Playgrounds by a highway: Understanding the effects of increased ambient noise levels on Northern Resident killer whales (*Orcinus orca*) during beach rubbing

by
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Declaration of Committee

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Abstract

Northern resident killer whales (NRKW) perform a unique beach rubbing behaviour on three beaches within the Johnstone Strait, British Columbia, Canada. Two beaches are encompassed in the Robson Bight (Michael Bigg) Ecological Reserve (RBMBER), and one beach lies outside of the RBMBER. Acoustic analysis of 20 beach rubbing events between July and September 2021 was performed to identify differences in call type occurrence and ambient noise levels (ANLs) between beaches within (Strider) and outside (Kaizumi) RBMBER. Call type occurrence was found not to be affected by which beach NRKW rubbed at, similar to previous studies on the social affiliations of resident killer whales. A preference for rubbing within RBMBER was seen, with more beach rubbing events occurring at the Strider rubbing beach inside RBMBER (n = 15) compared to the Kaizumi rubbing beach outside (n=5). A 10.64 dB difference was found in the ANLs between beaches within and outside RBMBER, and a significant correlation between ANLs and average NRKW call rates ($p = 0.033$) was determined. Further studies on other environmental variables, such as beach composition and structure, weather patterns, and bathymetry are recommended to determine if increased ANLs are the primary reason for the preference for the Strider rubbing beach. Recommendations for both RBMBER and the Canadian BeWhaleWise guidelines are discussed.

Keywords: marine acoustics; vessel noise; killer whales (*Orcinus orca*); Salish sea; Robson Bight.

Dedication

This report is dedicated to all the children whose love and passion drive them to a life spent protecting the oceans.

Acknowledgements

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And finally to my partner Callum, who has been there since the day I got my acceptance letter, and who has been there to take the laptop away and provide balance in my life – you are my rock, and there is nothing I could do that wouldn't be made better by your endless love and support. I love you.

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Introduction

Anthropogenic-noise pollution is a stressor in many ecosystems. In marine environments, acoustic disturbances such as deep-sea mining, military activity, and coastal manufacturing contribute to increased ambient noise levels (Hildebrand 2004). A major source of noise pollution comes from marine vessels, including eco-tourism boats, cruise ships, and private motors (Hildebrand 2004; Erbe et al. 2019). Vessel presence in the ocean has increased since the 1940s and was responsible for a 3.3-dB increase in ambient noise per decade between 1950 and 2007 (Frisk 2012). Ambient noise occupies a range of acoustic frequencies (Erbe et al. 2019). Larger ships – such as ferries, merchant ships, and cruise ships – emit low-frequency noise (10-100 Hz) (Eberhardt & Evans 1962; McKenna et al. 2012; Cranford & Krysl 2015; Simard et al. 2017; Erbe et al. 2019). Smaller vessels – such as rigid-hull inflatable boats (RHIB), jet skis, and whale watching boats – emit mid- to high-frequency noises in the same range of many marine mammal vocalizations (tens of kHz) (Erbe 2002; 2013; Erbe et al. 2016; 2019). Both low- and high-frequency noise pollution negatively impacts the life history of coastal cetaceans living in areas with high vessel presence (Malcolm et al. 2002; Houghton et al. 2015; Cominelli et al. 2018).

The coastal waters of British Columbia are inhabited by various cetaceans, including two culturally distinct populations of Resident killer whales (*Orcinus orca*) (Ford et al. 2011). Southern Resident killer whales (SRKW) range from Central Vancouver Island south to Washington State, and Northern Resident killer whales (NRKW) between Central Vancouver Island north to Alaska (Krahn et al. 2002; Parsons et al. 2013; DFO 2018). NRKW and SRKW are organized into clans, pods, and matrilines (Figure 1.1). There are four clans of Resident killer whales – the SRKW population comprises one clan (J-Clan), while the NRKW population is divided into the remaining three (A-, G-, and R-Clan) (Baird & Stacey 1988; Nousek et al. 2006; Cominelli et al. 2018). Each clan is made up of subclans with pods that share similar call types distinct from those in other clans (Ford 1991; Nousek et al. 2006). Pods are made up of matrilineal units that associate with one another (Nousek et al. 2006).

