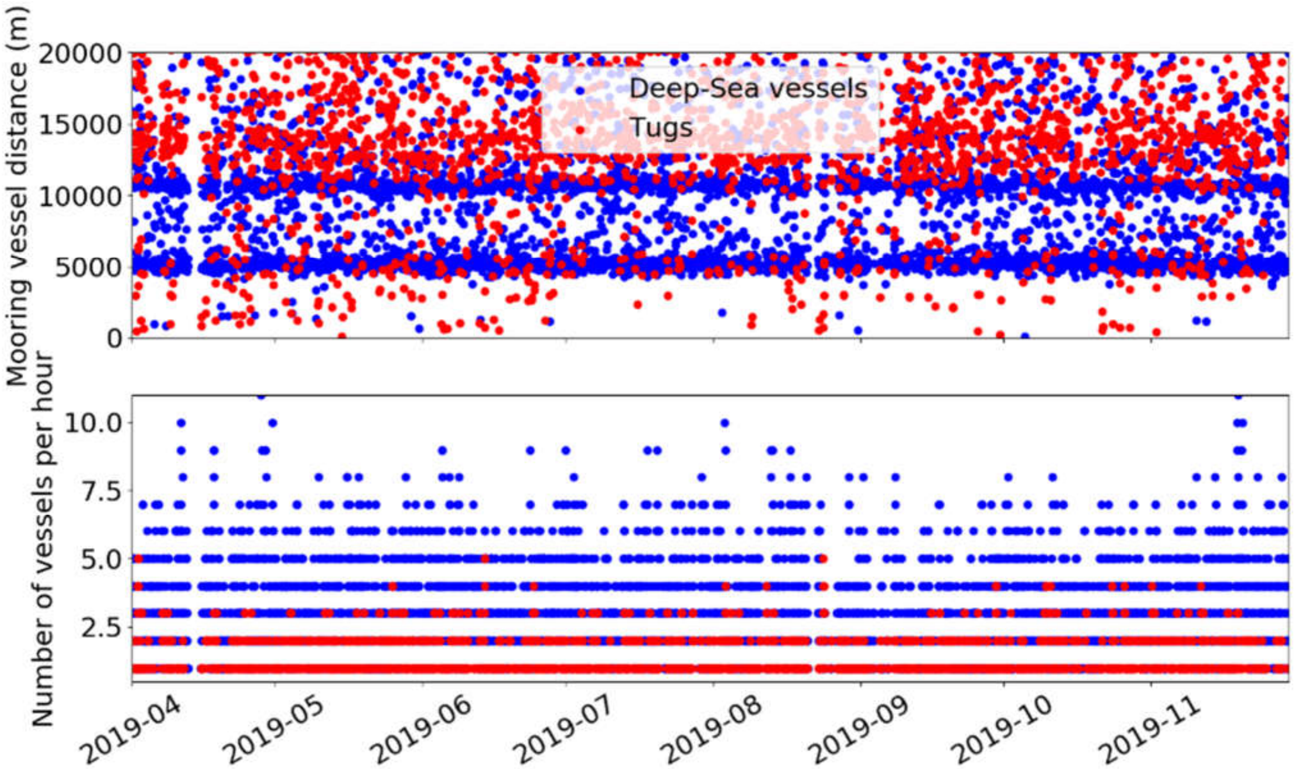

Figure 9. The ranges to all deep-sea vessels (bulk carriers, container vessels, tankers, vehicle carriers and cruise ships) and tugs within 30 km of the Jordan River mooring every hour (upper panel) and the number of these two classes of vessels per hour within 30 km of the mooring.

Compliance to the lateral displacement measures were examined by comparing the number and distance from mooring of deep-sea and tug vessels per lunar month over the course of the pre-, post- and trial periods (Figure 10). These comparisons were not possible for the 2018 trial as the measures were put in place much later in the summer (August 2018 rather than June in 2019).

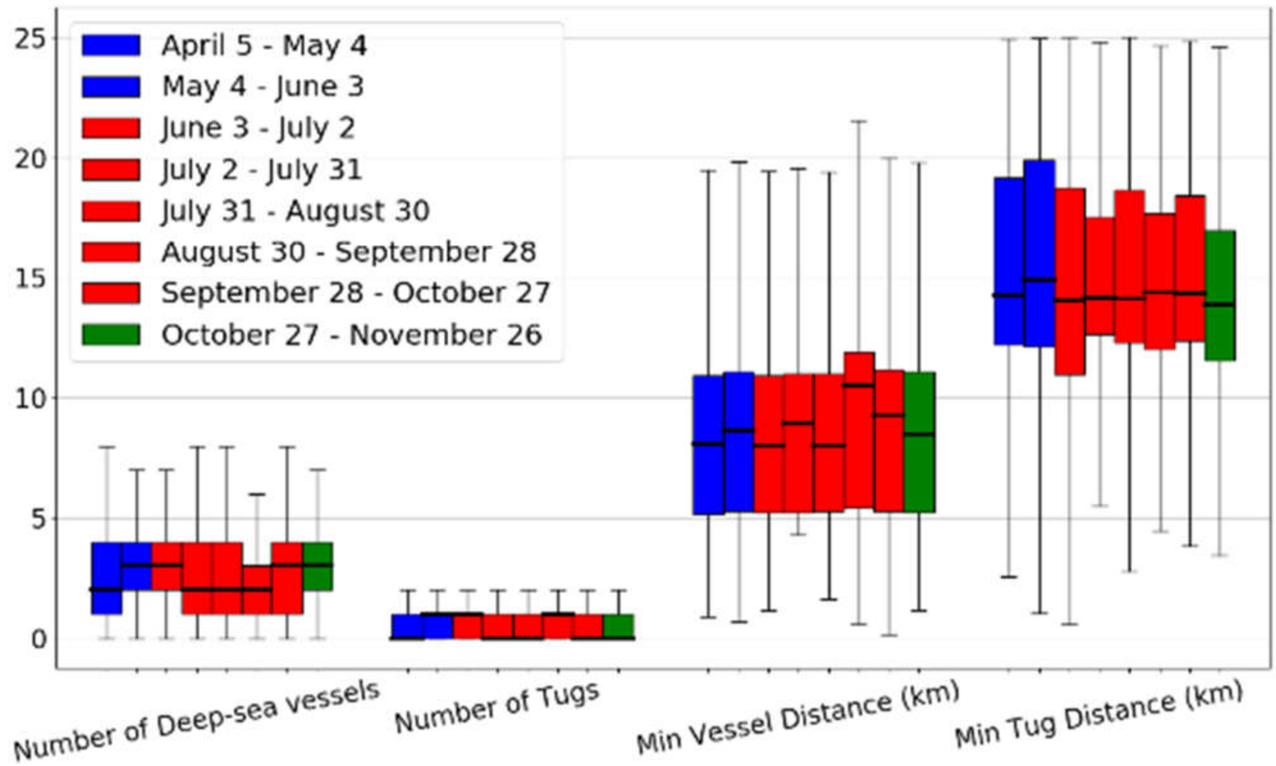

Figure 10. Lunar-month boxplots to show range of four different measures associated with deep-sea vessels and tugs passing the Jordan River mooring in 2019. The blue boxes are lunar months prior to the trial, the red boxes are lunar months during the trial and the green boxes represent the month after the trial period. Order is from left to right in accordance with the top to bottom listing in the legend.

There was a general decrease in number of transits, and increased of distance between the transiting vessel and the mooring for both the deep-sea vessels and the tugs as the summer progressed.

To evaluate the effects of the altered transit routes on the noise levels at frequencies relevant to SRKW in the portion of their critical habitat that was monitored by the Jordan River hydrophone mooring, we compared the SPL in seven different bands: 10-100,000 Hz, 500-15,000 Hz, 15,000-100,000 Hz, 10-100 Hz, 100-1000 Hz, 1000-10,000 Hz and 10,000-100,000 Hz from the pre-trial period (April 1 – June 17) with all available data from the trial (June 19 – October 31) and post-trial (November 1 – November 30) periods.

The results are shown in Figure 11 and tabulated in Table 2. In the results shown, only data during slack tide (defined as current speeds being less than 0.3 m/s as obtained from a current meter deployed off Sooke) were used. This minimized any impact of low-frequency flow noise on the acoustic data. In these box plots the solid horizontal lines in the middle of the boxes are the median (L50) values and the boxes are defined by the 25^{th} percentiles, L25, and 75^{th} percentiles, L75, respectively. 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 25^{th} to the 75^{th} percentile.

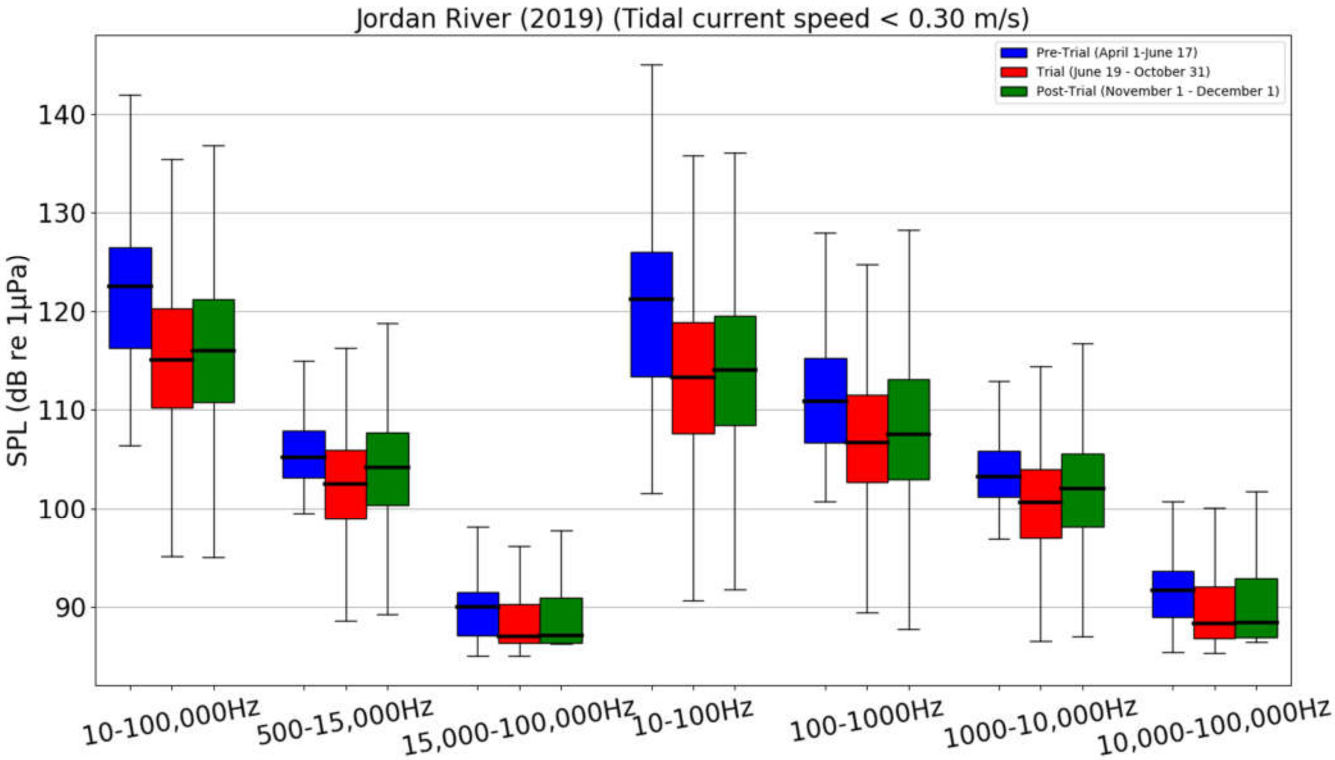

Figure 11. Jordan River SPL boxplots for seven frequency bands for the pre-trial period (blue boxes), the trial period (red boxes) and for the post-trial period (green boxes). Values tabulated in Tables 2 and 3.

At the Jordan River location all relevant metrics, in all frequency bands, indicated reduced SPL during the lateral displacement trial (Figure 11 and Table 2). 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 2 to make a trial-control assessment. These results show that L25, L50, L75 and the means (Leq) were all reduced by between 0.6 and 3.7 dB during the lateral displacement period in this portion of SRKW critical habitat (Table 3).

This is a surprising result when considering tugs were the only vessel class included in the lateral displacement trial in 2019, and that they only represented a small proportion (2-9%) of vessels passing the mooring location. To investigate these results further, a temporal comparison was made, considering the changes over the eight lunar months spanning the pre-trial, trial and post-trial periods. The same L25, L50, L75 and the means were calculated as before. These results are shown in Figure 12 below. During the trial period there was a general month to month downward trend in noise levels in most of the frequency bands was evident, followed by an increase after the trial was over.

As a comparison, the results from the 2019 trial are shown with similar results from the 2018 lateral displacement trial (Vagle and Neves, 2019) seen in Figure 13. It is interesting to note that in the lower frequency bands the pre-trial SPL of 2019 were significantly higher than in those recorded in 2018.

Table 2. Jordan River location tabulated values from Figure 7. Values lower during the trial period are highlighted by being presented in bold face. The values in brackets are the corresponding values obtained during the 2018 lateral displacement trial (Vagle and Neves, 2019).

Pre-trial	**0.01-100kHz (dB re 1µPa)**	**0.5-15kHz (dB re 1µPa)**	**15-100kHz (dB re 1µPa)**	**10-100Hz (dB re 1µPa)**	**0.1-1kHz (dB re 1µPa)**	**1-10kHz (dB re 1µPa)**	**10-100kHz (dB re 1µPa)**
Min.	93.4 (68.5)	86.2 (60.3)	84.6 (67.7)	84.8 (47.4)	84 (51.0)	84.6 (58.3)	85.1 (67.9)
75th percentile	113.2 (114)	101.4 (100.3)	85.4 (86.1)	111.1 (112.2)	104 (103.7)	99.3 (98.4)	86.2 (86.8)
Median	118.9 (120.4)	104.5 (103.6)	87.5 (88.1)	117.4 (119.4)	108.3 (108.1)	102.4 (101.7)	89.3 (89.8)
Mean	124.2 (127.5)	107.7 (106.8)	91.1 (91.3)	123.4 (127.1)	113.3 (113.1)	105.6 (104.9)	93.1 (93.2)
25th percentile	126.4 (130.6)	109.3 (111.1)	95.9 (97.0)	126.1 (130.3)	114.9 (117.9)	107.1 (109.6)	99.4 (100.0)
Max	166.2 (165.7)	153.3 (158.9)	145.9 (147.5)	166.1 (162.9)	156.5 (161.8)	152.7 (158.7)	148.5 (148.9)
Trial							
Min.	**91.3** (93.2)	**83.5** (82.8)	85.1 (85.0)	**81.9** (84.9)	**83.9** (86.0)	**82.1** (81.2)	85.4 (85.3)
75th percentile	**110.4** (114.1)	**99.2** (97.1)	**86.4** (85.4)	**107.8** (112.5)	**102.9** (103.0)	**97.3** (94.9)	86.8 (85.9)
Median	**115.3** (120.1)	**102.7** (101.1)	**87** (86.2)	**113.5** (119.1)	**107** (107.8)	**100.8** (98.9)	**88.2** (87.6)
Mean	**120.6** (125.5)	**106** (105.5)	**90** (89.2)	**119.1** (125.1)	**111.8** (112.8)	**104.1** (103.0)	**91.8** (91.4)
25th percentile	**123** (126.5)	**108** (110.8)	**95.8** (97.2)	**122.2** (126.1)	**114.2** (115.5)	**106.1** (109.1)	**98** (100.2)
Max	**163.7** (165.2)	155.7 (156.5)	**143.6** (141.6)	**160.4** (163.4)	160.7 (160.9)	154.9 (155.4)	**146.9** (143.1)
Post-trial							
Min.	92.9 (91.9)	85.4 (85.7)	86.3 (85.4)	86 (81.8)	83.2 (86.6)	84.1 (83.5)	86.5 (85.6)
75th percentile	110.7 (114.5)	100.3 (99.5)	86.4 (86.1)	108.4 (112.8)	103 (102.8)	98.2 (97.0)	86.9 (87.2)
Median	116 (121.1)	104.2 (103.6)	87.1 (89.0)	114.1 (120.2)	107.6 (107.6)	102 (101.2)	88.4 (91.1)
Mean	121.2 (126.9)	107.7 (107)	90.8 (93.5)	119.4 (126.4)	113.2 (113.2)	105.6 (104.7)	92.8 (95.6)
25th percentile	121.9 (129)	109.7 (112.1)	96 (100.5)	120.8 (128.6)	114.5 (116.7)	107.6 (109.3)	101 (104)
Max	156.3 (165.1)	154 (154.1)	135.9 (141.6)	151.6 (163.7)	151.6 (158.9)	153.6 (152.9)	148.3 (143.8)

Table 3. Jordan River location difference between pre-trial and trial periods from Table 2 for the seven frequency bands being considered.

Trial minus Pre-trial band SPL	**0.01-100kHz(dB re 1µPa)**	**0.5-15kHz(dB re 1µPa)**	**15-100kHz (dB re 1µPa)**	**10-100Hz (dB re 1µPa)**	**0.1-1kHz (dB re 1µPa)**	**1-10kHz (dB re 1µPa)**	**10-100kHz (dB re 1µPa)**
75^{th} percentile	**-2.8**	**-2.2**	1.0	**-3.3**	**-1.1**	**-2.0**	0.6
Median	**-3.6**	**-1.8**	**-0.5**	**-3.9**	**-1.3**	**-1.6**	**-1.1**
Mean	**-3.6**	**-1.7**	**-1.1**	**-4.3**	**-1.5**	**-1.5**	**-1.3**
25^{th} percentile	**-3.4**	**-1.3**	**-0.1**	**-3.9**	**-0.7**	**-1.0**	**-1.4**

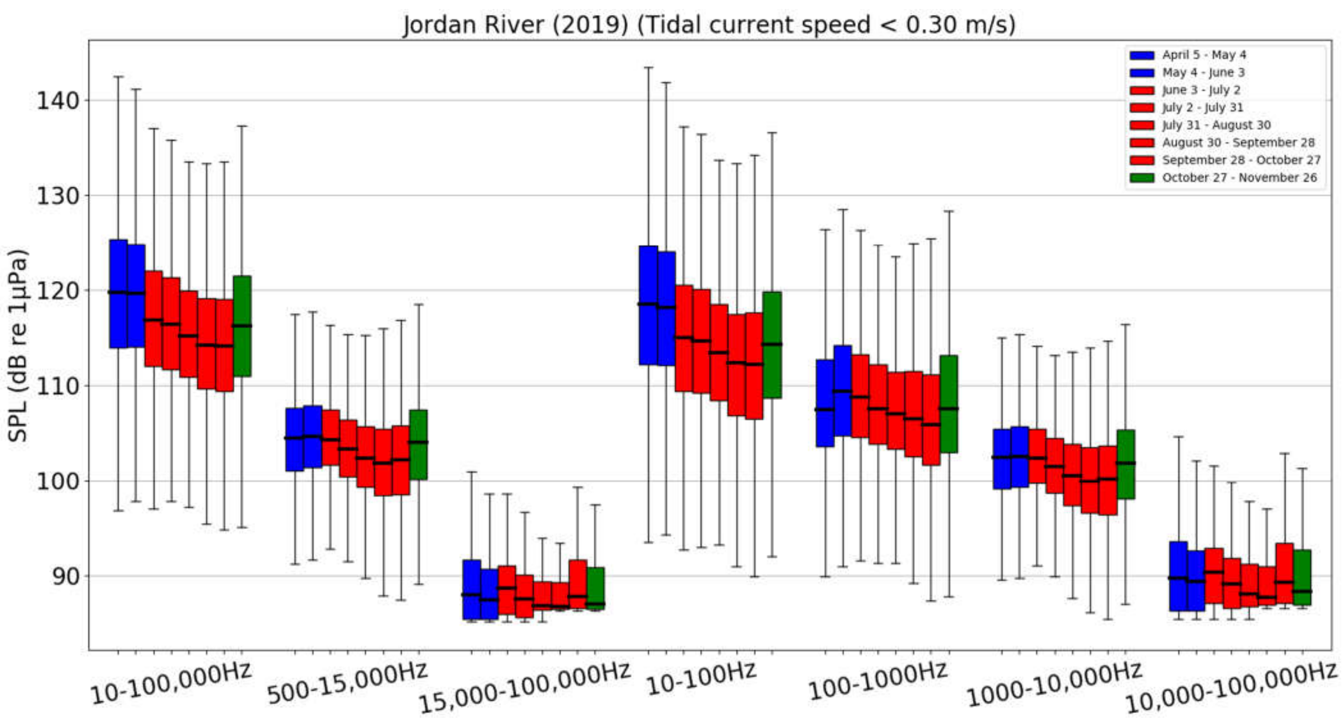

Figure 12. Jordan River SPL boxplots for seven frequency bands separated into lunar months between April 5 and November 24, 2019. The blue boxes are lunar months prior to the trial, the red boxes are lunar months during the trial and the green boxes represent the month after the trial period. Order is from left to right in accordance with the top to bottom listing in the legend.