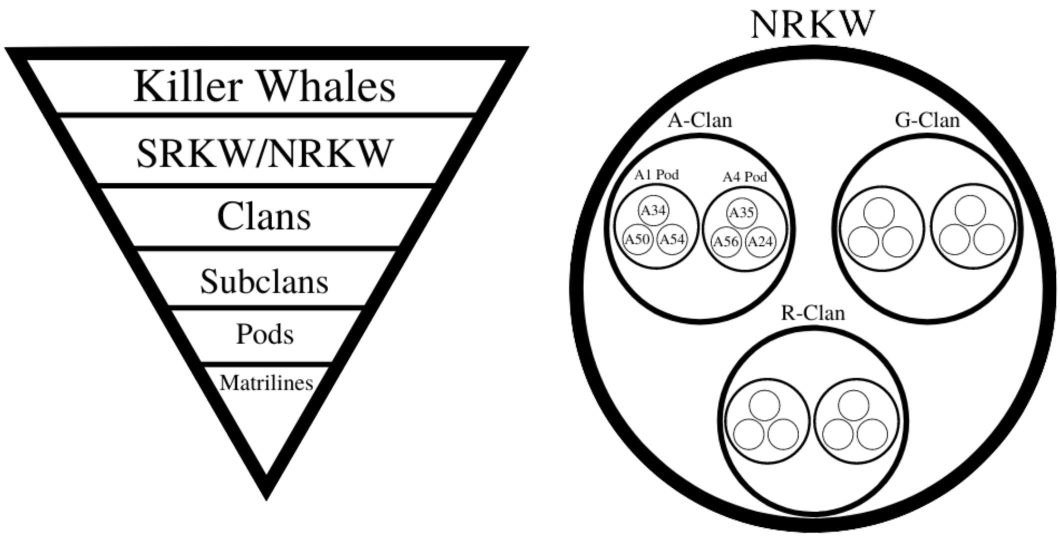

Figure 0.1 Social organization of the resident killer whale populations. Left: Organization hierarchy of resident killer whales from least specified (killer whales) to most specified (matrilines). Note SRKW/NRKW are two populations of the 'resident' killer whale ecotype, a taxomic grouping that separates the 'resident' ecotype of killer whale from the 'transient' or Biggs ecotype. Right: Example structure of NRKW organization. Three acoustically-distinct clans make up the NRKW population, with multiple pods and matrilines organized within them (not all pods/matrilines shown in the figure).

Resident killer whales rely on low ambient noise levels to carry out vital life behaviours. They use echolocation and communication while foraging to alert others in the pod of a successful prey capture (Ford 2014). Killer whales have three distinct sound classifications: clicks, which are pulses of sound that are used for echolocation; whistles, which are non-pulsed sounds used for short-range signalling; and pulsed calls, which include distinct tonal properties from high pulse-repetition rates (Ford 1989, Thomsen et al. 2001). Acoustic lineages are maintained at the subclan level. Each pod belongs to a subclan that has an average of 10-11 unique, discrete calls that do not vary over years, allowing members to recognize others in the same group (Ford 1989). The slight variation between pods, as well as the distinct differences in call types between NRKW subclans and clans, is a key strategy for individuals to identify mates from outside their clan to maintain genetic diversity (Barrett-Lennard 2000). Studies have shown that small vessel noise, which peak at frequencies in the same range of killer whale communication (mid-frequencies, i.e., 500-15000 Hz), can impact this species' behaviour and vocalizations (Erbe 2002; Trites et al. 2007; Williams et al. 2009a; Holt et al. 2009; Noren et al. 2016; S. Vagle, pers. comm.). Evidence of the Lombard effect – the tendency of individuals to increase communication effort in the presence of higher noise levels – has been observed in SRKW and is hypothesized to increase stress levels and energetic costs and decrease communication efficiency (Holt et al. 2009). Because of the negative impacts, the government of Canada established the Be Whale Wise guidelines in 2001 to mitigate the stressors created by increased whale-watching and recreational boating. These guidelines include a federal law that all boats must stay 400 m from killer whales observed in water surrounding southern Vancouver Island between Campbell River and north of Ucluelet, and 200 m from killer whales observed in other Canadian Pacific waters (BeWhaleWise.org, n.d.). Emphasis has previously been on studying vessel noise impacts on SRKW critical habitats. However, as vessel noise levels increase in NRKW critical habitat (Williams et al. 2014), an understanding of its effects on both populations is imperative.

Vessel noise has the potential to negatively impact NRKW communication by masking their vocalizations, including those that are performed during beach rubbing. Beach rubbing is a unique NRKW behaviour in which individuals will rub their bodies along smooth-pebbled beaches, typically as a group. This behaviour has been observed repeatedly at four beaches: three within the Johnstone Strait on the northeastern shore of Vancouver Island, two of which (Strider and Main) are located within the Robson Bight Michael Bigg Ecological Reserve (RBMBER), and one (Kaizumi) that is located to the west of the RBMBER; and one at Bere Point Beach, located on the northern shore of Malcolm Island, BC. A fifth location on the Sunshine Coast has also been observed as a rubbing beach but this location is rarely used (Bartlett 2022).

Research on the functional role of beach rubbing has been inconclusive. It is believed to be a form of socialization or recreational activity (Ford et al. 1996; Williams et al. 2009b), with the number of vocalizations during rubbing reported at similar levels to vocalizations during socialization (Ford 1989). Little research has been done to determine if there are specific call types used during rubbing, or how vessel noise impacts these vocalizations. Because of the rubbing beaches' locations in NRKW critical habitat, there is an opportunity to better understand how vessels impact the NRKW vocalizations during this unique behaviour.

Goals and Objectives

The goal of this study was to better understand the impacts that vessel noise has on NRKW vocalizations, particularly during beach rubbing. The Johnstone Strait and RBMBER are considered critical habitat for NRKW. Requirements for NRKW critical habitat include a marine soundscape that does not impede successful communication (DFO 2018, Riera et al. 2019). Therefore, this study aimed to inform policy on RBMBER's current marine restrictions (voluntary “No-Go Zones”) and coverage (two of three rubbing beaches within RBMBER boundaries) to mitigate future vessel noise stressors on the NRKW population. These goals were achieved by completing the following respective objectives:

Goal 1: Develop a call list of NRKW beach rubbing vocalizations between rubbing beaches within and outside of RBMBER.

> *Objective 1.1:* Cross-reference visual and acoustic data to isolate periods of beach rubbing.
>
> *Objective 1.2:* Determine the three most common calls used during beach rubbing for each observed clan.
>
> *Objective 1.3:* Determine if there is a difference in call types between beaches within RBMBER (Strider) and beaches outside RBMBER (Kaizumi).
>
> *Objective 1.4:* Compare the three most common call types at beaches within (Strider) and outside (Kaizumi) RBMBER against call libraries maintained by DFO and OrcaLab to determine if calls are unique to rubbing behaviour or used in other contexts.

Goal 2: Determine whether higher ambient noise levels resulting from vessel noise pollution play a role in the NRKW decision to rub at the beach located outside of RBMBER (Kaizumi).

> *Objective 2.1:* Isolate and analyze instances of ambient noise during period of beach rubbing and non-beach rubbing at the beach outside of RBMBER (Kaizumi).

Objective 2.2: Compare average ambient noise levels during instances before, during, and after beach rubbing events.

Objective 2.3: Compare average ambient noise levels during beach rubbing and non-beach rubbing events at the beach outside of RBMBER to determine if increased ambient noise levels affect the decision of NRKW to rub (Kaizumi).

Goal 3: Determine whether NRKW alter aspects of beach rubbing in the presence of increased ambient noise levels.

Objective 3.1: Determine if ambient noise levels have a significant impact on beach rubbing lengths or average call rates.

Methods

Study Site

The Robson Bight (Michael Bigg) Ecological Reserve (RBMBER) is located in the Johnstone Strait off the northeastern coast of Vancouver Island, British Columbia, Canada (Fig 2.1). It was established in 1982 to protect a minimally disturbed marine environment so that research on NRKW behaviours could occur (Blood et al. 1988, B.C. Parks n.d.). Vessel activity is minimized within RBMBER through an established voluntary "no-go zone", and access to the shoreline is prohibited (B.C. Parks n.d.). The marine portion of reserve is 10 km southeast of Telegraph Cove, and 2.5 km south of West Cracroft Island. It is bordered to the south by Tsitika River Provincial Park and north by Johnstone Strait. It encompasses 1715 ha of marine and terrestrial ecosystems and includes 10.7 km of Vancouver Island shoreline (B.C. Parks n.d.). From July to September, NRKW migrate into RBMBER and surrounding waters to hunt, mate, and socialize (Williams 2006). Three smooth-pebbled beaches are used by NRKW to perform a unique rubbing behaviour. Two beaches (Main and Strider) are located on the eastern shoreline of RBMBER; one beach (Kaizumi) is located to the west, outside of RBMBER's boundaries (Fig 2.1).

Visual and acoustic data was collected from 1 July to 5 September, 2021, in collaboration with CETUS Research & Conservation Society and OrcaLab. Visual data was collected from a land-based monitoring platform on West Cracroft Island. Acoustic data was collected using pre-deployed hydrophones at each of the rubbing beaches. Data from the

Main beach hydrophone was not used because of technical difficulties throughout the field season resulting in corrupt audio files.

Visual Data

Visual data was collected to supplement acoustic data and identify beach rubbing events. Visual data was collected daily from the Eagle Eye marine observation station between 09:00-16:30. The observation station was located across from RBMBER and offered a vantage point into the sanctuary and greater Johnstone Strait (Fig 2.1). The study site was scanned for vessels and killer whales every 15 minutes using binoculars. Scans started at the eastern edge of the study