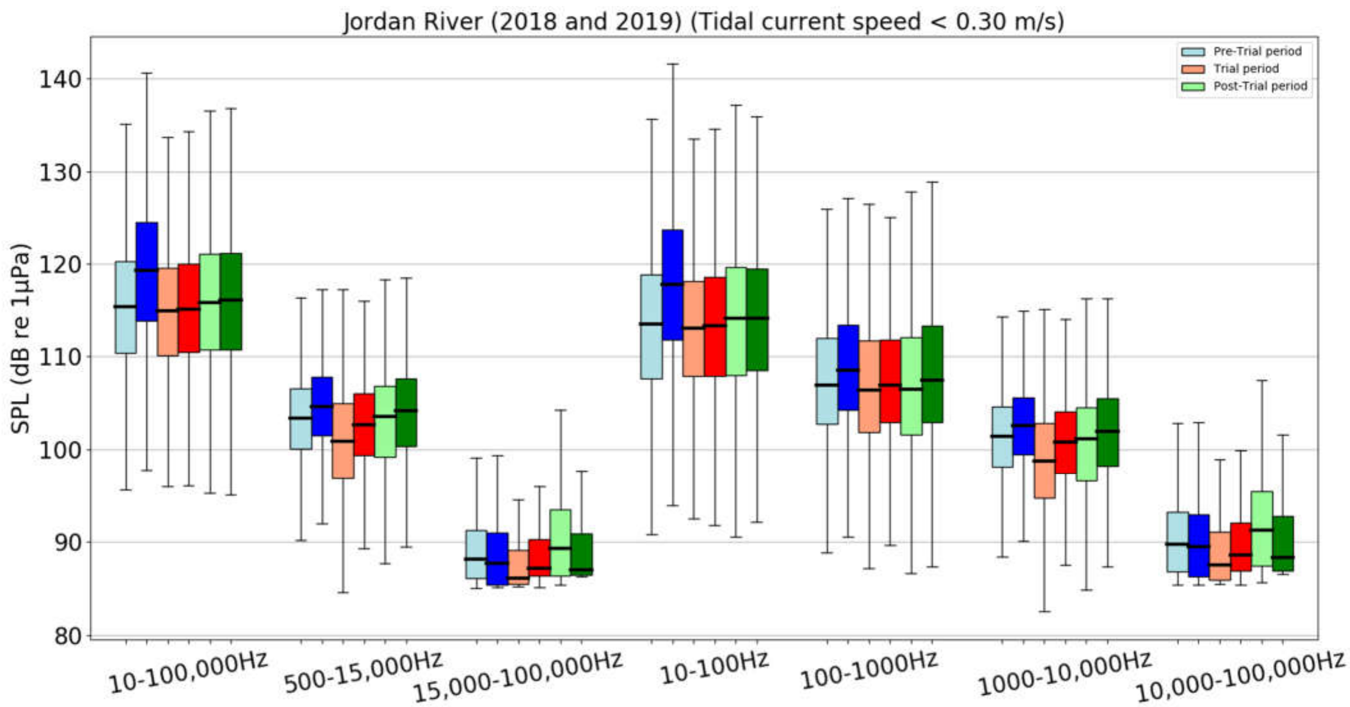

Figure 13. Jordan River SPL boxplots for seven frequency bands from the pre-trial, trial, and post-trial periods in 2019 (dark blue, dark red and dark green boxes, respectively) compared with similar results from the 2018 lateral displacement trial (Vagle and Neves, 2019) (light colored boxes).

4.1.1.2 Daily and weekly coherent variability in the noise field in the Strait of Juan de Fuca.

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 14-16 show daily rhythm SPL box plots (with the same L25, L50, L75 and the mean parameters as in in the earlier box plots) across the lunar month for each hour of the day in daylight savings time during the eight lunar months considered for recordings made by the Jordan River mooring. The data are shown for the three SRKW relevant frequency bands. Only data during times when the current speed at the nearby Sooke hydrophone was less than 0.3 m/s were included in this analysis.

In the SRKW disturbance band (10-100,000 Hz; Figure 14) there was generally little hourly variability, except for perhaps during the first four months (April 5 – July 31) when the results suggested a general increase in the afternoon, with a peak around 15:00.

The communication masking band (500-15,000 Hz; Figure 15) showed little hourly variability in all eight lunar months.

In the echo-location masking band (15,000-100,000 Hz; Figure 16) there was a significant increase in SPL in the afternoon and evening (12:00-20:00) in June and July, and to a lesser degree in August. It can be expected that this variability is related to small boat presence during these summer months. A similar daylight hour increase in SPL was observed in October (Figure 16b; third panel).

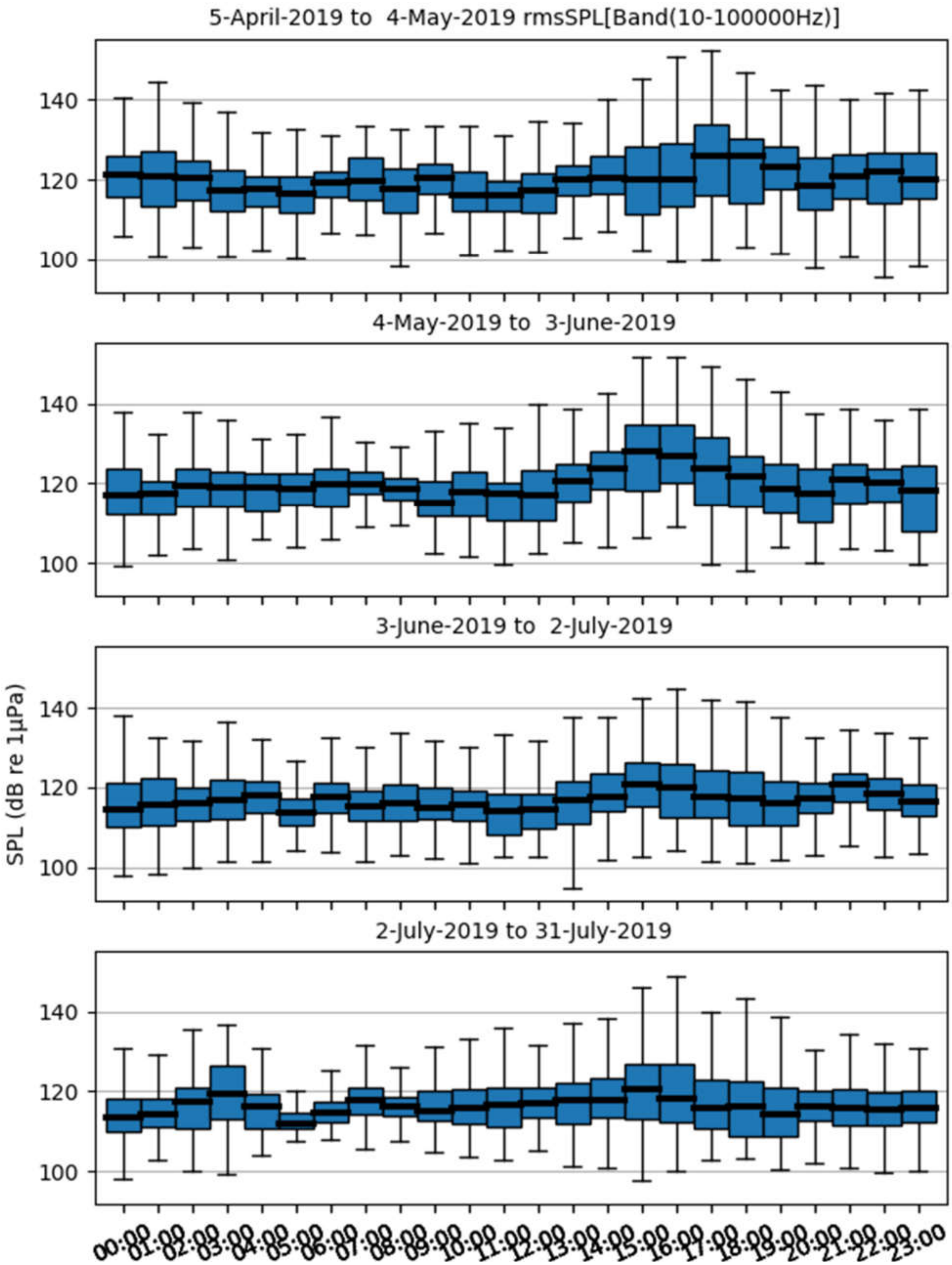

Figure 14a. Daily rhythm plots for the first four lunar months at Jordan River within the SRKW disturbance band (10-100,000 Hz).

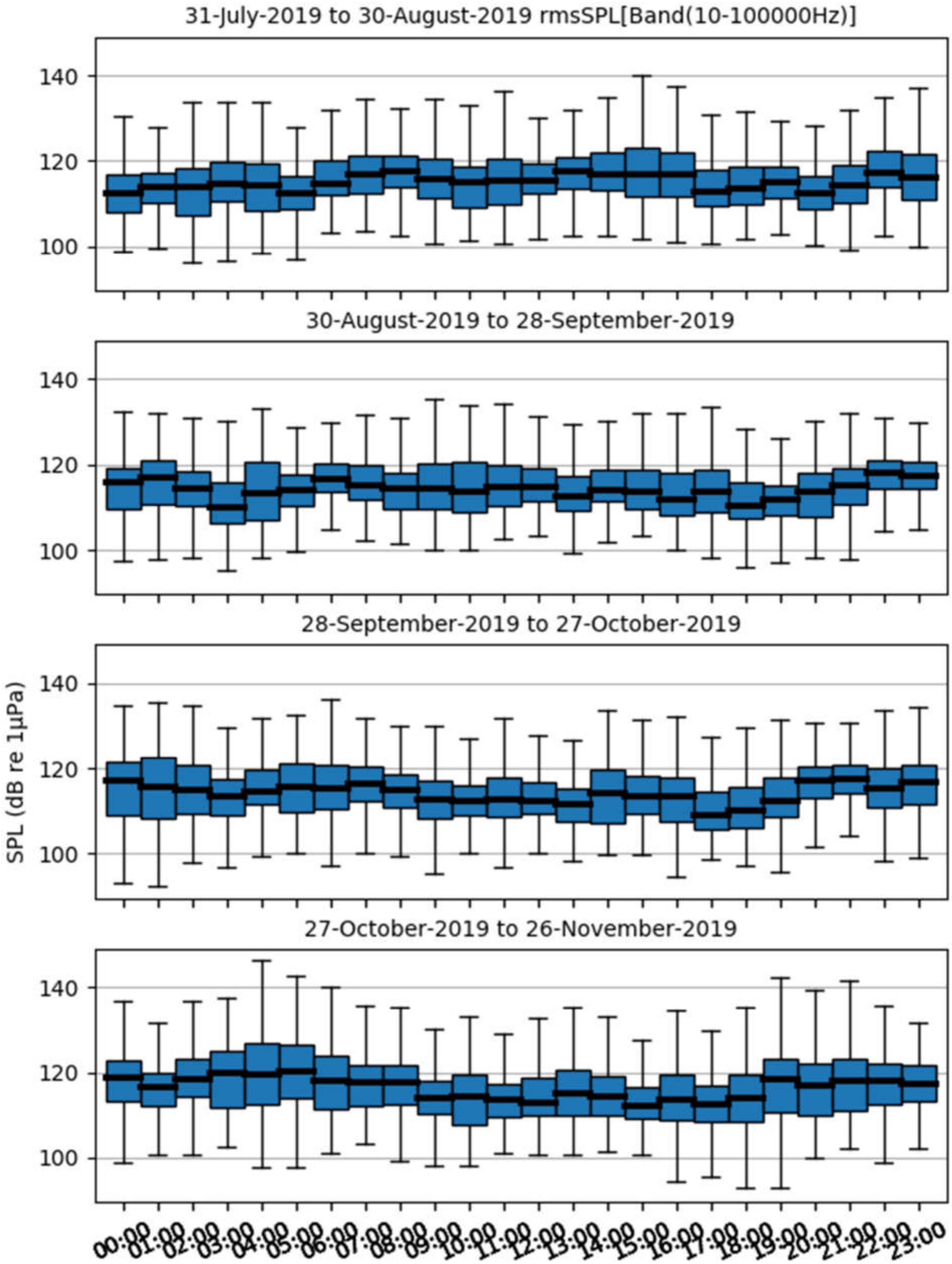

Figure 14b. Daily rhythm plots for the last four lunar months at Jordan River within the SRKW disturbance band (10-100,000 Hz).

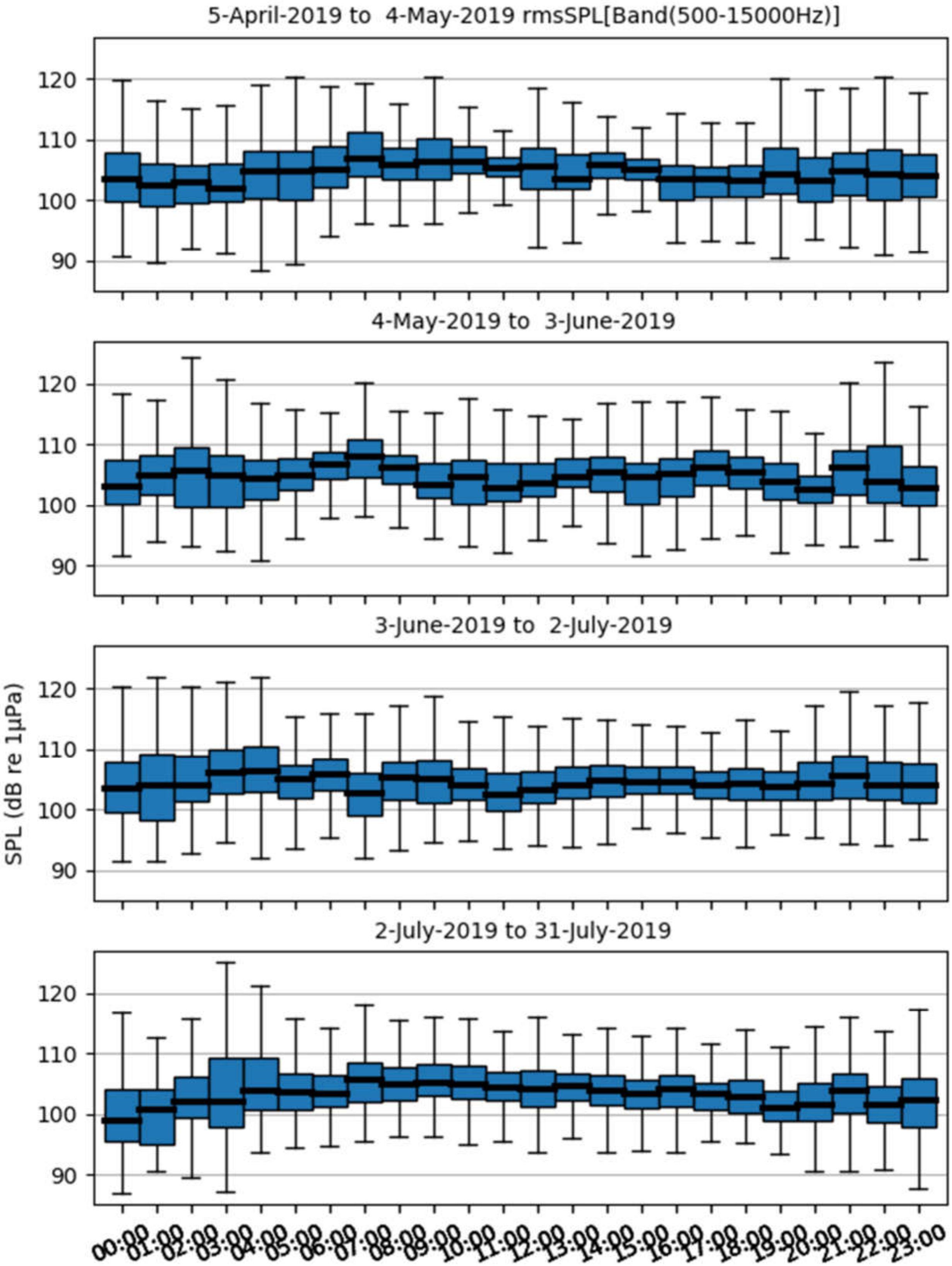

Figure 15a. Daily rhythm plots for the first four lunar months at Jordan River within the SRKW communication masking band (500-15,000 Hz).

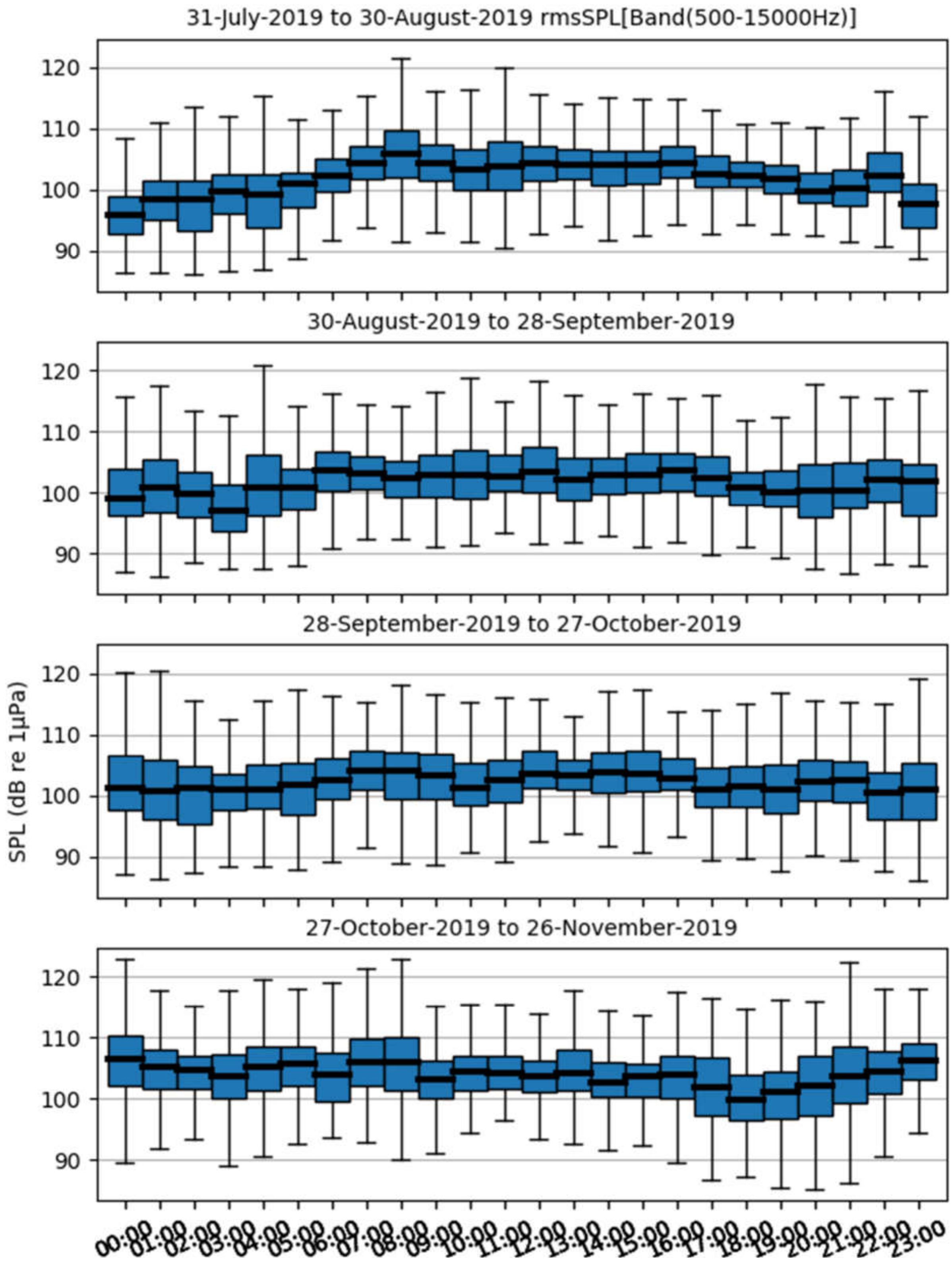

Figure 15b. Daily rhythm plots for the last four lunar months at Jordan River within the SRKW communication masking band (500-15,000 Hz).

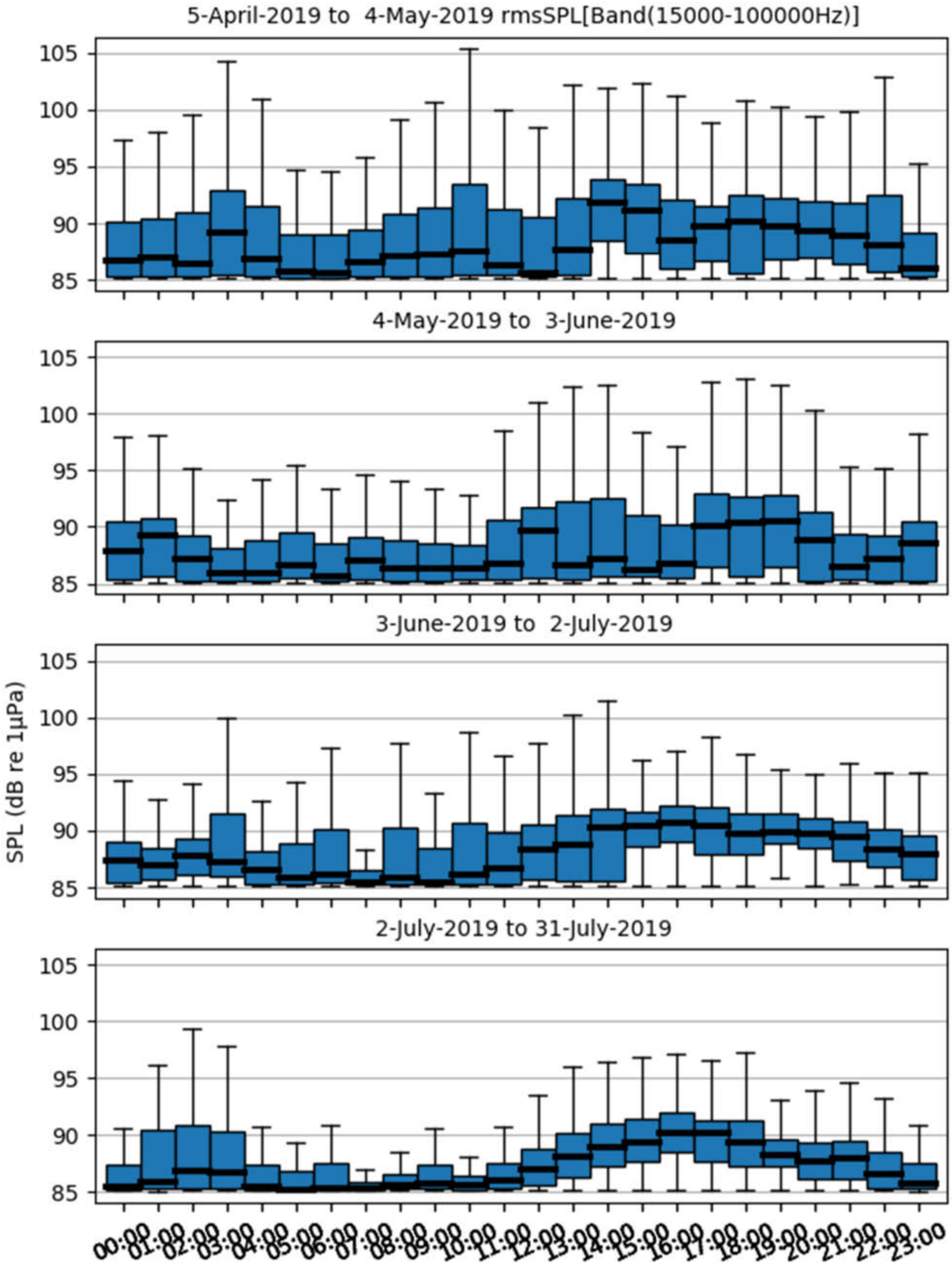

Figure 16a. Daily rhythm plots for the first four lunar months at Jordan River within the SRKW echo-location masking band (15,000-100,000 Hz).

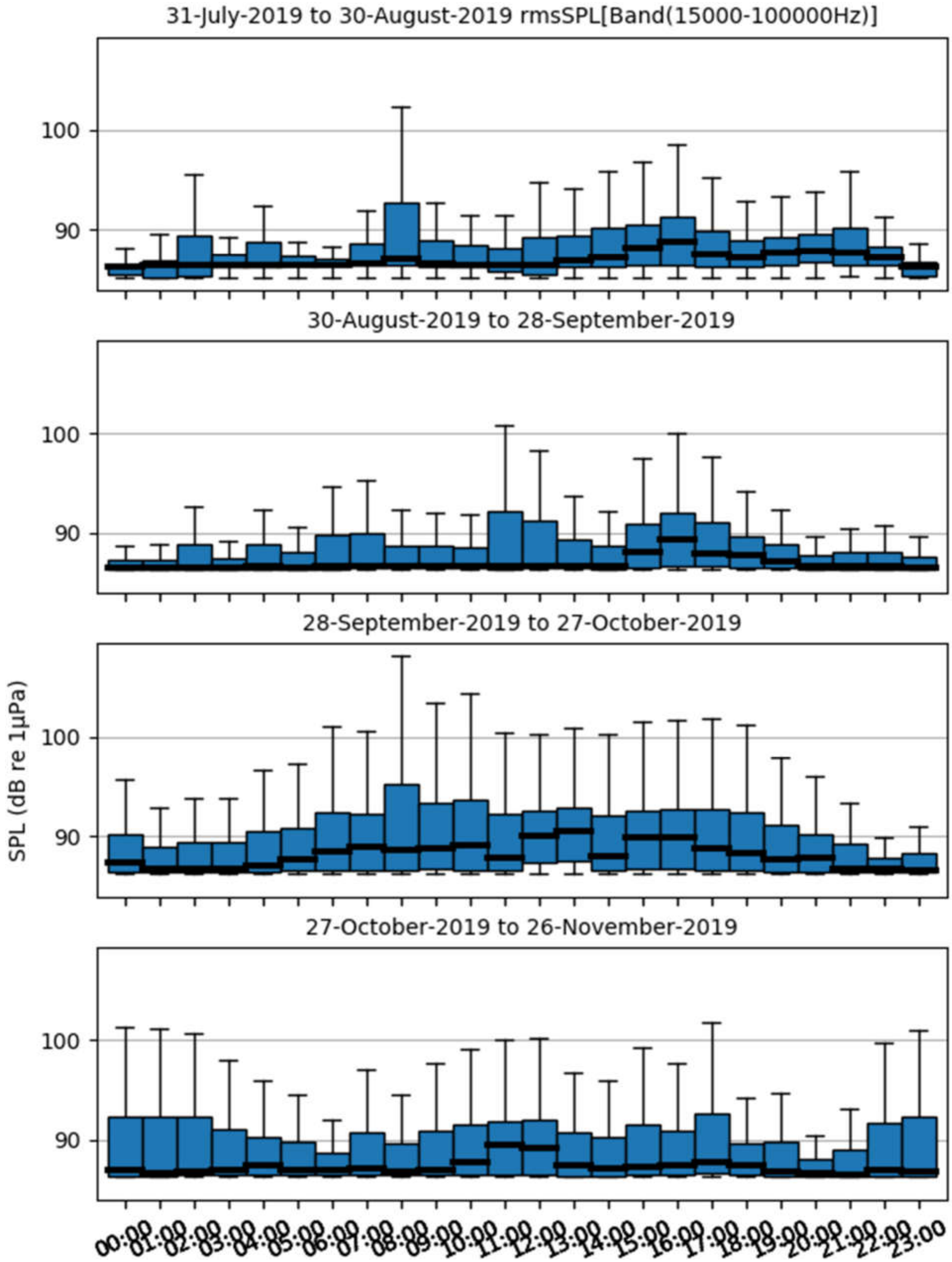

Figure 16b. Daily rhythm plots for the last four lunar months at Jordan River within the SRKW echo-location masking band (15,000-100,000 Hz).

Similarly, figures 17-19 show weekly rhythm plots for each of the eight lunar months at the SRKW frequency bands from Jordan River. There was very little day to day variability within the broadband and communication masking bands, while for the echo-location masking band (15,000-100,000 Hz) there was significant day to day variability, presumably due to the presence and absence of smaller pleasure crafts. Small, but significant increases in SPL levels were seen during the weekends, particularly for mid- to late-summer.

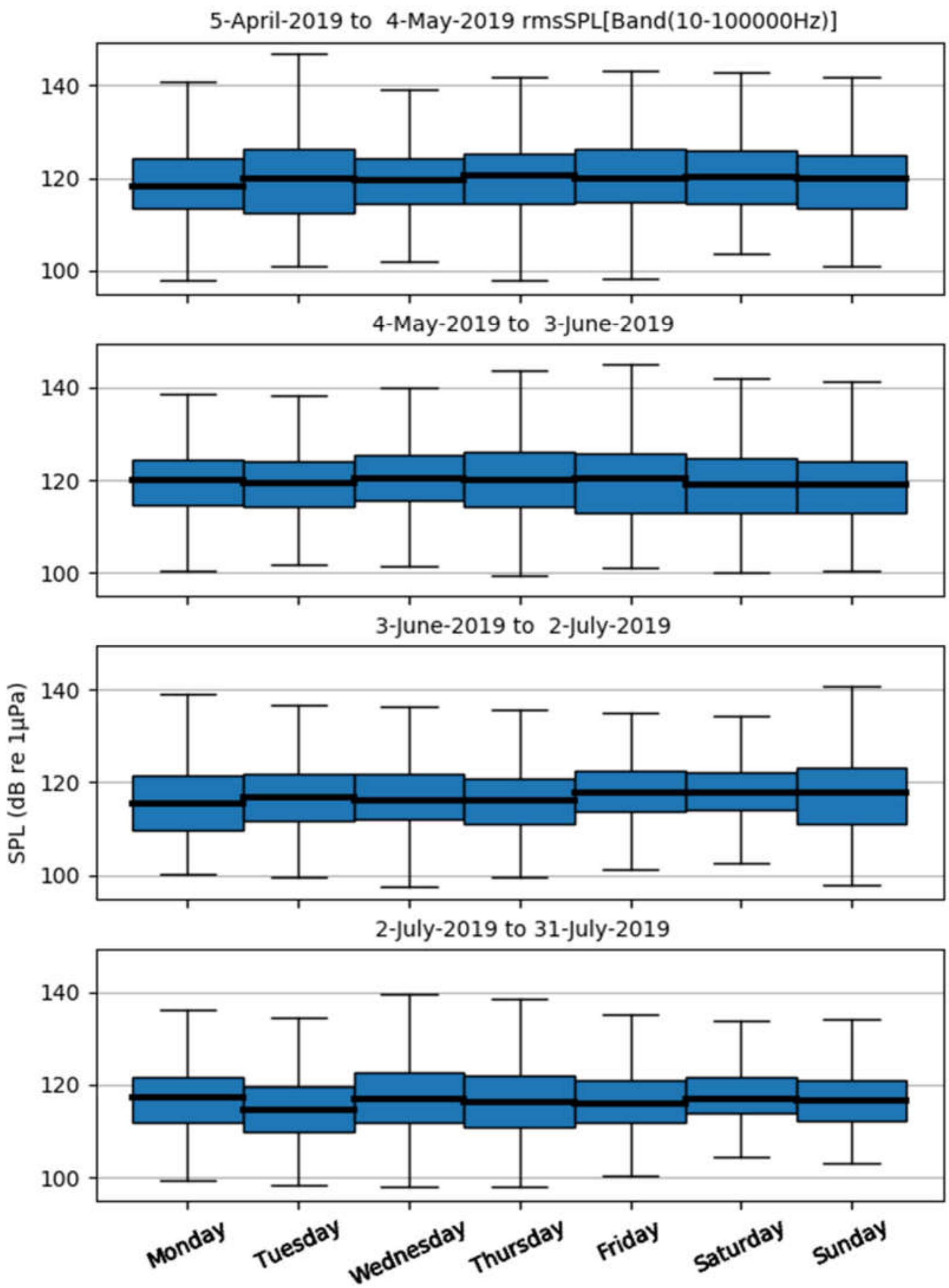

Figure 17a. Weekly rhythm plots for the first four lunar months at Jordan River within the SRKW disturbance band (10-100,000 Hz).

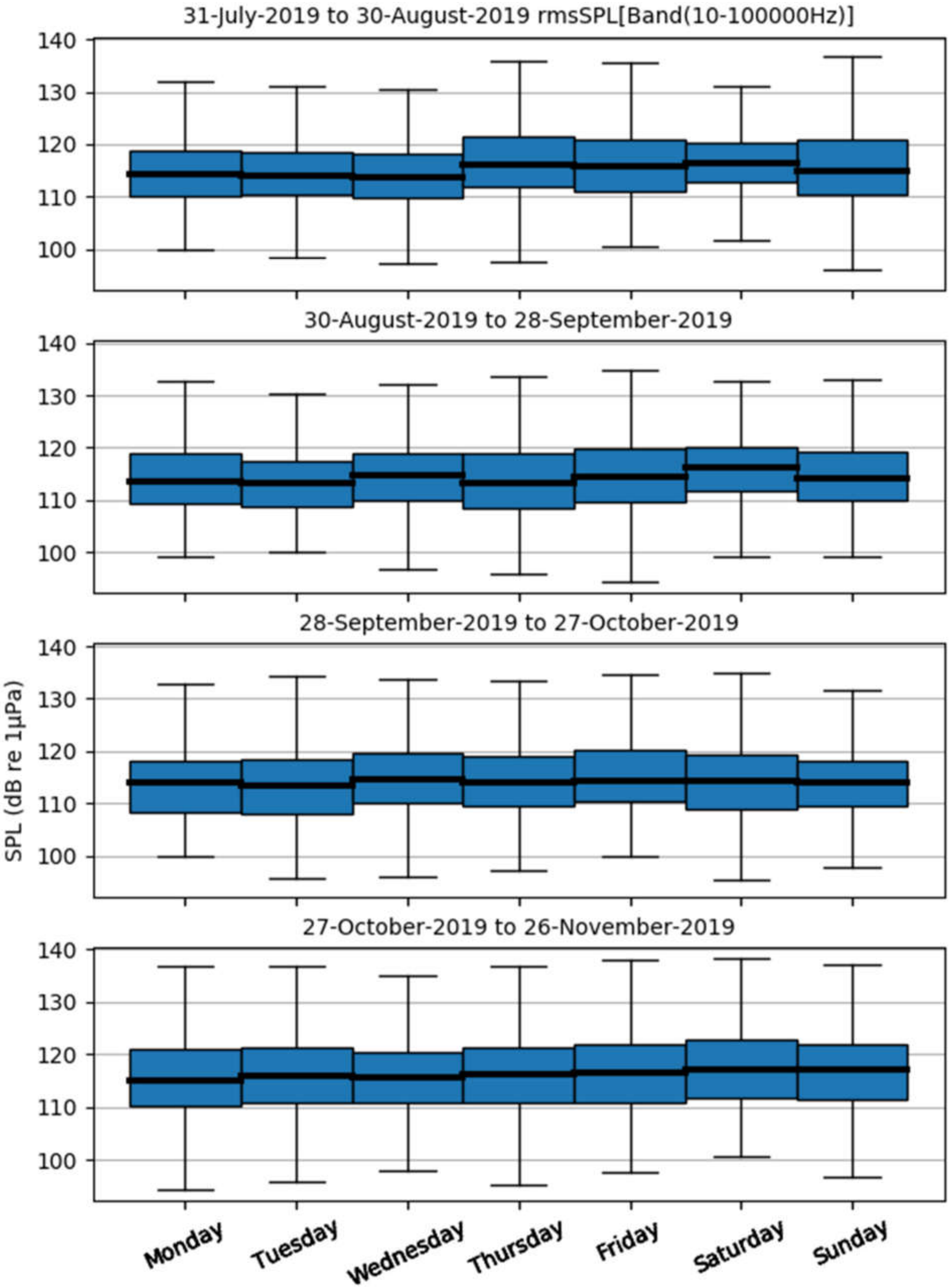

Figure 17b. Weekly rhythm plots for the last four lunar months at Jordan River within the SRKW disturbance band (10-100,000 Hz).

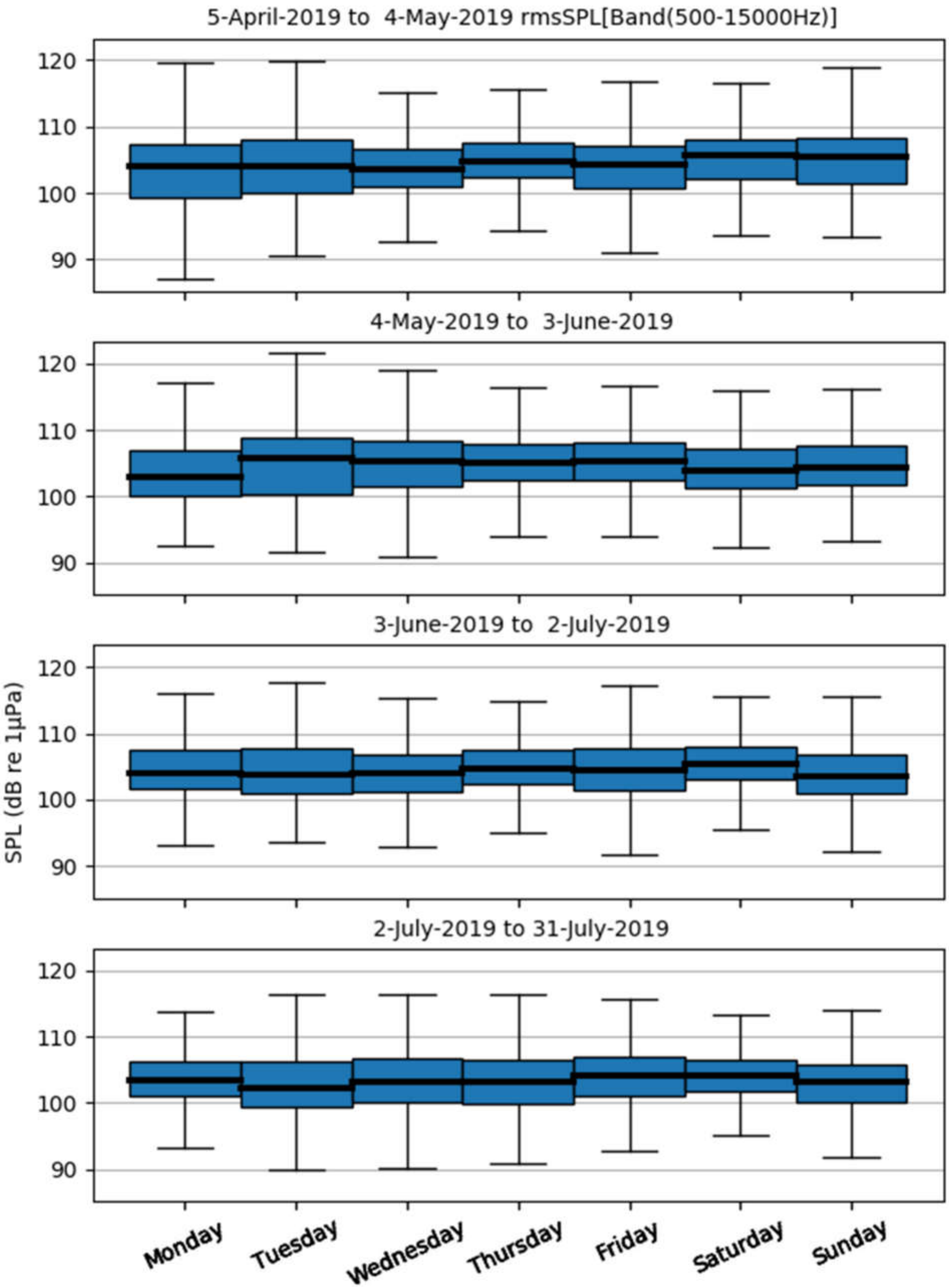

Figure 18a. Weekly rhythm plots for the first four lunar months at Jordan River within the SRKW communication masking band (500-15,000 Hz).