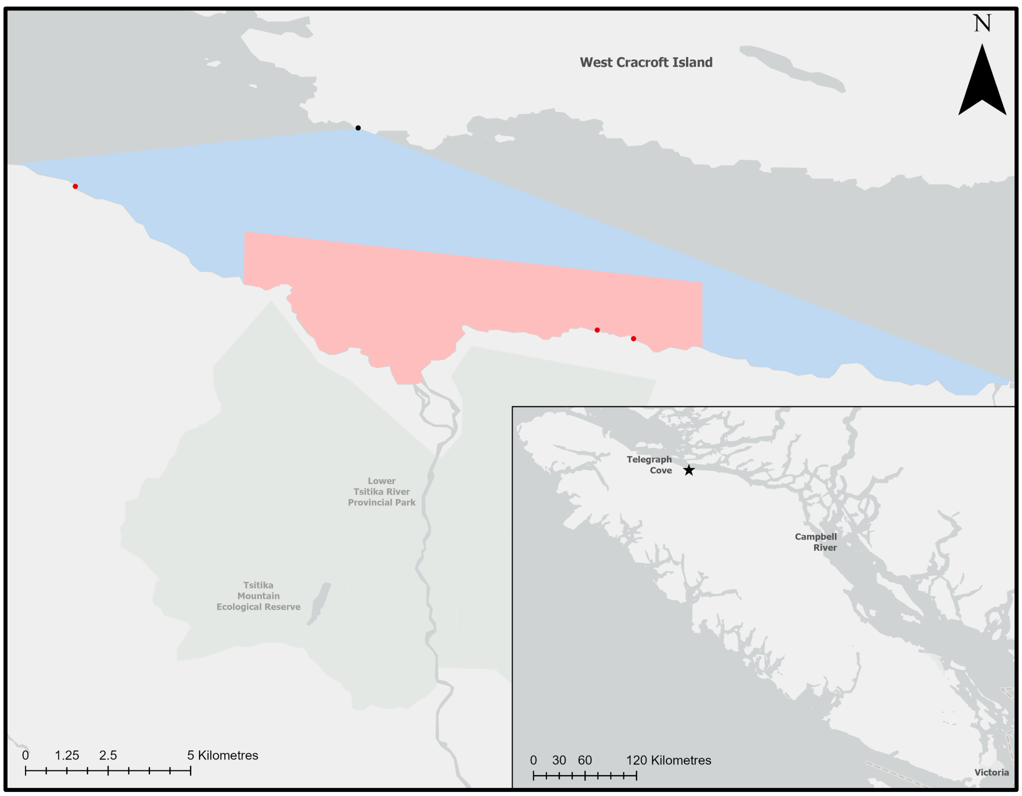

Figure 0.2 **Study site for the assessment of vessel noise impacts on NRKW communication while beach rubbing in the Johnstone Strait, British Columbia, Canada. The Robson Bight (Michael Bigg) Ecological Reserve (light red) and surrounding study area (light blue) are shown. The land-based monitoring platform (black dot) and the three NRKW rubbing beaches (red dots, from left to right: Kaizumi, Strider, Main) are also depicted. The inset represents the study site's location relative to notable areas on Vancouver Island. Map created in ArcPro 10.8.**

area and concluding at the western edge (Fig 2.1). This was done to ensure that vessels and killer whales outside the study site were not double counted. Scans were conducted in the same way as those set out by the DFO (2021) field protocol. During each scan, positions of vessels and killer whales present in the study site were recorded and documented as “sightings”. To record these sightings, a Topcon DT-200 theodolite connected to Mysticetus software (Fig 2.2) was used. New sightings were taken on vessels and killer whales that remained in the study site for multiple scans. For example, a private motor that stayed within the boundaries of the study site for thirty minutes would be sighted twice, and killer whales that stayed for one hour would be recorded four times.

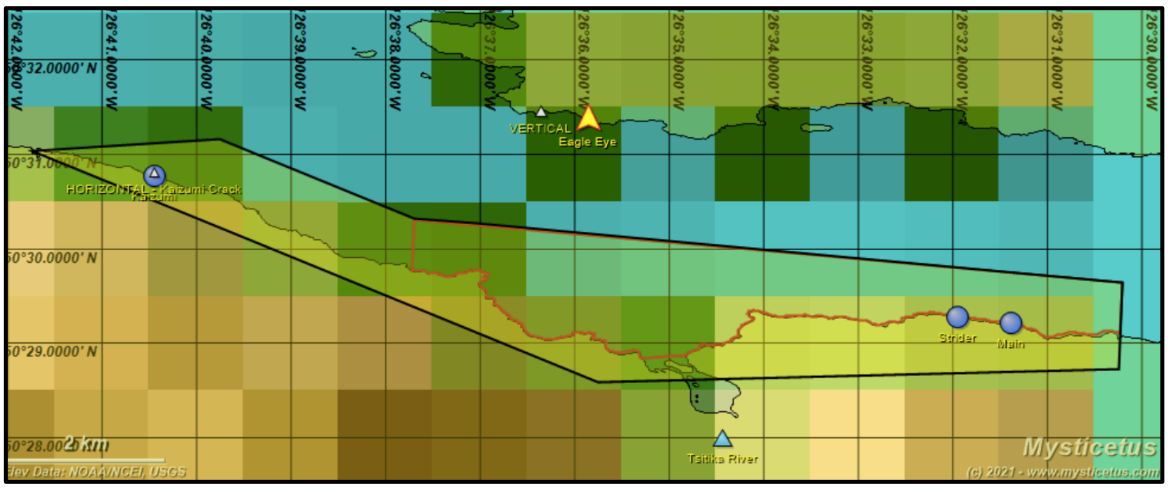

Figure 0.3 **A screenshot of the study area for the assessment of vessel noise impacts on NRKW communication while beach rubbing in the Johnstone Strait, British Columbia, Canada, as seen in the Mysticetus software (DFO 2021). The DFO study area (thick black outline with yellow shading), RBMBER (red outline), land-based observation platform (yellow marker, “Eagle Eye”), and three rubbing beaches (blue circles) are shown.**