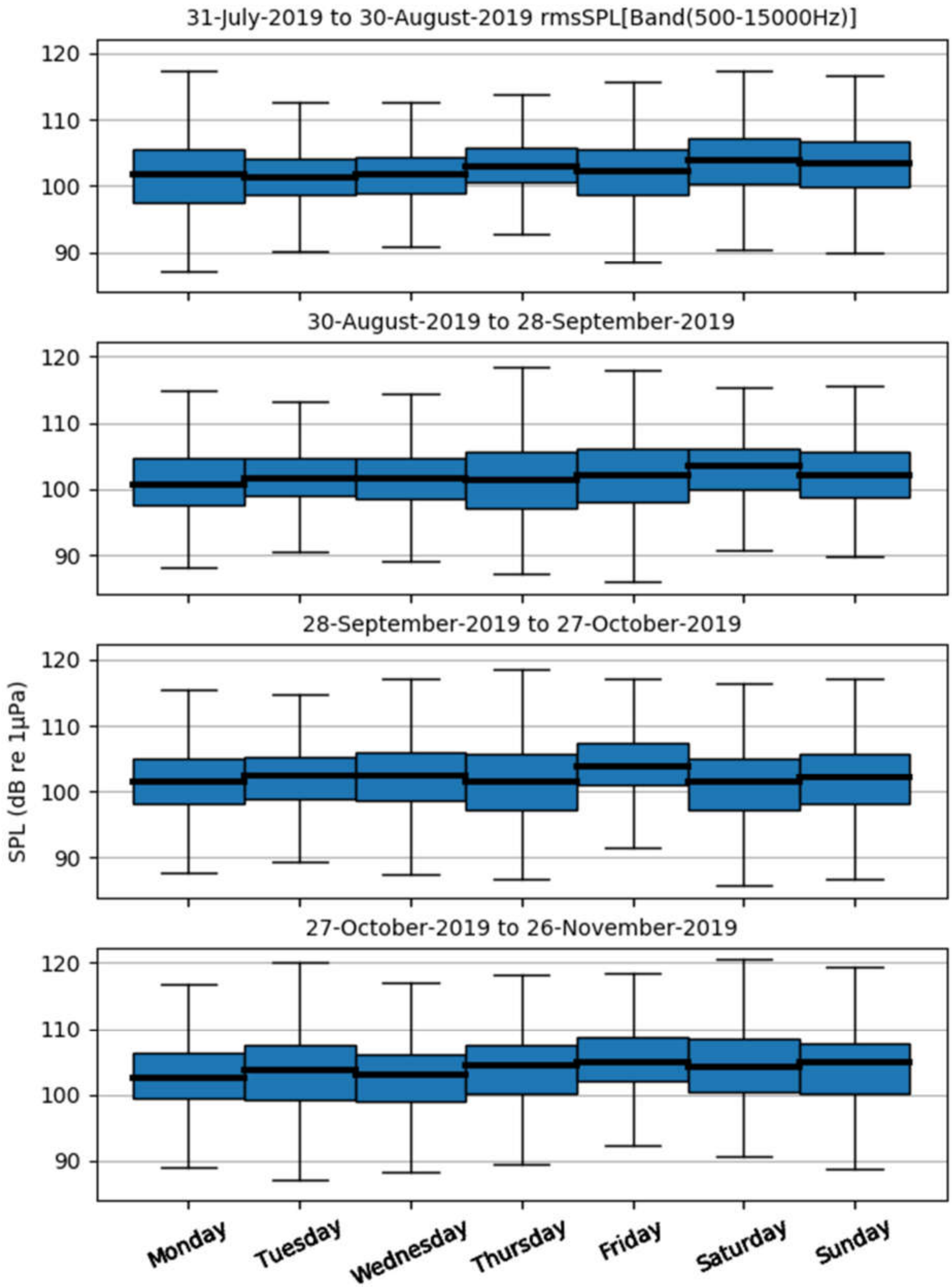

Figure 18b. Weekly rhythm plots for the last four lunar months at Jordan River within the SRKW communication masking band (500-15,000 Hz).

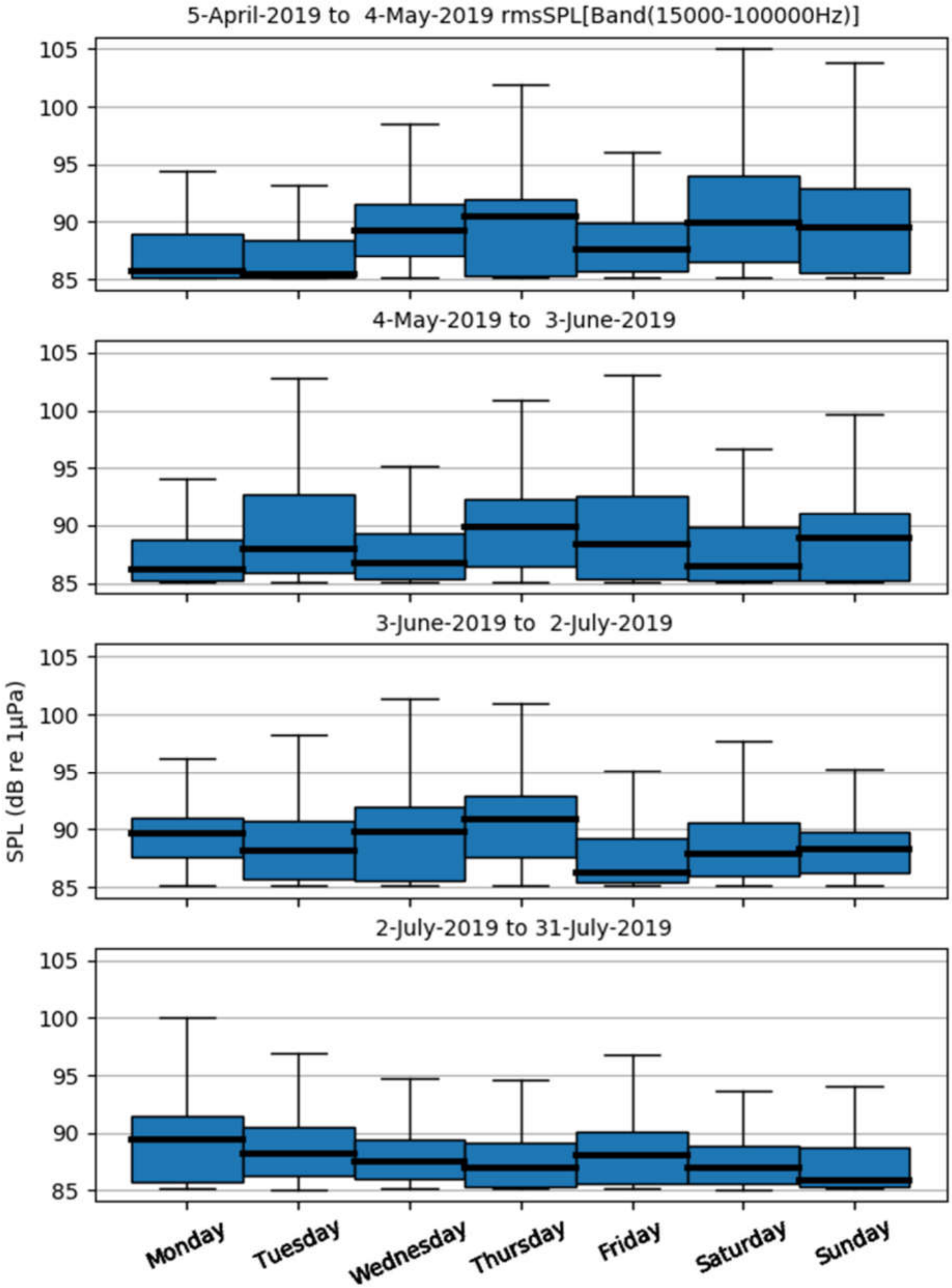

Figure 19a. Weekly rhythm plots for the first four lunar months at Jordan River within the SRKW echo-location masking band (15,000-100,000 Hz).

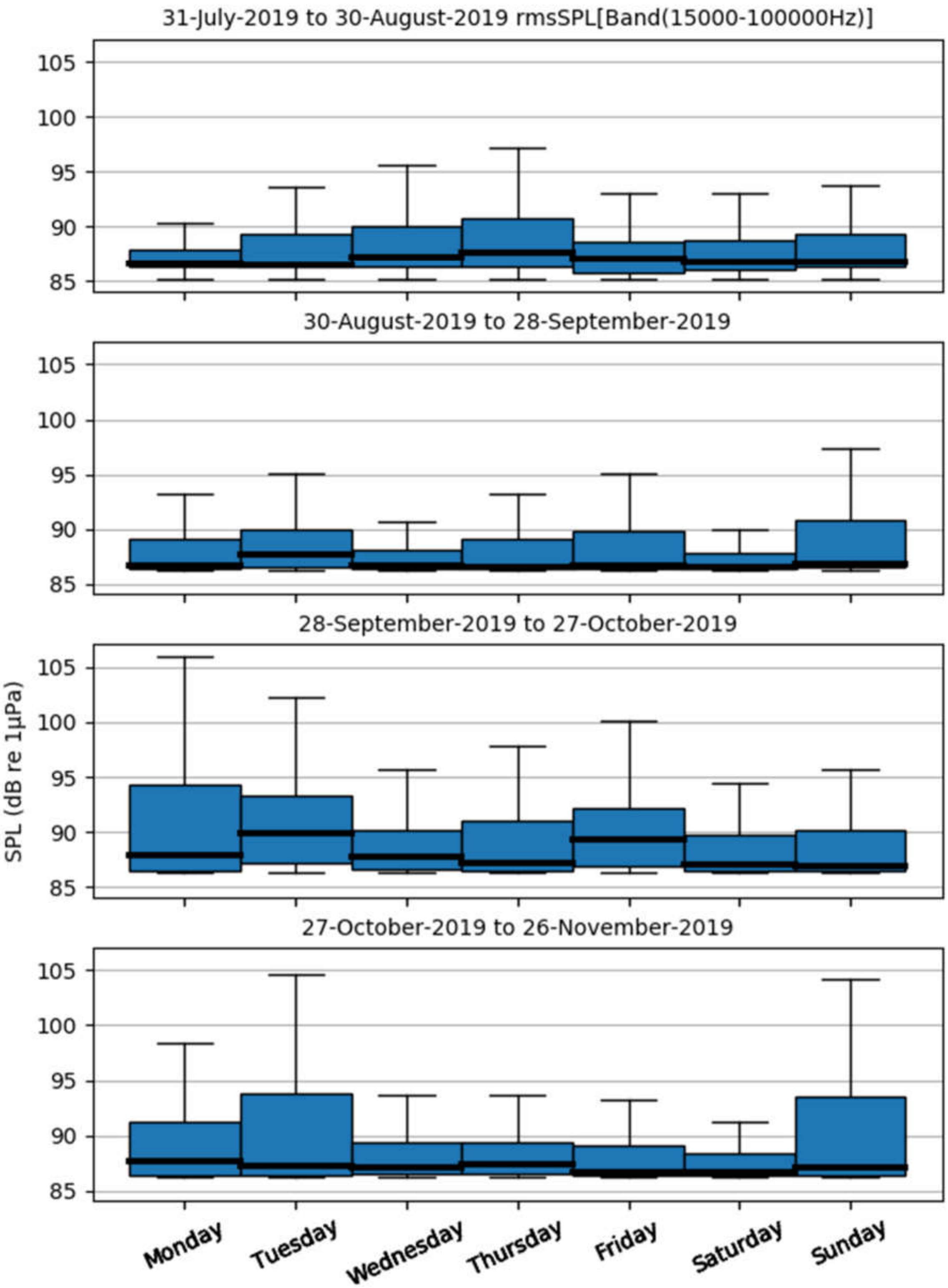

Figure 19b. Weekly rhythm plots for the last four lunar months at Jordan River within the SRKW echo-location masking band (15,000-100,000 Hz).

4.1.2 Noise impact of tugs participating in nearshore lateral displacement trial

From April 1 to November 30, 2019 112 different tugs were tracked to within 30 km of the Jordan River mooring from the AIS data. During the same period 1513 individual bulk carriers, tankers, container vessels, passenger ships and vehicle carriers were tracked within 30 km of the mooring location. Also, from April 1 to November 1, 2019 34 different tugs were detected to be the nearest vessels to the mooring within the set of 5-minute time steps used in this analysis. All the tugs tended to travel in three different regions as identified in panels (b), (c), and (d) in Figure 20; south of the incoming shipping lanes or in those lanes, in the outgoing shipping lanes, and in the nearshore waters south of Vancouver Island, respectively.

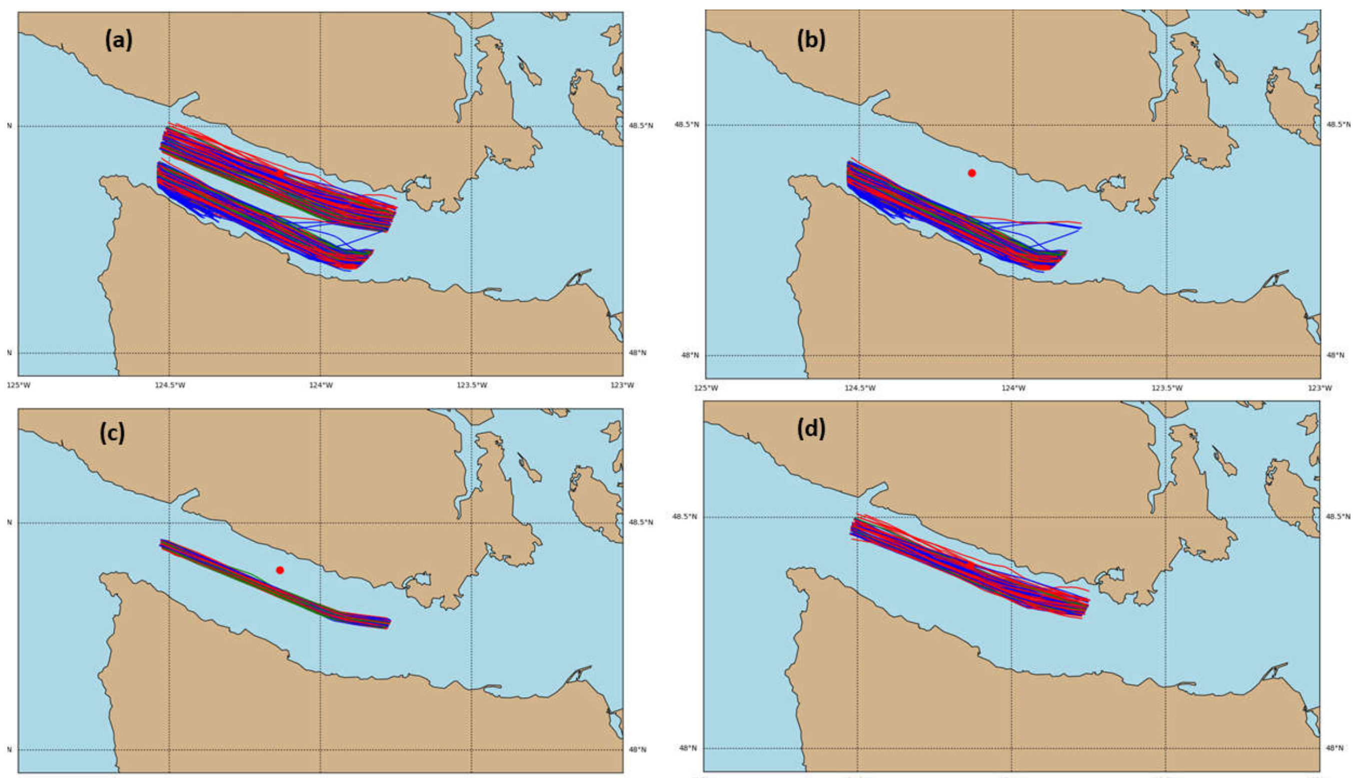

Figure 20. AIS tug tracks within 30 km of the mooring location identified by a red dot. Blue lines were pre-trial, red lines were trial and green lines were post-trial tracks (a) shows all tug tracks, (b) shows tracks south of the incoming shipping lane, (c) shows tracks in the outgoing shipping lane and (d) shows the remaining nearshore tracks that could be influenced by the 2019 lateral displacement trial.

In the nearshore south of Vancouver Island 7 different tugs were tracked prior to the trial, 12 different tugs during the trial period and 3 different tugs after the trial period was over.

The overall number of individual vessel trips within 30 km of the mooring location and within these different bands are summarized in Table 4. The figures in brackets show the percentage of tug trips relative to the overall number of vessel transits. As expected, the nearshore area is dominated by tug traffic. Only vessels operating in this nearshore area made any observable changes to their tracks during the trial period.

Table 4. Number of individually tracked vessel trips in the different range bands defined in the text and shown in Figure 16. All other large vessels are comprised of bulk carriers, tankers, container ships, vehicle carriers and cruise ships. The numbers are given for the pre-trial, trial and post-trial periods.

Period and area	Inbound trips - Tugs	Outbound trips – Tugs	Inbound trips – All other large vessels	Outbound trips- All other large vessels
Pre-Trial – All	166 (15%)	127 (12%)	911	883
Trial – All	240 (14%)	223 (13%)	1438	1467
Post-Trial – All	55 (13%)	53 (13%)	367	351
Pre-Trial – In inbound lane and south	144 (14%)	79 (80%)	901	20
Trial – In inbound lane and south	223 (13%)	147 (72%)	1435	56
Post-Trial – In inbound lane and south	52 (12%)	29 (88%)	365	4
Pre-Trial – In outbound lane	0	31 (3%)	1	855
Trial – In outbound lane	0	58 (4%)	1	1403
Post-Trial – In outbound lane	0	21 (6%)	1	345
Pre-Trial - Nearshore	22 (71%)	17 (68%)	9	8
Trial - Nearshore	17 (89%)	18 (90%)	2	8
Post-Trial - Nearshore	3 (75%)	3 (60%)	1	2

Four different tugs were found to travel primarily within the nearshore waters, and were seen to make a number of trips prior to and during the trial period. They all altered their routes during the trial. To exemplify the impact of route changes on the soundscape in SRKW critical habitat, we focused to our analysis on these four tugs as case studies; labelling tugs 1, 2, 3, and 4. The vessel tracks of these vessels are shown in Figure 21. The lengths of the vessels ranged between 12 and 34 m.

Tug 1 made 11 trips prior to the trial, with a mean distance from the hydrophone of 2740 m. During the trial period this tug made two trips and the mean range increased to 3529 m. Tug 2 had 11 trips prior to the trial period and had a mean range to the hydrophone of 823 m. During the trial this tug made 5 trips and increased its distance to the mooring to a mean of 2596 m. After the trial tug 2 made another 2 trips with a mean range of 3170 m. Tug 3 had 4 trips prior to the range, with a mean range of 2124 m. During the trial period the vessel made 6 trips where the mean range increased to 2871 m. After the trial period two more trips were detected, with a mean range of 2924 m. Tug 4 made 4 trips prior to the trial with a mean range of 1613 m. However, during its single trip during the trial period, the vessel decreased the range to only 911 m. All these ranges are shown in Figure 21 and summarized in Table 5.