Vessel Data

Each vessel was recorded once per scan. Vessels were sighted two consecutive times at five seconds intervals to determine their speed and direction. Sightings were taken by placing the theodolite’s crosshairs under the wheelhouse of the vessel at the waterline for accuracy. Vessels’ type and activity, as well as size, hull type, and engine location were recorded for each vessel (See Appendix A, Table A1).

Killer Whale Data

Killer whales were recorded once per scan to determine their location. Individuals within 10 body lengths (i.e., 50-70 m) of one another were considered a group (DFO 2021). Two sightings were taken for each group – one on the “lead whale” (the whale considered to be at the front of the group, or the whale furthest from the theodolite), and one on the “follow whale” (the whale considered to be at the back of the group, or the whale closest to the theodolite). Killer whales greater than 10 body lengths away from one another were sighted once as “solo whales” and sighted once per scan (DFO 2021). The following data was recorded for killer whales: group size, group spread, group configuration, and behaviour (See Appendix A, Table A2). Group behaviour was recorded as the observed behaviour performed by majority of the group. For example, if four of five NRKW are resting and one is travelling, the group behaviour was recorded as resting. Behaviours were recorded based on the definitions used by the CETUS Research and Conservation Society (See Appendix A, Table A2).

Acoustic Data

Three icListen HF Smart Hydrophones (SC2-ETH) with Ethernet (10 Hz to 200 kHz) and 200 m depth rating were purchased through Ocean Sonics. One hydrophone was initially deployed at each of the three rubbing beaches in the study site between mid-July 2020 for multi-year continuous data collection. The hydrophone at the Strider rubbing beach was replaced in the summer of 2021. Hydrophones were deployed using 100 m cable running from a power box at each of the beaches and were deployed to a maximum of 90 m from the shoreline (see Appendix A, Table A3). Hydrophones were deployed at a depth of 15 m $\pm$ 3 m, facing upwards towards the ocean’s surface on a tripod made of PVC piping. Test results showed calibration levels of -174.1 $\pm$ 4.0 dB re μPa (10 kHz to 100 kHz) and -172.5 $\pm$ 5.7 dB re μPa (10 kHz to 200 kHz) (Ocean Sonics 2015). Receiving direction of the hydrophones were omnidirectional, and receiving range was dependent on a variety of factors (e.g., sound source level and frequency of desired detection, environmental conditions, etc.). Acoustic data was continuously collected and stored by the hydrophones during the study period. Uncompressed acoustic data was collected as waveform audio files and stored as .wav file

Data Analysis

Acoustic Analysis

Acoustic and visual data were cross-referenced to isolate instances of beach rubbing at the Strider and Kaizumi rubbing beaches. Corresponding acoustic data was then extracted from the hydrophones, split into five-minute .wav clips and analyzed *post-hoc* in RavenPro (Version 1.6.1 (1.6.1) for macOS, accessed 9 November 2021). Isolated clips were first examined for evidence of beach rubbing, characterized by high-frequency (2-28 kHz) bands on the spectrogram (Fig 2.3). If beach rubbing was present, a clip was considered part of a beach rubbing "encounter". Encounters were defined as the total length of time that beach rubbing was acoustically present, in addition to a 10-minute buffer period before and after beach rubbing events. Visual data was used as a reference for approximate beach rubbing lengths. If acoustic data indicated that beach rubbing occurred for a greater or lesser amount of time than the visual data did, it was considered more accurate. Acoustic data analysis was restricted to the same time that visual data was collected (i.e., 09:00-16:30). Sections of encounters that extended outside of these hours were not analyzed.

Each clip within an encounter was then analyzed and annotated. Analysis of each clip included a complete playthrough to both visually and acoustically detect any beach rubbing and/or NRKW vocalizations. Vocalizations and beach rubbing evidence within the clips was annotated (i.e., they were defined as their own entity by isolating it from the rest of the .wav file – see Fig. 2.3). Evidence of beach rubbing was annotated once per clip to indicate its presence in the clip. Pulsed NRKW calls were annotated whenever visually and/or acoustically identified. Pulsed calls were characterized by pulse repetition rates of 250-2000 pulses/s, primary energy levels between 1-6 kHz, and high-frequency components that could extend to >30 kHz, as per Ford (1989) (Fig. 2.3). All discernable calls were annotated within each encounter. Non-calls – such as NRKW whistles, vessel noise, and unusual ambient noises – were annotated when observed. Echolocating clicks were not annotated for this study.