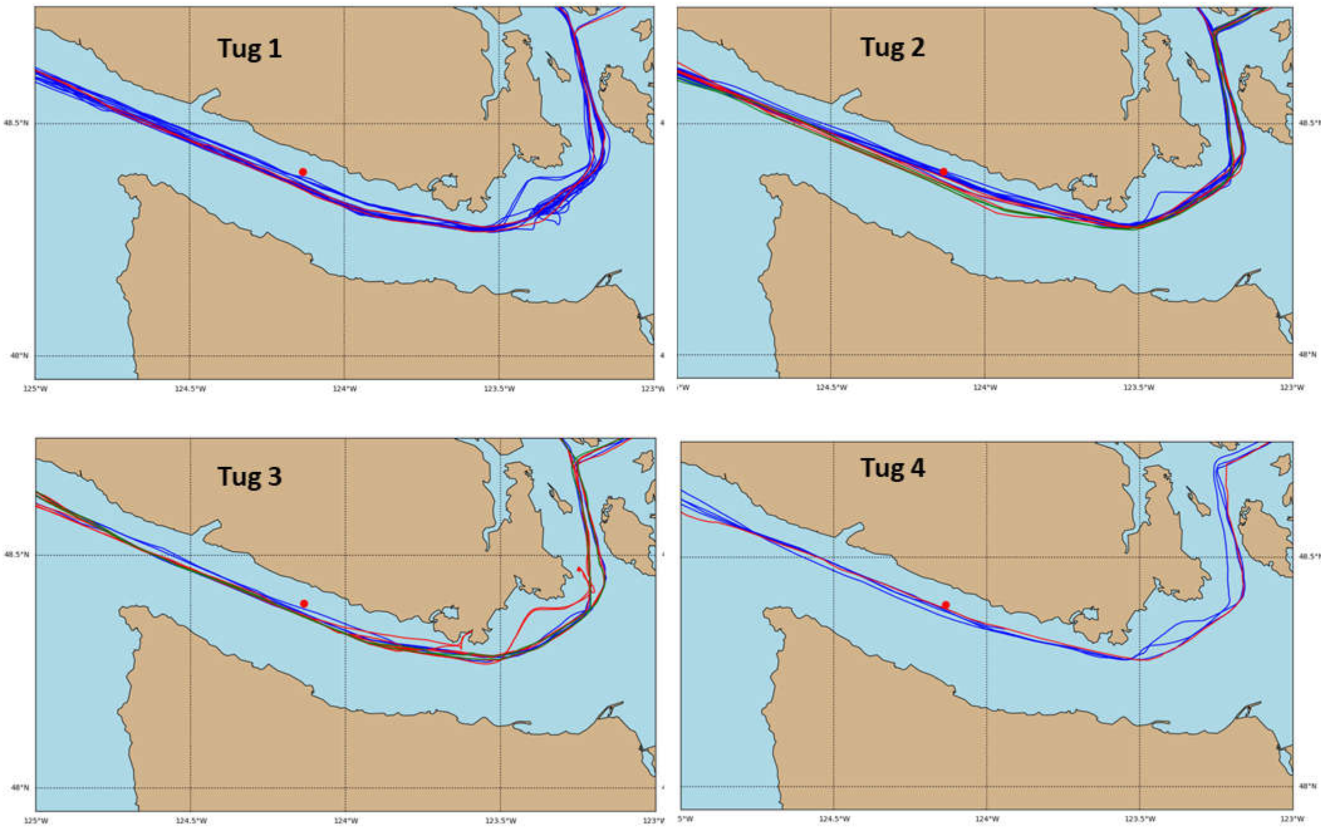

Figure 21. AIS vessel tracks for the four tugs analyzed in more detail in the text. The mooring location is shown with a red dot. Blue tracks were before the trial, red tracks during the trial and green tracks after the trial period.

Table 5. Closest approach distances and whether the vessels were inbound or outbound for the four tugs discussed in the text.

Tug and track number	Period	Closest approach distance (m)	Course
1-1	Pre-Trial	3649	East
1-2	Pre-Trial	1761	East
1-3	Pre-Trial	3451	West
1-4	Pre-Trial	1583	East
1-5	Pre-Trial	3699	West
1-6	Pre-Trial	1667	West
1-7	Pre-Trial	1208	East
1-8	Pre-Trial	3792	West
1-9	Pre-Trial	2929	East
1-10	Pre-Trial	2963	West
1-11	Pre-Trial	3448	East
1-12	Trial	3180	East
1-13	Trial	3878	West
2-1	Pre-Trial	272	East
2-2	Pre-Trial	697	West
2-3	Pre-Trial	900	East
2-4	Pre-Trial	1010	West
2-5	Pre-Trial	1042	East
2-6	Pre-Trial	141	West
2-7	Pre-Trial	2126	East
2-8	Pre-Trial	107	West
2-9	Pre-Trial	1037	East
2-10	Pre-Trial	699	West
2-11	Pre-Trial	1019	East
2-12	Trial	2735	East
2-13	Trial	3355	West
2-14	Trial	1256	East
2-15	Trial	2297	East
2-16	Trial	3337	West
2-17	Post Trial	2866	West
2-18	Post Trial	3475	East
3-1	Pre-Trial	1236	West
3-2	Pre-Trial	2866	East
3-3	Pre-Trial	2276	West
3-4	Pre-Trial	2119	East
3-5	Trial	2833	West
3-6	Trial	2611	East
3-7	Trial	2989	East
3-8	Trial	2950	West
3-9	Trial	2996	East
3-10	Trial	2846	West
3-11	Post Trial	2913	West
3-12	Post Trial	2935	East
4-1	Pre-Trial	822	West
4-2	Pre-Trial	1213	East
4-3	Pre-Trial	1576	West
4-4	Pre-Trial	2840	East
4-5	Trial	911	East

The number of tugs transiting the Strait of Juan de Fuca was low compared to the number of other commercial vessels, therefore the impact of the noise generated by the tugs on the overall soundscape was relatively low. However, since a number of these tugs travel in or near areas considered to be important to SRKW, the potential noise reduction from a relatively modest shift in the routes of these vessels could be significant. This is shown in Figure 22 for the 15-100 kHz, SRKW echolocation masking band. The root-mean-square (rms) SPL increased significantly in the echolocation frequency band as the tugs transited closer to the SRKW critical habitat (Figure 22). For tug 1 the rms SPL reached a maximum of 102.5 dB re 1µPa during one of the passages prior to the trial. This is more than 12 dB higher than the highest observed values during the trial. Similarly, for tug 2, the maximum measured rms SPL before the trial was nearly 130 dB re 1µPa, while during the trial this was reduced to about 106 dB re 1µPa (a reduction of 24 dB). For tug 3 the reduction was approximately 10 dB. The converse was seen for tug 4, where there was actually an increase of about 10 dBs, resulting from this vessel travelling closer to the mooring during the trial.

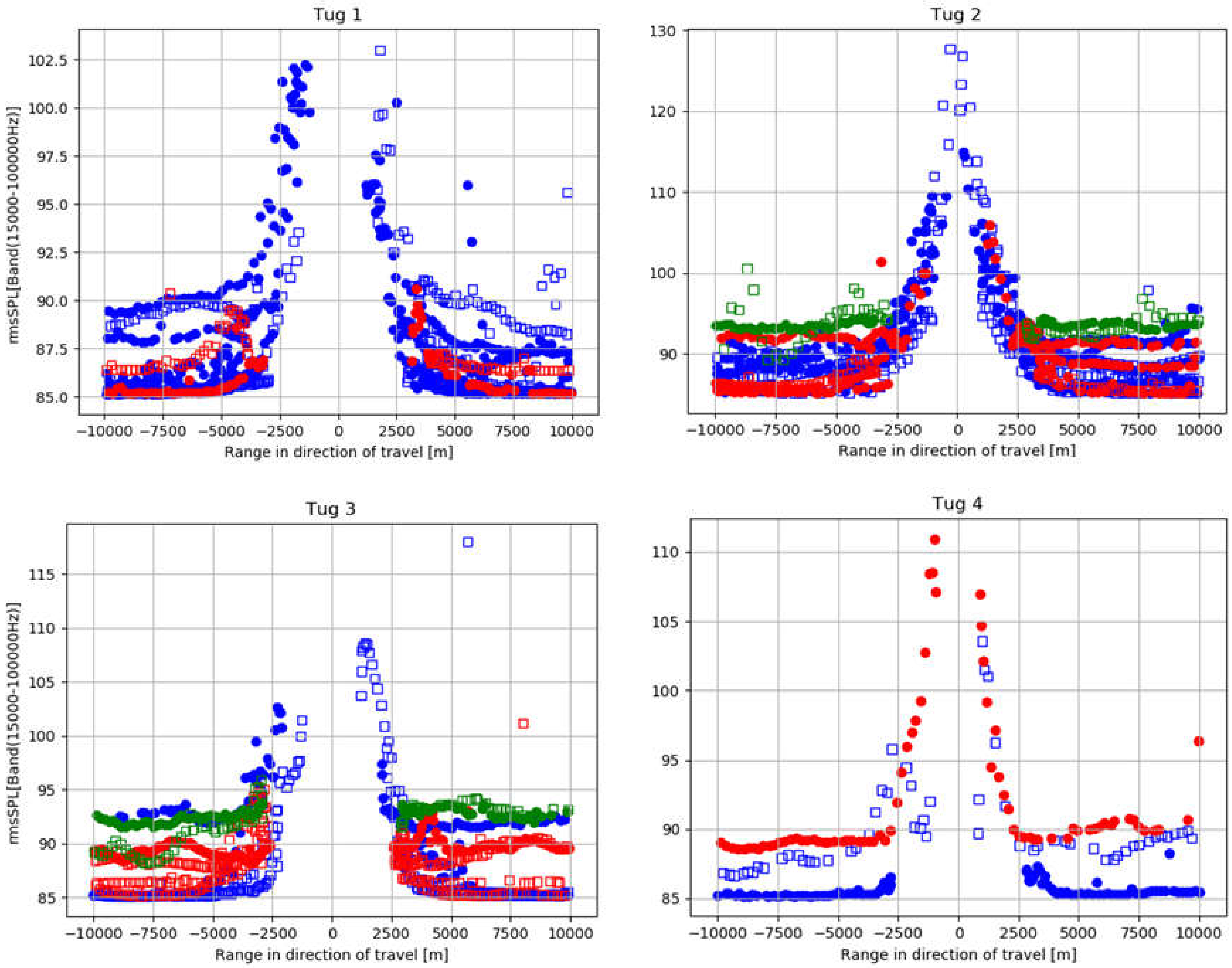

Figure 22. Rms SPL in the SRKW echolocation band (15-100 kHz) for different tracks of the four tugs considered in this analysis as functions of range from the Jordan River mooring. Data shown in blue are from pre-trial tracks, red are tracks during the lateral displacement trial, and green symbols show post-trial tracks, when available.

The impact on the received noise levels from these 4 tugs altering their travel routes was assessed by measures being fitted to the transmission loss model (equation 1, Section 3.4). To minimize the possible effect of flow noise from tidal currents, the results shown in Tables 6-9 only include vessels recorded on the Jordan River mooring from periods when the current speed was below 0.3 ms^{-1}; here defined as slack tide. For all tugs, except tug 4, all pre-trial trips were used to obtain SL0, while for tug 4 only one pre-trial trip was used. A N/A in the tables denotes when the tug was too far away to observe any acoustic effect at the mooring. This was common for measures of tug 1 and 3 made during the trial. Measures for both pre-trial and trial trips could be detected at the hydrophone site for tug 2, whereby the RLs in the measured noise field were reduced in the order of between 5.8 and 11.5 dB, depending on the frequency band being considered (Table 7, last column).

Table 6. Tug 1. Results of fitting data to the model in equation 1.

Band	**SL0 (dB re 1µPa)**	**α (dB/km)**	**Pre-Trial range (m)**	**Trial range (m)**	**Median Pre-Trial RL (dB re 1µPa)**	**Median Trial RL (dB re 1µPa)**	**Pre-Trial, Trial difference (dB)**
10-100,000Hz	190.9	0.00035	2831	3529	128.0	N/A	N/A
500-15,000Hz	184.5	0.0234	2831	3529	119.7	N/A	N/A
15,000-100,000Hz	167.5	6.737	2831	3529	101.4	N/A	N/A
10-100Hz	N/A	N/A	2831	3529	N/A	N/A	N/A
100-1000Hz	190.6	0.0031	2831	3529	120.1	N/A	N/A
1000-10,000Hz	181.2	0.106	2831	3529	118.2	N/A	N/A
10,000-100,000Hz	179.6	3.244	2831	3529	110.3	N/A	N/A

Table 7. Tug 2. Results of fitting data to the model in equation 1.

Band	**SL0 (dB re 1µPa)**	**α (dB/km)**	**Pre-Trial range (m)**	**Trial range (m)**	**Median Pre-Trial RL (dB re 1µPa)**	**Median Trial RL (dB re 1µPa)**	**Pre-Trial, Trial difference (dB)**
10-100,000Hz	189.7	0.00035	840	2596	131.1	124.1	-7.1
500-15,000Hz	179.1	0.0234	840	2596	120.4	113.4	-7.0
15,000-100,000Hz	167.4	6.737	840	2596	106.7	N/A	N/A
10-100Hz	183.1	0.00034	840	2596	128.9	120.4	-8.5
100-1000Hz	187.9	0.0031	840	2596	127.9	122.1	-5.8
1000-10,000Hz	177.8	0.106	840	2596	118.8	111.5	-7.3
10,000-100,000Hz	175.1	3.244	840	2596	115.2	103.7	-11.5

Table 8. Tug 3. Results of fitting data to the model in equation 1.

Band	**SL0 (dB re 1µPa)**	**α (dB/km)**	**Pre-Trial range (m)**	**Trial range (m)**	**Median Pre-Trial RL (dB re 1µPa)**	**Median Trial RL (dB re 1µPa)**	**Pre-Trial, Trial difference (dB)**
10-100,000Hz	193.2	0.00035	2124	2772	126.2	N/A	N/A
500-15,000Hz	185.4	0.0234	2124	2772	119.9	N/A	N/A
15,000-100,000Hz	171.8	6.737	2124	2772	105.0	N/A	N/A
10-100Hz	186.8	0.00034	2124	2772	122.8	N/A	N/A
100-1000Hz	190.6	0.0031	2124	2772	125.9	N/A	N/A
1000-10,000Hz	181.9	0.106	2124	2772	116.7	N/A	N/A
10,000-100,000Hz	186.3	3.244	2124	2772	114.5	N/A	N/A

Table 9. Tug 4. Table, Tug 4, one of the trial tracks was used to get median SL0, all the other ones the pre-trial runs were used.

Band	**SL0 (dB re 1μPa)**	**α (dB/km)**	**Pre-Trial range (m)**	**Trial range (m)**	**Median Pre-Trial RL (dB re 1μPa)**	**Median Trial RL (dB re 1μPa)**	**Pre-Trial, Trial difference (dB)**
10-100,000Hz	190.4	0.00035	1613	911	N/A	127.1	N/A
500-15,000Hz	176.0	0.0234	1613	911	N/A	116.9	N/A
15,000-100,000Hz	167.7	6.737	1613	911	N/A	105.7	N/A
10-100Hz	188.8	0.00034	1613	911	N/A	125.1	N/A
100-1000Hz	181.7	0.0031	1613	911	N/A	122.2	N/A
1000-10,000Hz	174.8	0.106	1613	911	N/A	115.5	N/A
10,000-100,000Hz	180.4	3.244	1613	911	N/A	110.6	N/A

The effect on received noise levels by these tugs transiting further from the mooring location was then tested in the SRKW frequency bands, to simulate the potential noise reductions that might result from moving vessels away from the SRKW critical habitat in the Strait of Juan de Fuca, again using the simple transmission loss model in equation 1. The results are illustrated in Figure 23.

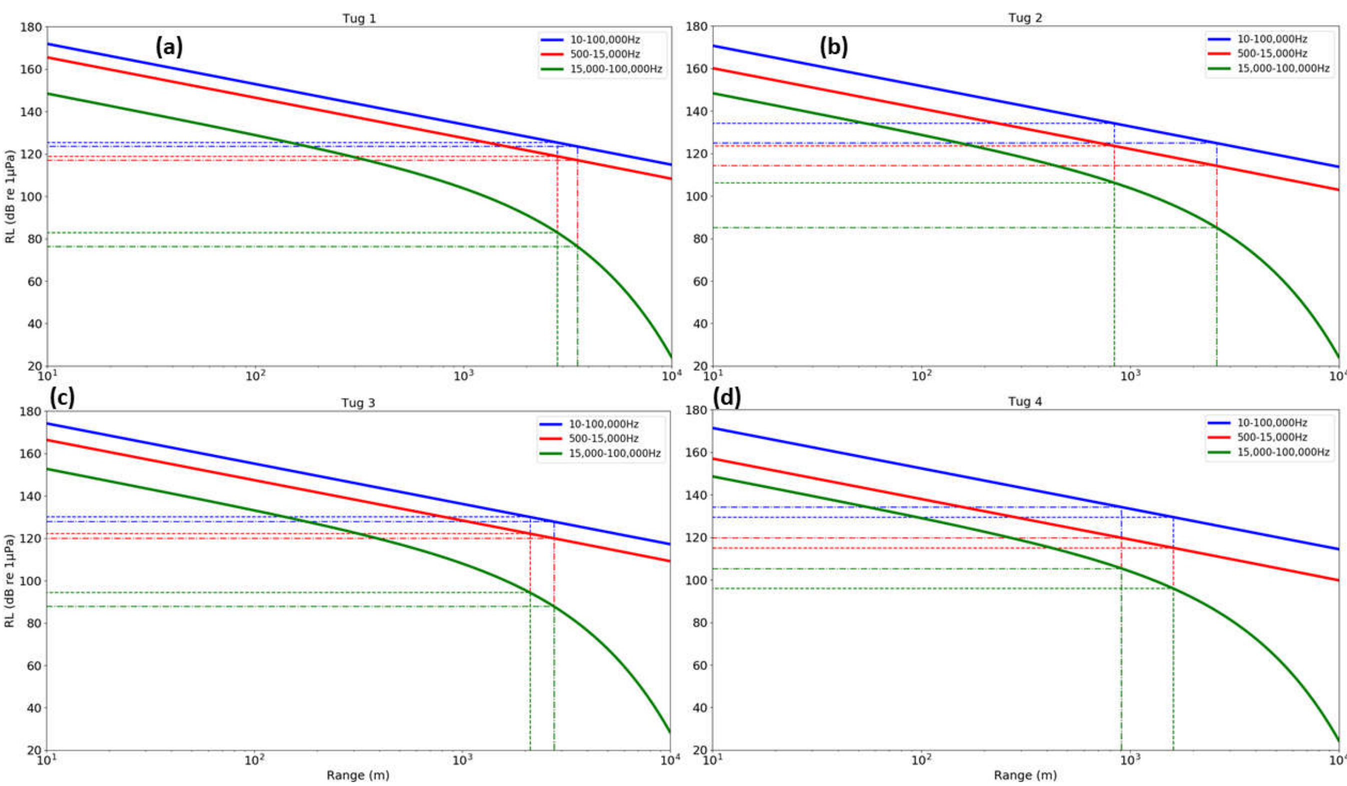

Figure 23. Modeled effect of shifting vessel tracks away from critical habitats for the three SRKW bands for the 4 tugs discussed in this report. The horizontal lines are the corresponding RL at the ranges given by the vertical lines. Solid lines are for the ranges and RL prior to the trial, while the dashed lines are for the ranges observed during the trial period.

4.1.2.1 The impact on noise levels by slowing down a tug

By chance, when analysing the tug vessel tracks and corresponding noise level measurements we noted a tug slowing down very close to when it passed over the Jordan River hydrophone mooring (Figure 24). This tug slowed down from an average speed of 8 knots to a speed of approximately 6.6 knots. As a result of this speed reduction the noise levels received from the vessel beyond a distance of approximately 4 km was reduced by 2 dB in the SRKW echo-location masking band (15-100 kHz) (blue lines in Figure 24). This corresponds nicely to the results by Veirs et al. (2016) who found a speed related noise reduction of approximately 1 dB per knot.

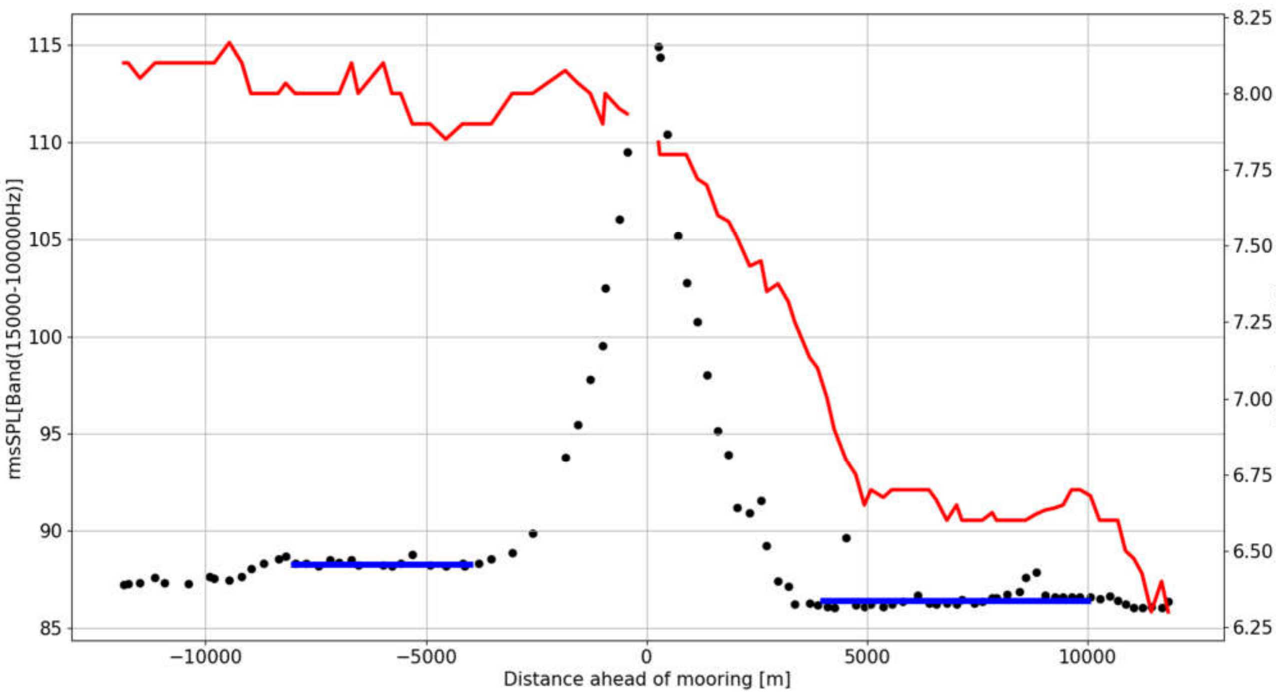

Figure 24. Rms SPL in dB re 1µPa in the SRKW echolocation band (15-100 kHz) for a tug passing over the Jordan River mooring and slowing down (red line).

4.2 Interim Sanctuary Zone Assessment

4.2.1 The vessels within the Swiftsure Bank ISZ

Using both the Class A and Class B AIS data, vessel transits were tracked within the Swiftsure Bank ISZ (Figure 4a) as a function of time. The number of hours a day each vessel type was present was calculated. It is worth noting that it is likely this analysis is missing a number of vessels operating in the area because these vessels were not equipped with AIS transmitters. However, without any other means of tracking vessels, this is considered to be the best available at this time.

Figure 25 shows the number of hours per day that fishing vessels, tugs, vessels in the ‘Deep Sea’ (Class A classes 1,2,7,9,11) and ‘Other’ (classes 3,4,5,6,8,12,13 from Class A) categories and Class B were present within the sanctuary zone at Swiftsure Bank. The results were aggregated for every 2 days from April 1 to the end of November 2019.

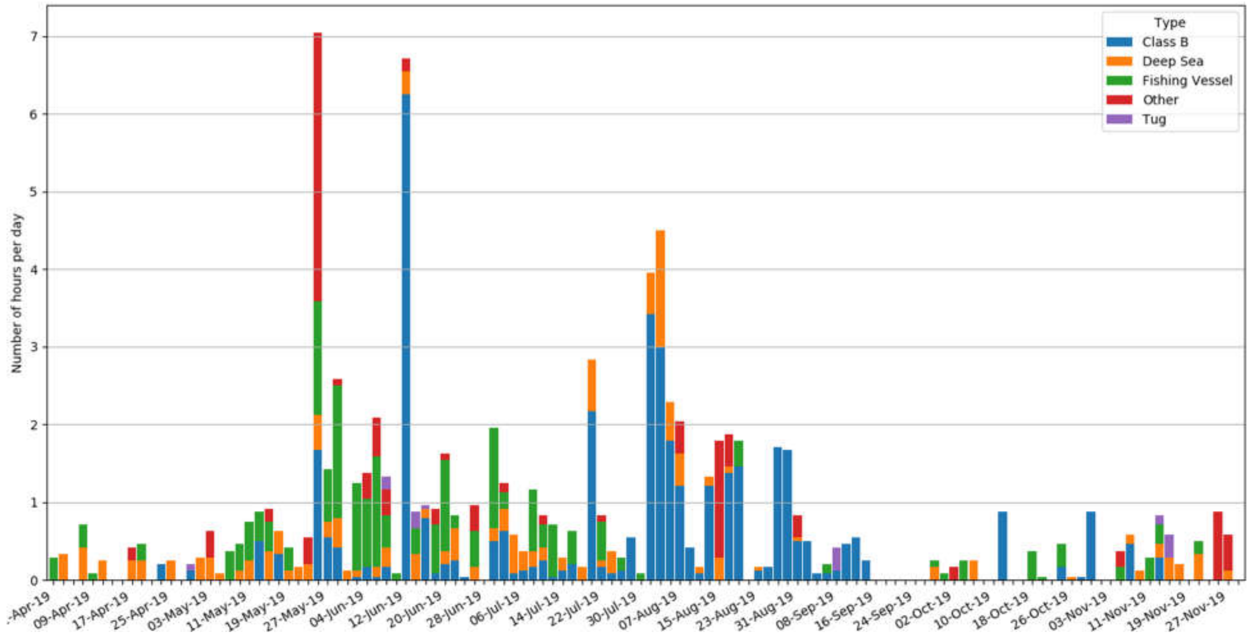

Figure 25: Hourly presence of the different vessel classes defined in the legend as observed to be within the Swiftsure Bank ISZ.

4.2.2 The vessels in Swanson Channel (North Pender Island)

The same analysis as described in the section above was performed on the AIS equipped vessels within the Swanson Channel ISZ (Figure 4b).

Figure 26 shows the number of hours per day that vessels within the different classes were present within the sanctuary zone in Swanson Channel. Again, these results were then aggregated for every 2 days from April 1 to the end of November 2019.

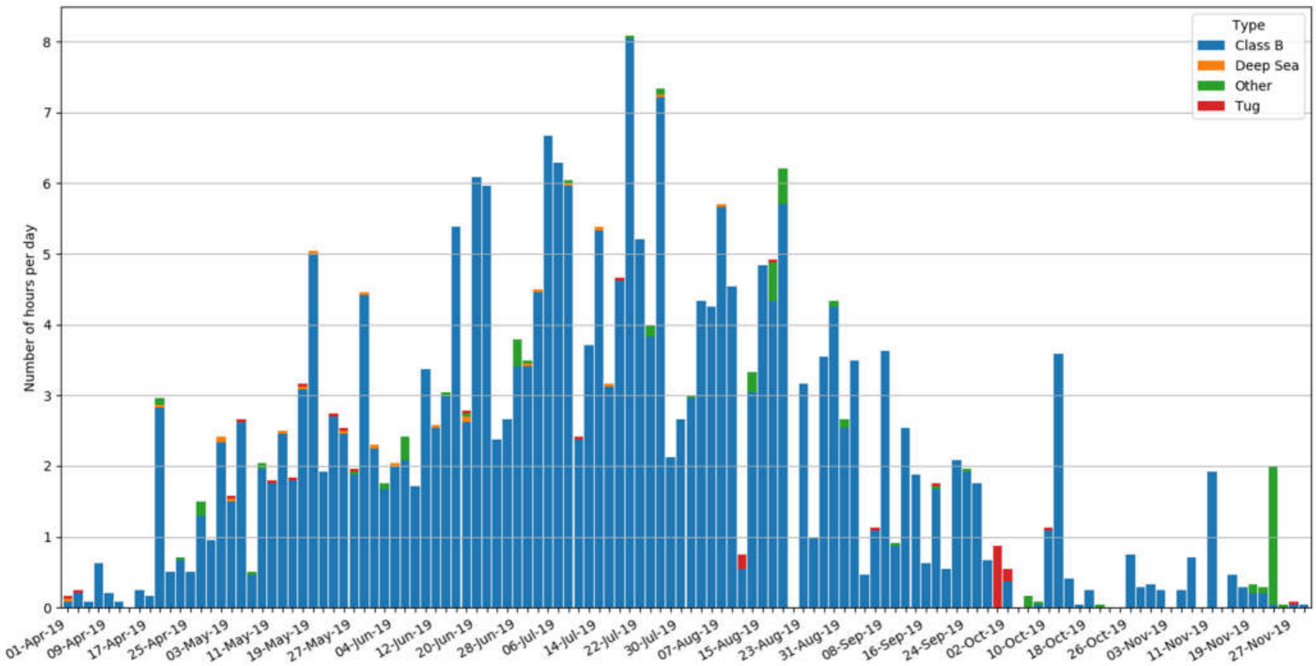

Figure 26. Hourly presence of the different vessel classes defined in the legend as observed to be within the Swanson Channel ISZ.

4.3 Noise levels in the Swiftsure Bank and Swanson Channel ISZs

To evaluate the effects on the noise levels at frequencies relevant to SRKW in the two sanctuary zones, we compared the SPL in seven different bands: 10-100,000 Hz (behavioral modification), 500-15,000 Hz, (vocalization) 15,000-100,000 Hz (echolocation), as well as frequency ranges 10-100 Hz, 100-1000 Hz, 1000-10,000 Hz and 10,000-100,000 Hz. The levels were compared for the pre-sanctuary zone period (April 1 – June 1, 2019) with all available data from the sanctuary zone period (June 1 – October 31), as well as recordings made after the exclusions on these zones were lifted (November 1 – November 30, 2019). This full pre-, during, and post trial was possible for the mooring data recorded at Swiftsure Bank. However, it is worth noting that our hydrophone mooring on Swiftsure Bank was actually located south of the sanctuary zone; in the outbound shipping lane. A hydrophone mooring has been deployed in this location since April 2018, which also allowed for comparison with the same seasonal periods from the year before the 2019 trial. The mooring in Swanson Channel was not deployed until the middle of August 2019, so no data were available for the period before the sanctuary zone was put in place. Only a comparison of sound levels following the ISZ was imposed was possible at this site.

All available noise data are included in the results presented below.

4.3.1 Underwater noise levels at Swiftsure Bank

At the Swiftsure Bank location all relevant metrics, in all frequency bands, indicated reduced underwater noise levels (~2dB reduction in band averaged SPL) during the summer and fall ISZ timeframe, except in the large-vessel-dominated 100-1000 Hz band (Figure 27). Consistent with the results from the lateral displacement trial, the results are presented here in box plots which have the solid horizontal lines in the middle of the boxes representing the median (L50) values with the boxes otherwise defined by the 25th percentiles, L25, and 75th percentiles, L75, respectively. 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.

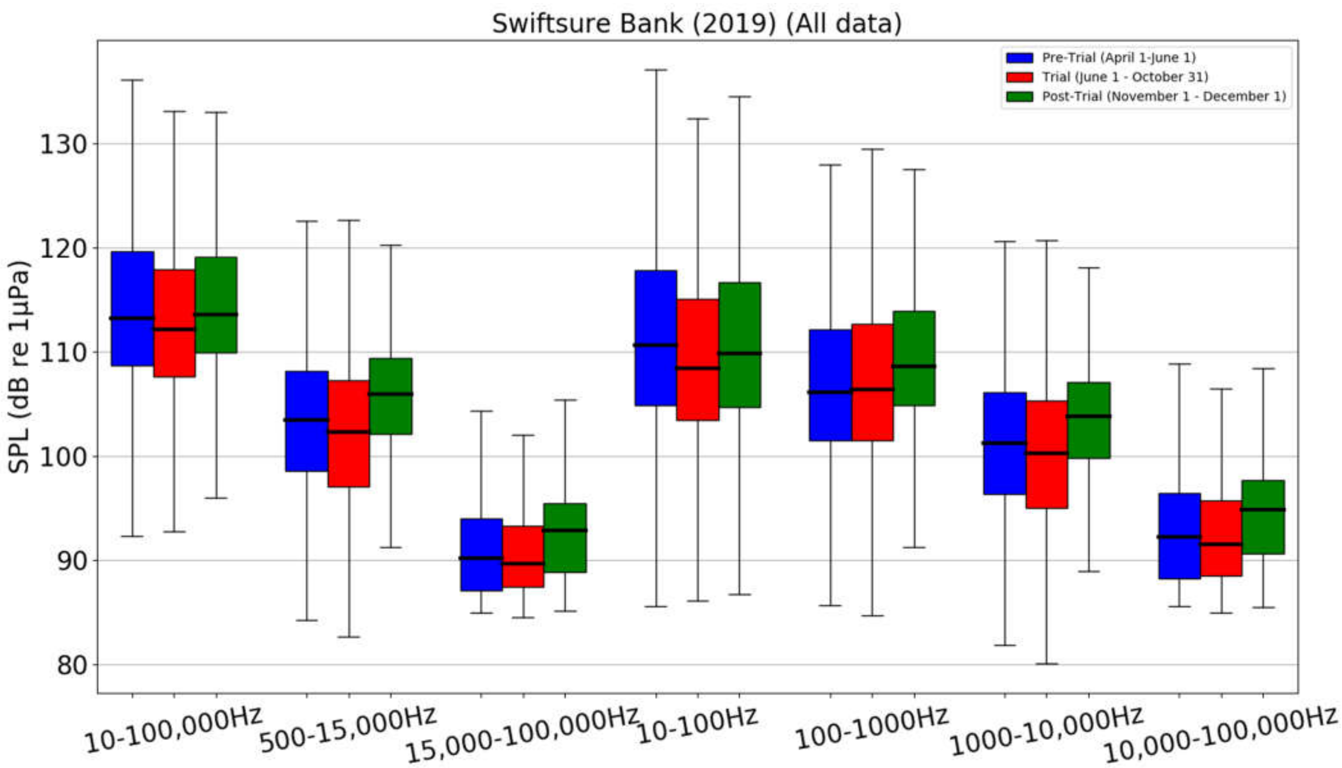

Figure 27. Swiftsure Bank SPL boxplots for seven frequency bands for the pre-trial period (blue boxes), the trial period (red boxes) and for the post-trial period (green boxes).

These data were further separated into lunar month metrics to investigate seasonal trends, as shown in Figure 28, and then compared to the same periods in 2018 (Figure 29). No daily or weekly coherent variability was found from analysis of the Swiftsure Bank underwater noise data (not shown).

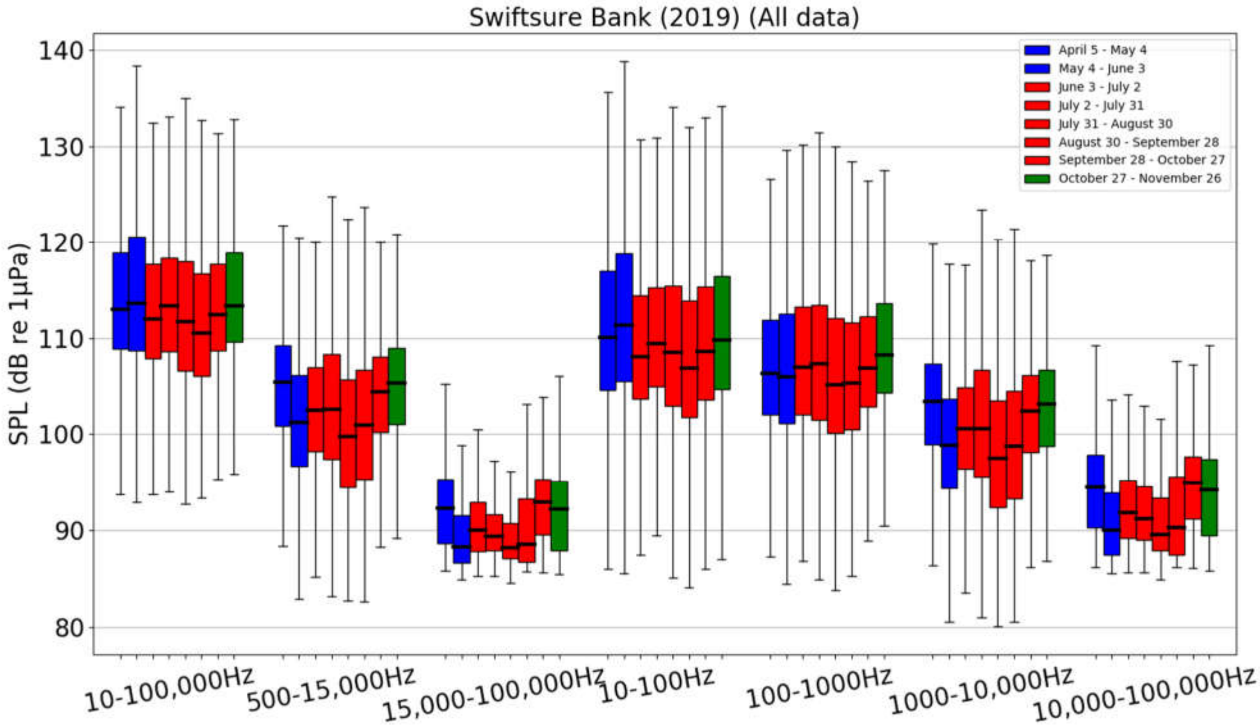

Figure 28. Swiftsure Bank SPL boxplots for seven frequency bands for lunar months covering the period from April 5 to November 26, 2019. The blue boxes are lunar months prior to the trial, the red boxes are lunar months during the trial and the green boxes represent the month after the trial period. Order is from left to right in accordance with the top to bottom listing in the legend.