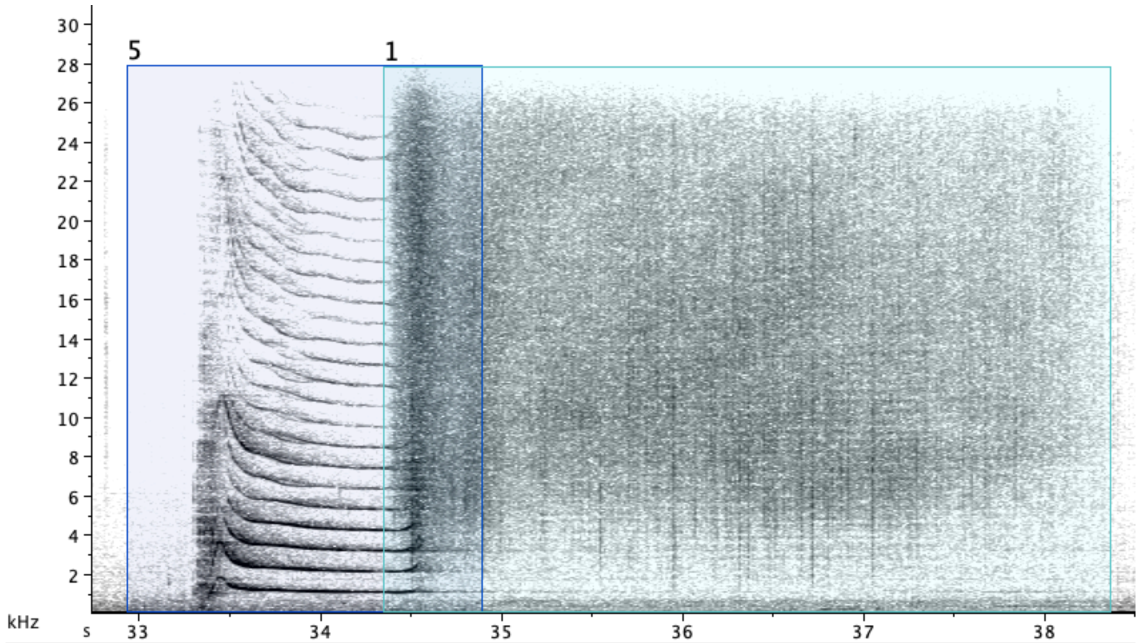

Figure 0.4 **Example of a beach rubbing spectrogram seen during the assessment of vessel noise impacts on NRKW communication while beach rubbing in the Johnstone Strait, British Columbia, Canada. Annotation 1 (outlined in light blue) indicates evidence of beach rubbing; Annotation 5 (outlined in dark blue) is an example of a NRKW pulsed call, in this case N04.**

Identification of call types was performed manually using an unpublished call catalogue from the Department of Fisheries and Oceans Canada (DFO). Each discernable call in a clip was first isolated and then played back. Calls were then cross-referenced against the call catalogue by comparing both spectrographic (e.g., harmonic variations, spectrogram shape, etc.) and acoustic (e.g., pitch changes, general similarities in tone, etc.) features. For a call to be identified with certainty, both spectrographic and acoustic likeness needed to be described. An aquatic science technician from the DFO specializing in resident killer whale call identification acted as a secondary verifier during instances of uncertainty, as well as a final verifier to determine identification skillsets. Calls where spectrographic and/or acoustic likeness could not be verified (e.g., they were considered too distant or muffled) were annotated and marked as such.

For each annotation, the following measurements were recorded: begin and end times, duration 90%, low/high frequencies, 25% frequency, 75% frequency, average power density, peak power density, and energy (See Appendix A, Table A4 for definitions).

Specific characteristics such as call type, vessel noise presence/absence, overlap, and non-call identification were also included in the selection table.

Ten-second clips of ambient noise were isolated from .wav files of both beach rubbing events and non-beach rubbing events. During beach rubbing events, ambient noise was divided into three parts: pre-beach rubbing, beach rubbing, and post-beach rubbing. Pre- and post-beach rubbing included the 10-minute buffer periods on either end of beach rubbing events where no beach rubbing evidence was found. Ambient noise annotations were isolated from clips at a minimum of every fifteen minutes during beach rubbing. In all cases, a minimum goal of three 10-second clips per chosen .wav file was used – in cases where this couldn't occur (typically during beach rubbing), clips were identified for ambient noise level extraction every five to ten minutes. Isolation of ambient noise for non-beach rubbing events followed the same method as those for during beach rubbing instances.

Broadband noise analyses for non-beach rubbing clips were performed using the PAMGuide software in MatLab. Settings were isolated to the 500-15000 Hz band where resident killer whale discrete calls are observed, and calibration data was based on prior tests on the deployed hydrophones to verify their sensitivity to measures of sound levels across frequency bands (See Appendix A, Fig A1.). An average of each ambient noise clip's broadband noise results was taken per beach rubbing event to avoid pseudoreplication. Ambient noise clips from beach rubbing events were sent to the DFO for similar broadband analysis to compare results.