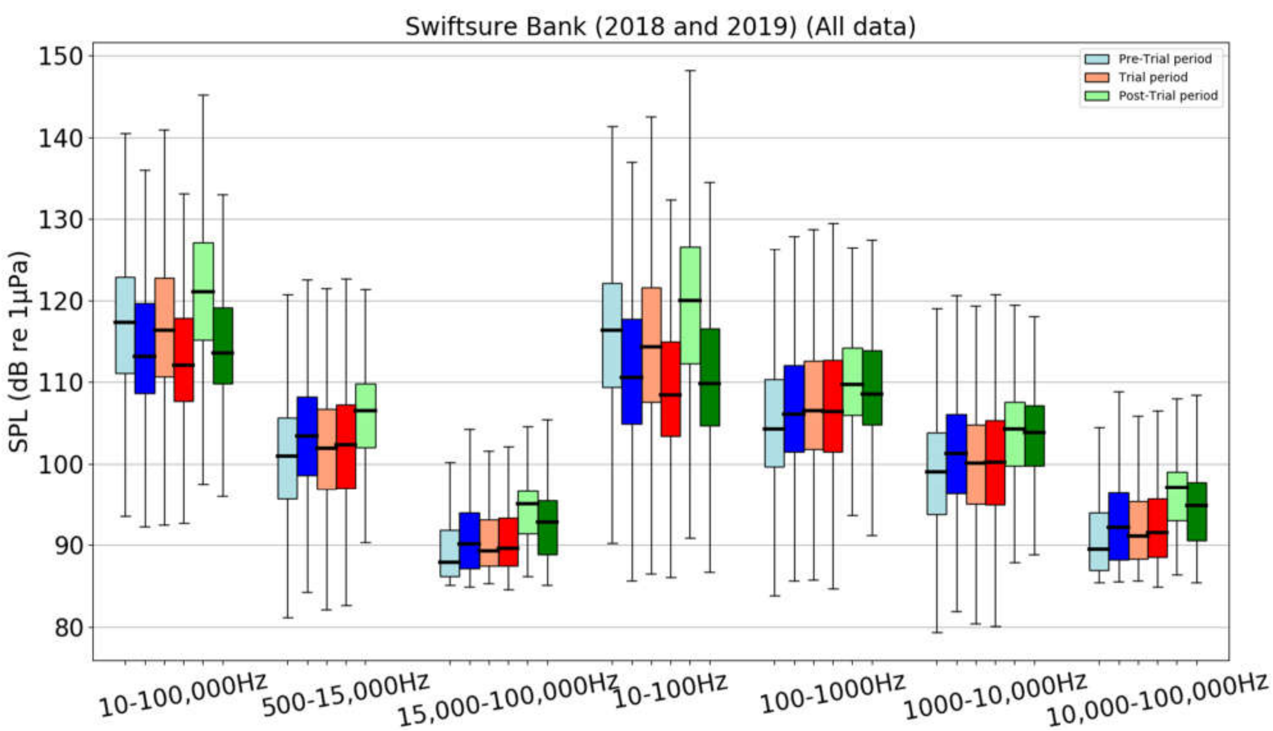

Figure 29. Swiftsure Bank SPL boxplots for seven frequency bands from the pre-trial, trial, and post-trial sanctuary zone periods in 2019 (dark blue, dark red and dark green boxes, respectively) compared with similar observations from the same 2018 period, when there was no sanctuary zone (Vagle and Neves, 2019) (light colored boxes).

The daily SPL levels, calculated at L5, L50 and L95, were compared for the three SRKW relevant frequency bands and compared for the trial periods of both 2018 and 2019 on Swiftsure Bank. There was a high level of congruence in these values between the trial years (Figure 30).

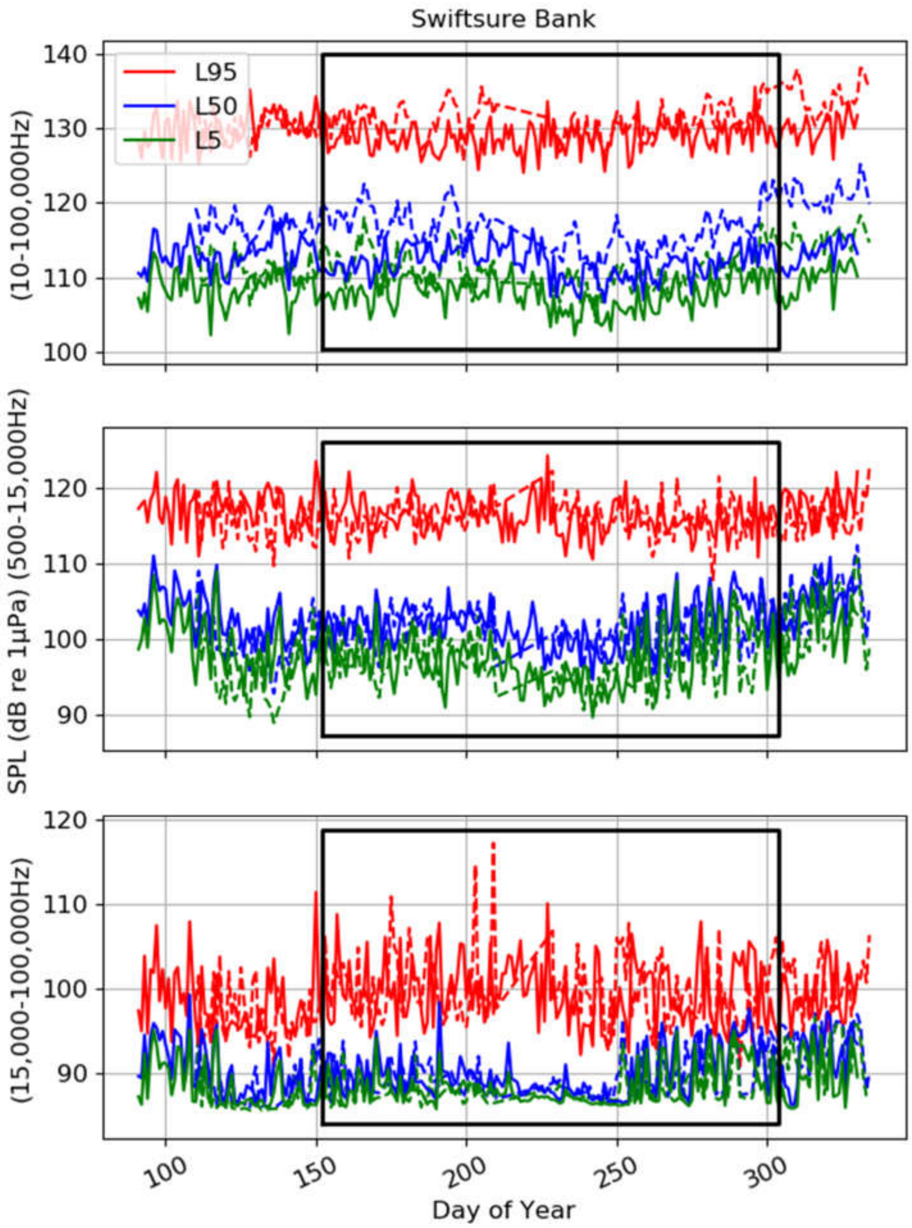

Figure 30. Three percentiles calculated on a daily basis for 2019 (solid lines) and 2018 (dashed lines) from the Swiftsure Bank data sets at the three SRKW relevant SPL bands. The red lines are the 95th percentiles (L95), the blue lines are the median values (L50) and the green lines are the 5th percentiles (L5). The sanctuary zone period is identified by the black box.

4.3.2 Underwater noise levels in Swanson Channel ISZ

The noise levels in the Swanson Channel location, within the sanctuary zone, in all frequency bands and for the relevant metrics, showed very limited differences between the trial period and the month following (Figure 31). It is worth noting here that the data set only starts on August 16, 2019, two and a half months into the trial period.

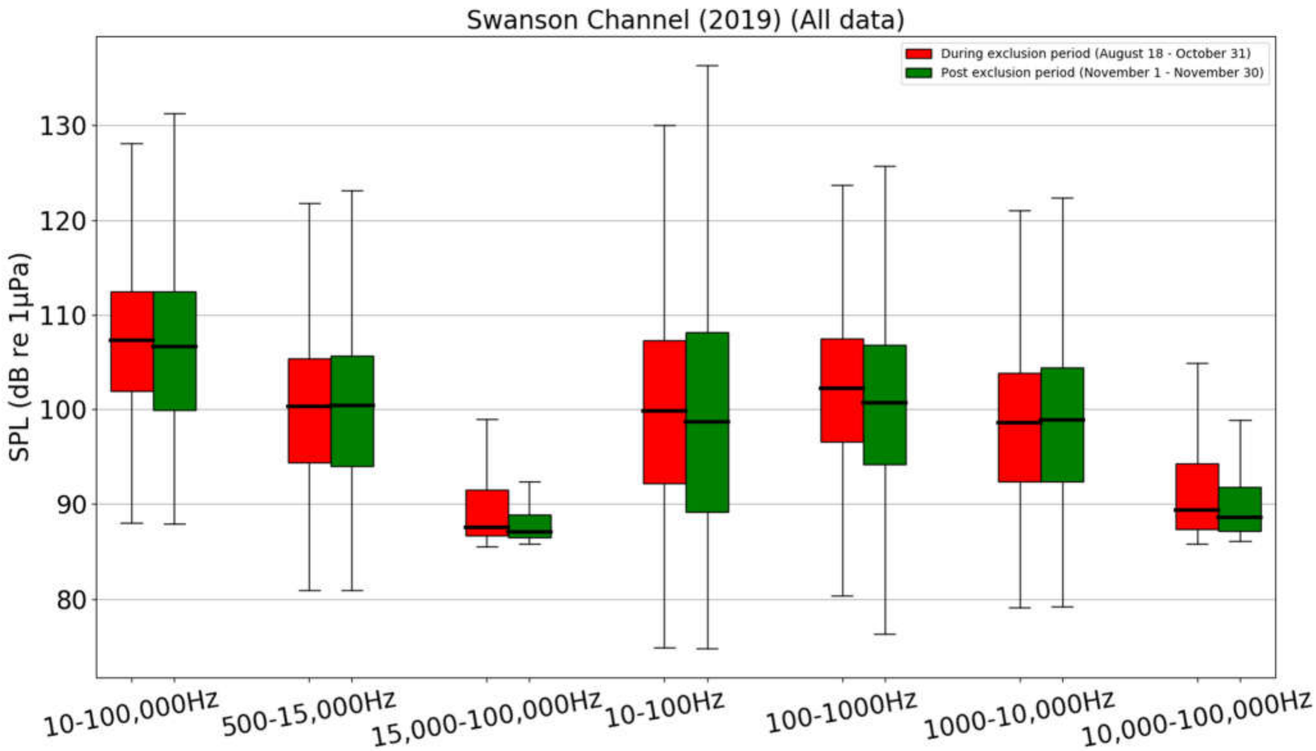

Figure 31. Swanson Channel SPL boxplots for seven frequency bands for periods covering some of the sanctuary zone period (August 18-October 31, red) and the month after the trial was over (green boxes).

Again, the available data were further split into lunar monthly data sets, to look for trends in the noise metrics (Figure 32). These results again did not show any significant trends in the observed noise levels at this location when using these metrics.

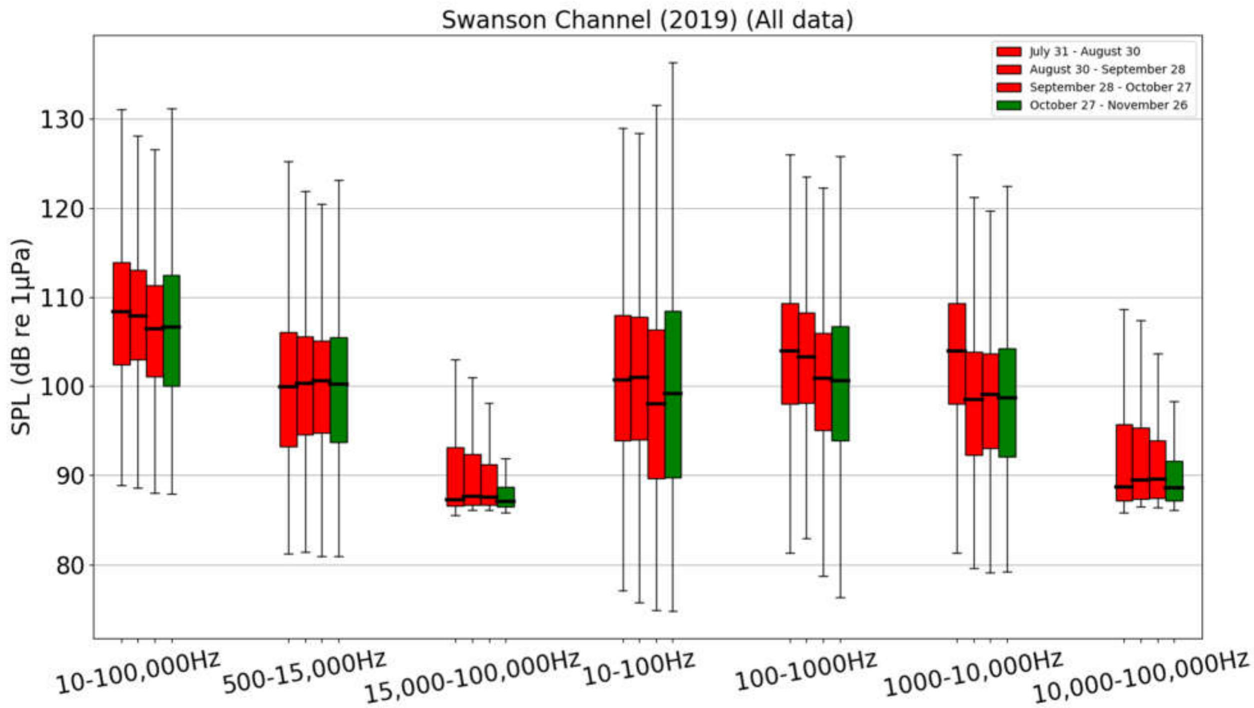

Figure 32. Swanson Channel SPL boxplots for seven frequency bands for lunar months in summer and fall of 2019. Red boxes represent the trial period, while the green box is the month after the trial was over.

4.3.2.1 Daily and weekly patterns in underwater noise metrics in Swanson Channel

Rhythm plots were used to examine the data for patterns, especially those associated with vessel activity in the sanctuary zone.

No weekly variability, indicating days that were more or less noisy than other days, was found in the Swanson Channel data set from the middle of August to the end of November 2019.

However, the daily rhythm data showed significant hour to hour variability, especially in the higher frequency bands (Figures 33-35). The broad-band (10-100,000 Hz), SRKW disturbance band, SPL showed elevated noise levels between 09:00 and 15:00 (DST) in August, and to a lesser degree in September (Figure 33). A similar pattern was seen in the data from the SRKW communication masking band (500-15,000 Hz) (Figure 34); again, predominantly in August and September with peak levels around 11:00 in the morning. For the SRKW echo-location masking band (15-100 kHz) this diel pattern was very obvious in the data (Figure 35) for all four lunar months. There was very little noise in this band between 19:00 and 06:00 in all the months. Also, between 06:00 and 19:00 the SPL are highest in August and dropping significantly month to month, with minimal noise in November. This may be representative of vessels in Class B, and recreational boating traffic in this area.

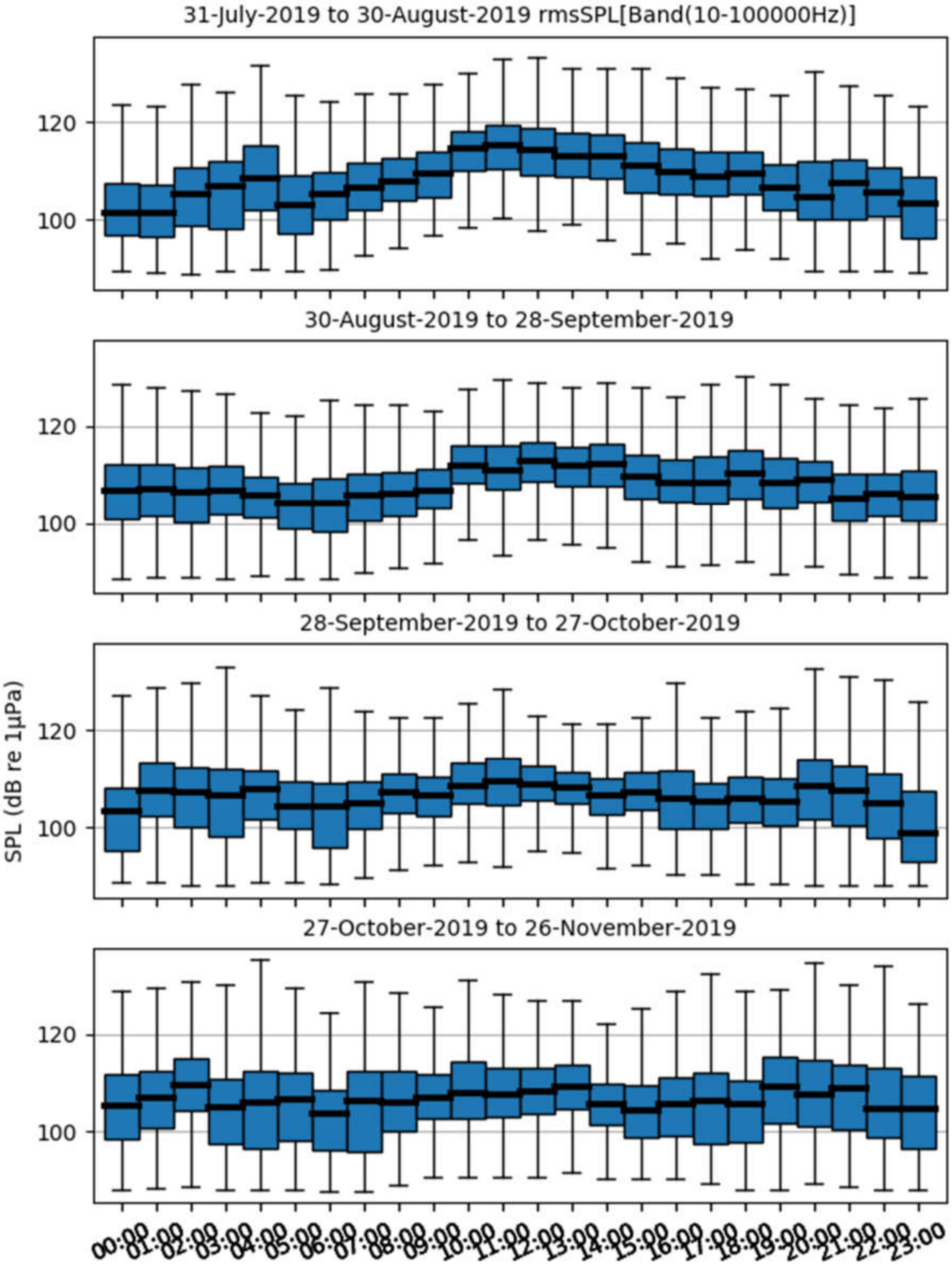

Figure 33. Daily rhythm plots for the four lunar months when data are available from the Swanson Channel sanctuary zone for the SRKW disturbance band (10-100,000 Hz). (Daily savings time (UTC-7 hours).

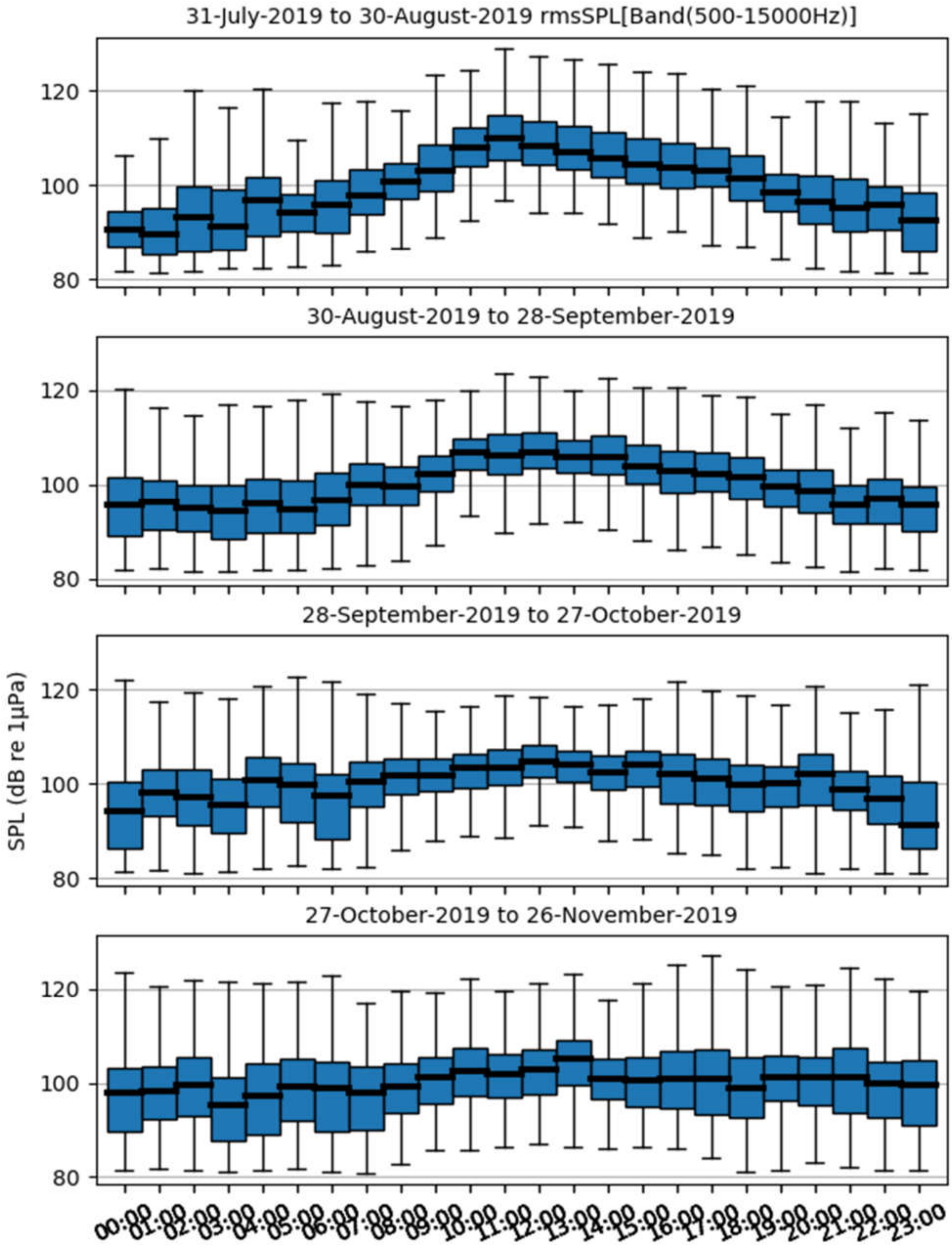

Figure 34. Daily rhythm plots for the four lunar months when data are available from the Swanson Channel sanctuary zone for the SRKW communication masking band (500-15,000 Hz). (Daily savings time (UTC-7 hours)).

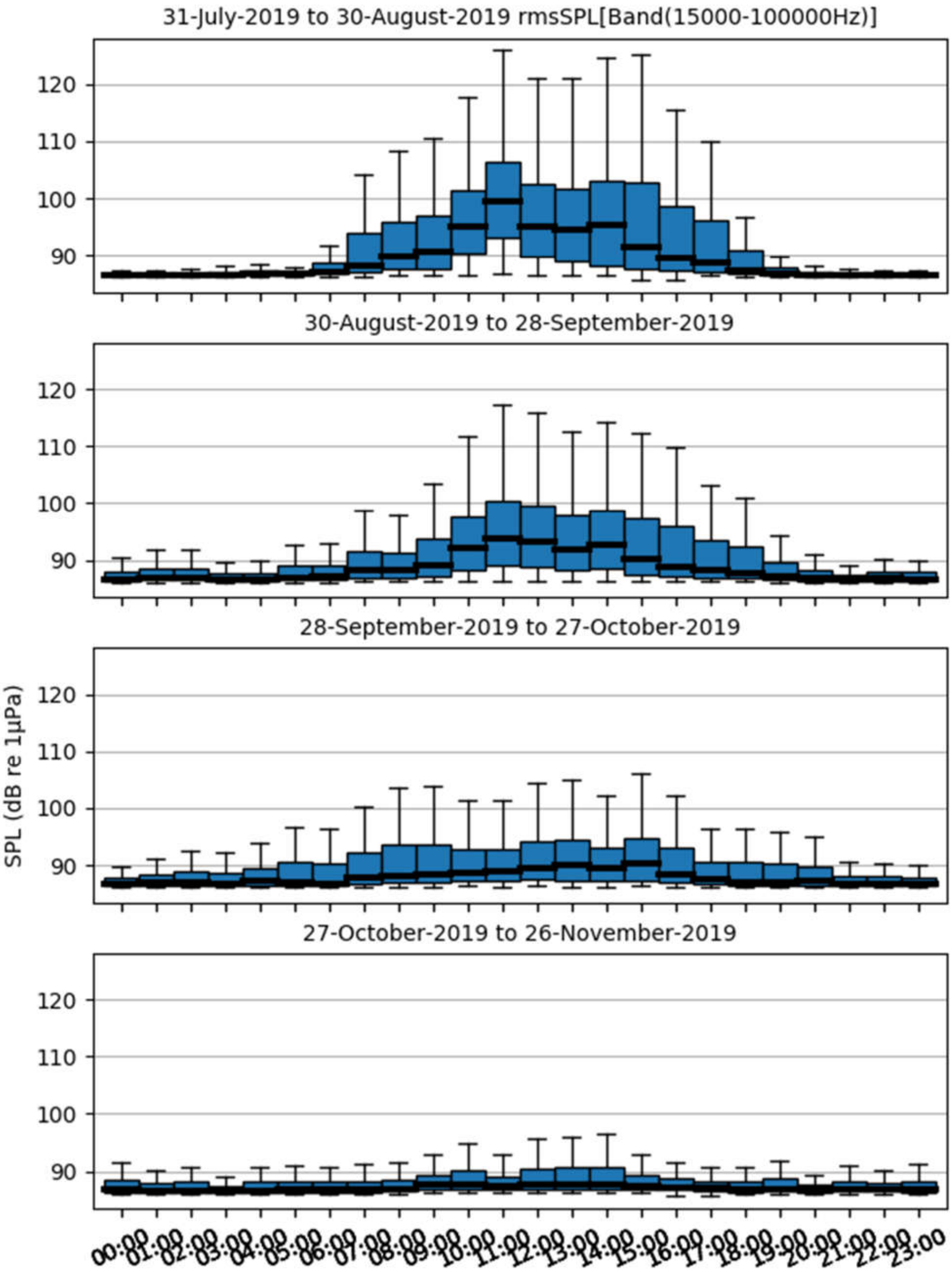

Figure 35. Daily rhythm plots for the four lunar months when data are available from the Swanson Channel sanctuary zone for the SRKW echo-location masking band (15,000-100,000 Hz). (Daily savings time (UTC-7 hours)).

The L5, L50 and L95 values of the SPL of the SRKW relevant frequency bands were compared on a daily basis for the period of the trial that the recorder was deployed, and for a period after the trail (Figure 36). No significant differences in noise levels were evident.

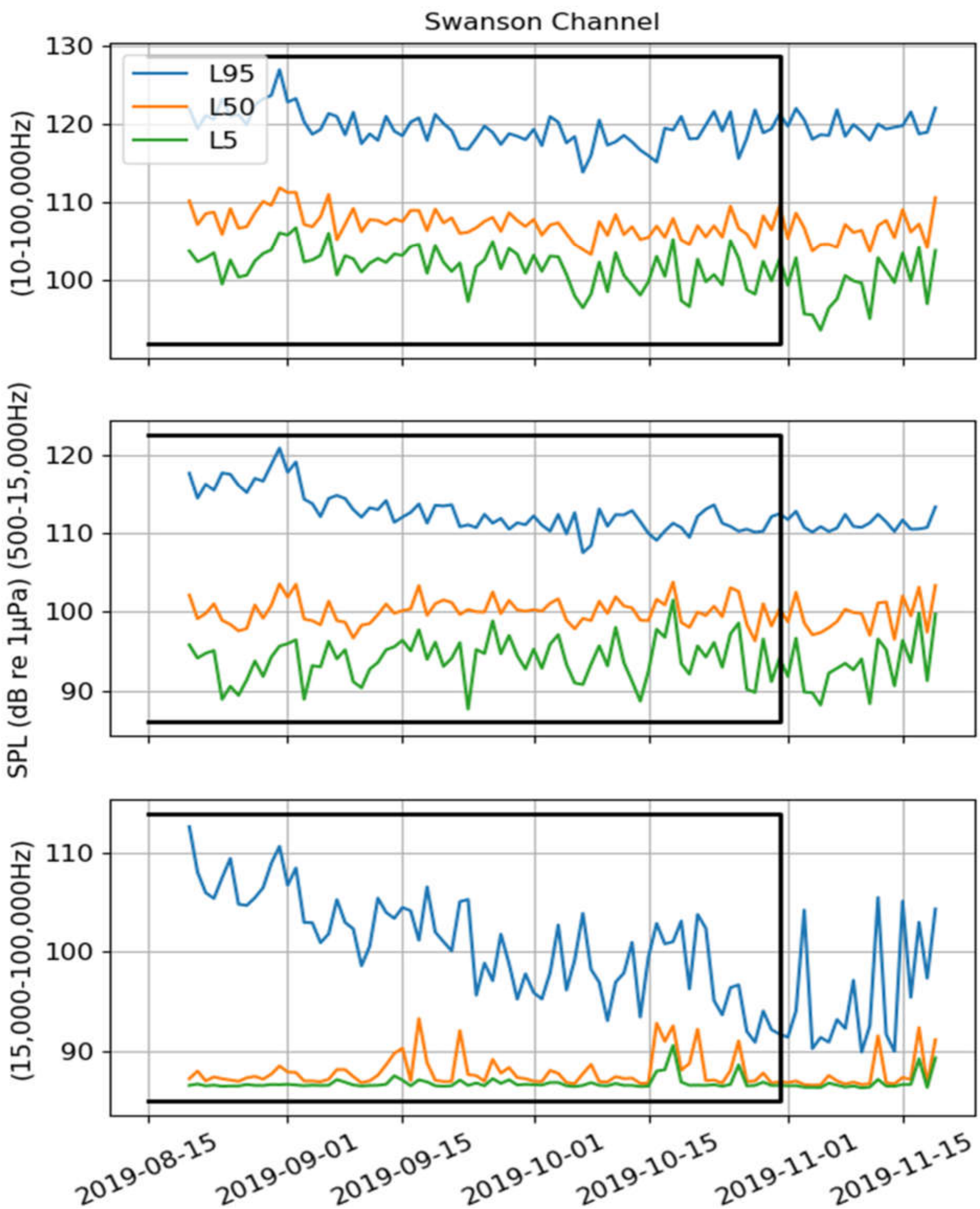

Figure 36. Three percentiles calculated on a daily basis for 2019 collected in the Swanson Channel ISZ at the three SRKW relevant SPL bands. The blue lines are the 95th percentiles (L95), the red lines are the median values (L50) and the green lines are the 5th percentiles (L5). The ISZ period is identified by the black box.

5 DISCUSSION AND CONCLUSIONS

The two different mitigation approaches evaluated in this study, lateral displacement and intermediate sanctuary zones (ISZs) were both implemented with the aim of reducing the noise impact on SRKW and other marine mammals and fishes in areas of importance to them. These measures were trialed under the assumption that moving anthropogenic noise sources away from, or out of, these areas would have a noticeable effect on the resulting ambient noise levels. The results presented in this report indicate that there were only modest reductions to the overall soundscape metrics in the areas considered. However, the results also showed significant local SPL decreases associated with individual vessel movements were possible. This suggests that, with a higher vessel participation rate, especially with regards to the ISZs, these techniques show promise as means to reduce noise levels in critical areas.

5.1 The lateral displacement trial in the Strait of Juan de Fuca, 2019

The voluntary lateral displacement trial in 2019 only requested that tugs altered their travel to stay further away from areas considered to be important feeding areas for SRKW in the Strait of Juan de Fuca. Our results showed that most tugs travelling in the Strait of Juan de Fuca travelled far away from the measurement site near Jordan River, southern Vancouver Island (mean distance of 14 km). Therefore, most of these tugs did not contribute significantly to the measured soundscape. Only between 2 and 9% of the vessels nearest the mooring at any given time were tugs, and only a small number of these traveled within ~4-5 km from the mooring and so overall contributed little to the noise levels recorded. However, individual vessels that had a close approach to the mooring site contributed much more to the measured noise metrics. Alteration of the transit route of these vessels contributed significantly to a reduction in received noise levels.

Vessel transits in the Strait of Juan de Fuca are predominantly deep-sea and other large cargo vessels. However, the displacement of tug vessels, which account for less than 10% of the overall transits in this area, lowered the SPL between 0.5 and 3.6 dB during the lateral displacement trial compared to the recording period directly prior (Table 3). This is presumed to be a result of moving the transits of tugs further south, but perhaps are also enhanced by a factor not considered in this analysis. The ability for deep-sea vessels to alter course is much reduced compared to tugs, with an average displacement of approximately 600m away from the SRKW feeding areas seen from the 2018 lateral displacement trial (Vagle and Neves, 2019).

The monthly results shown in Figure 12, suggest there was a general decrease in the SPL metrics throughout the trial period. Without getting into a significant acoustical modelling exercise, which is beyond the scope of this report, it is difficult to determine why this is so. However, the vessel composition and density shown in Figure 7 suggest that perhaps the overall number of deep-sea vessels passing the hydrophone mooring dropped somewhat throughout the summer months. To tease out more about changes in the distribution of vessels passing the mooring, we calculated lunar monthly box plots for the number of deep-sea vessels and number of tugs per hour, and the minimum deep-sea vessel-mooring distances and minimum tug-mooring distances in km (Figure 10). For the tugs, these results show insignificant month to month variability. However, for the deep-sea vessels, these results suggested that during the period from July to the end of September the number of vessels per hour dropped slightly while the minimum distance increased by several km. Decreasing numbers and increasing distances would both lead to reduced measured noise levels at the mooring location. It is therefore likely that both deep-sea vessel pattern and tug displacements influenced the observed noise level decreases. These trends would have been hard to discern in the 2018 trial as the measures were put into place much later in the summer. Voluntary actions were initiated in August, rather than in June as it was in 2019. If this same trend of declining vessel presence as the summer progresses had been present in 2018, it may have suggested that pre-trial level vessel passage levels would have been reduced compared to what they might be in late spring-early summer, which were the time periods used in the pre-trial comparison for 2019.

An important finding from the lateral displacement was observed when individual tugs shifted their routes further away from the areas important to SRKW. The results showed that a given tug can decrease its acoustic impact on a given area by between 6 and 11 dB, depending on the frequency band being considered. We showed, by investigating the transits of 4 tugs in more detail, that by moving their routes to more than 3 km away from any area of concern, their contributions to most bands become negligible (Figures 22, 23).The results also indicated significant decreases in noise levels by tugs reducing their speed in these areas (~1dB/knot).

5.2 The ISZ at Swiftsure Bank, 2019

Even though the hydrophone mooring on Swiftsure Bank was south of the sanctuary zone, the results show modest decreases in SPL (<2 dB) in most frequency bands during the period the sanctuary zone was in effect (June 1 – October 31, 2019) (Figure 25). However, there was significant month to month variability in the measured SPL (Figure 27, 28). Also, the 100-1000 Hz band, which is normally dominated by deep-sea vessels travelling through the area, did not show a reduction in SPL when considered for the whole trial period. In the monthly comparison, noise levels were reduced in the later summer during August and September. However, this observed SPL reduction in the summer months may be attributed to the general reduction in vessel movements during this period seen in the AIS data, rather than an avoidance of use of these areas. It is also worth noting that a similar pattern in SPL levels was observed at the Swiftsure Bank mooring during the same period in 2018, when no sanctuary zone was in place on the bank, presumable resulting purely from the changes in vessel transit numbers.

Merchant et al. (2016) suggested in their soundscape characterisation work that at least three decades of continuous monitoring would be required to detect significant trends in mean rms noise levels before true trends could be distinguished. This is because these metrics used to quantify the ambient noise levels, especially when averaged, can be highly skewed by outliers in the recordings. They concluded that percentiles should be used instead, which is in line with the methods used in this report. The findings from Merchant et al. (2016), also suggest that the conclusions drawn here from 2018 and 2019 recordings made at Swiftsure Bank are limited in scope and in their ability to detect real change resulting directly from the mitigation measures trialed. No significant differences between pre- and post- sanctuary zone periods and the sanctuary period itself, were found for Swiftsure Bank. However, it is interesting that the two years of ISZ trials track each other really well, with L50 and L5 being lower in the late spring and summer months. This could suggest that these measures may have same effect in decreasing vessel noise in this critical foraging area.

It is difficult to fully evaluate the success of the sanctuary zone because a number of smaller vessels, expected to travel through this area do not carry AIS transmitters. However, by using both Class A and B AIS data, a more comprehensive picture of the use of the sanctuary zone throughout the period from April 1 to November 30, 2019 is possible. It is a highly transited area, with the daily AIS reports suggesting that up to almost 25% of a day could have vessel presence. There was little change in the distribution of vessels within the sanctuary zone during the trial period shown in the AIS data. The only notable difference was that AIS equipped fishing vessels were absent from the ISZ after August 1 2019. It is unlikely that the reduced SPLs observed in this analysis were related to the distribution of vessels within the ISZ at Swiftsure Bank. More likely, they were a product of overall reduced transit number. Further applications of vessel exclusion, and a better means to evaluate the presence of vessels not yet accounted for in the AIS analysis may help determine more conclusively whether a whale sanctuary in this area is an effective means to reduce the acoustic disturbance of SRKW in this area.

5.3 The ISZ in Swanson Channel, 2019

Unfortunately, due to logistical constraints, it was not possible to collect underwater noise data in the Swanson Channel ISZ prior to the introduction of this zone and the first 10 weeks of the zone being active. The comparison of SPL values for the trial period where recordings were possible, and the post-trial period, did not show significant reductions as a result of the introduced measures. As with the analysis completed on Swiftsure Bank, there are many vessels using this area that are not accounted for in the interpretation of the AIS data in complement to the acoustic data. A significant proportion of the vessels in and around the ISZ do not have AIS transmitters, so the overall number of vessels in the area is uncertain and definitely under-reported. Nevertheless, by using the available Class A and B AIS data it is clear that this area is dominated by Class B, mostly pleasure and small fishing vessel These vessels likely contributed highly to the diurnal patterning that was found in the soundscape.

There was a steady increase in the number of hours per day when vessels were present in the ISZ, from close to 0 in the beginning of April to more than 8 in late July, followed by a gradual decrease to the middle of October. From these data it is difficult to find any actual reduction in the use of the ISZ during the period when it was active that would have been a result of the imposed exclusion. The soundscape in this area has contributors from both smaller and larger vessels and SPLs in the lower frequency bands are dominated by more distant shipping. However, in the higher frequency bands the L95 curves do suggest a decreasing trend over the period when the ISZ was active. This is most clearly apparent in the 15-100 kHz (SRKW echolocation band) band where there was a more than 10 dB drop between August 15 and November 1, 2019. These data suggest that there was improvement to the soundscape in the ISZ during the trial period, which may be as a result of a higher proportion of smaller vessels staying out of the zone and thereby reducing the highest pressure-levels in this area. This translates into a marked reduction in noise in the frequency band deemed important for SRKW echolocation. Disruption in the sending and receiving of these signals could reduce the efficacy of navigation and prey finding in killer whales. There was, however, no notable reduction of noise in the SRKW relevant frequency banks attributed to behavioural responses or masking of stereotypical calls. More accounting for the use of this area by smaller vessels during the implementation of the ISZ should attempted to better conclude if it was vessel exclusion that created the decrease in SPL levels seen.

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7 REFERENCES

Francois, R.E., and Garrison, G.R. 1982. Sound Absorption based on ocean measurements. Part II: Boric acid contribution and equation for total absorption. J. *Acoust.Soc. Am.* **72**, 1879.

Merchant, N.D., Brookes, K.L., Faulkner, R.C., Bicknell, A.W.J., Godley, B.J., and Witt, M.J. 2016. Underwater noise levels in UK waters. *Sci Rep* **6,** 36942. https://doi.org/10.1038/srep36942.

Heise, K.A., Barrett-Lennard, L.G., Chapman, N.R., Dakin, D.T., Erbe, C., Hannay, D.E., Merchant, N.D., Pilkington, J.S., Thornton, S.J., Tollit, D.J., Vagle, S., Veirs, V.R., Vergara, V., Wood, J.D., Wright, B.M., Yurk, H. 2017. Proposed Metrics for the Management of Underwater Noise for Southern Resident Killer Whales. Coastal Ocean Report Series (2), Ocean Wise, Vancouver, 30pp.

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.

Veirs, S., Veirs,V., and Wood, J. D. 2016. Ship noise extends to frequencies used for echolocation by endangered killer whales. PeerJ 4:e1657; DOI 10.7717/peerj.1657.