Statistical Analysis

Visual data was minimally analyzed apart from summary statistics to supplement the findings from the acoustic data. No statistical analysis was performed using the vessel data to avoid pseudoreplication. However, because the continued presence of a boat indicated presence of anthropogenic noise (e.g., engine running), summary statistics were used to determine the proportion of vessel sizes and engine types that were present throughout the season.

Statistical analysis was performed using RStudio ("Ghost Orchid" Release (077589bc, 2021-09-20) for macOS, accessed 2 February 2022), which focused primarily on acoustic data. A chi-square analysis for independence ($\alpha = 0.05$) was used to identify differences between the observed and expected values for call occurrence frequencies at the two beaches. In all other cases, non-parametric tests were used because of non-normal data distributions. Mann-Whitney U tests were performed to compare ambient noise levels (ANLs) before, during, and after beach rubbing at the two beaches, as well as ANLs between non-beach rubbing and pre-beach rubbing events at Kaizumi. Spearman rank correlation coefficient tests were performed to identify relationships between ANLs and length of beach rubbing, and between ANLs and average call rates per 15-minute intervals. A standard Type I error rate of $\alpha = 0.05$ was used in all statistical analyses.

To compare ANLs between beach rubbing event instances (i.e., between pre-rubbing and during rubbing, and between during rubbing and post-rubbing), Wilcoxon signed ranks tests were used. Because of the increased risk of a Type I error occurring using the same data for multiple statistical tests, a Bonferroni correction was applied, resulting in a corrected hypothesis rejection threshold of $\alpha' = 0.025$.

Relevant graphs and figures were created using RStudio's ggplot2 package.

Results

Vessel Data

Vessels were present daily throughout the study period, with a total of 8985 sightings. Private vessels were the most abundant, while coast guard vessels and other non-descript vessels were least commonly sighted (Fig 3.1., see Appendix B, Fig B1 for full definitions). Of the 8985 vessel sightings, 48.8% used inboard engines (Fig 3.2), and 71.9% were small (<30 ft) (Fig 3.3).

Killer Whale Data

Visual Data

NRKW were present on 30 days. The maximum number of NRKW present in the study site at one time was 27 (3 September 2021). The minimum number of NRKW present at one time, when whales were present, was 2 (16 August 2021) (See Appendix B, Table B1). Two of the three clans, A clan and G clan, were identified within the study site and period. A clan pods sighted included A1, A4 (A24 and A35 matrilines), and A5 (A42 matrilines), while only one G clan pod, I11 (I4, I27, and I65 matrilines) were present throughout the study period. No R clan sightings were recorded.

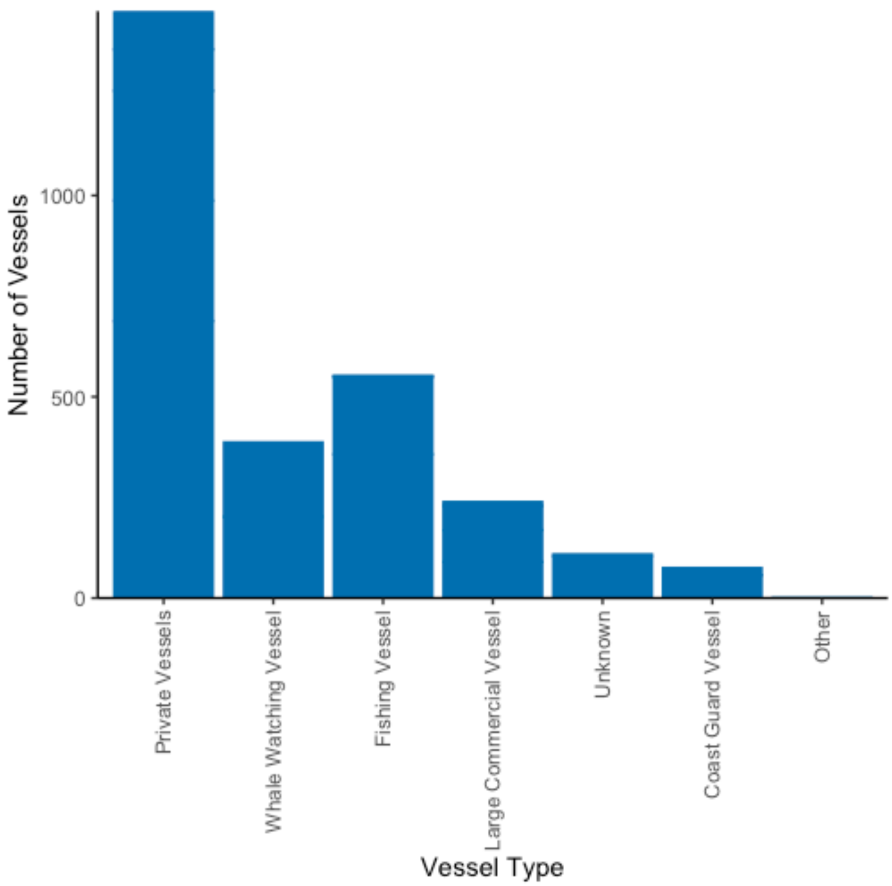

Figure 0.5 **Frequency of vessel types sighted in the study site for the assessment of vessel noise impacts on NRKW communication while beach rubbing in the Johnstone Strait, British Columbia, Canada. Vessel types are grouped into seven categories: Private, whale watching, fishing, large commercial, unknown, and coast guard.**

Visual sightings showed that NRKW spent most time in the study zone travelling, the least resting, and 9% beach rubbing (Fig 3.4). Beach rubbing was observed on 17 of the 30 days (Fig 3.5). Subsequent acoustic analysis revealed two instances (i.e., 28 August and 5 September, both Kaizumi), where NRKW were incorrectly identified during visual data collection as beach rubbing rather than travelling. The total number of days where beach rubbing definitely occurred was therefore 16 (a beach rubbing event occurred on 5 September at Strider). Beach rubbing occurred at Kaizumi on five days, at Strider on 14 days, and at both beaches on the same day on three days.

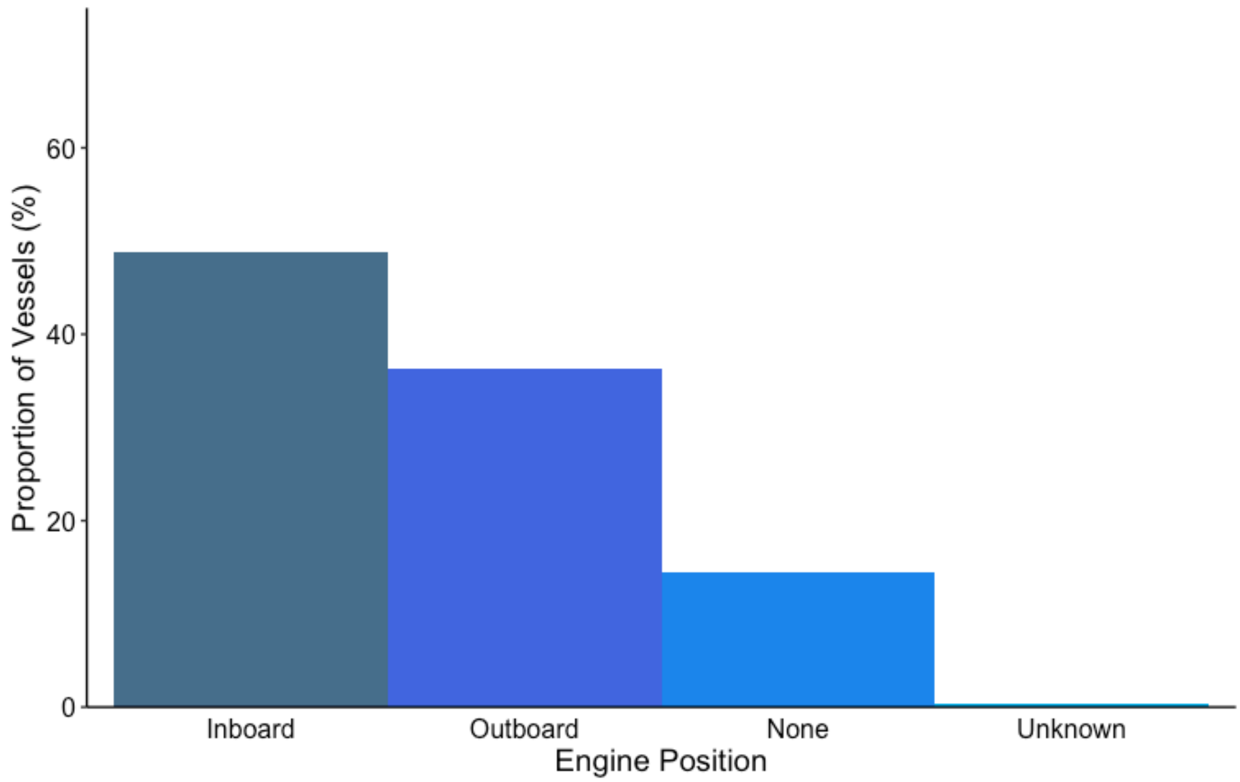

Figure 0.6 Frequency of the engine position for each vessel sighting collected for the assessment of vessel noise impacts on NRKW communication while beach rubbing in the Johnstone Strait, British Columbia, Canada. The following definitions are used: inboard – engine is positioned inside the boat; outboard – engine is positioned outside the boat, typically at the stern; none – no engine is present.

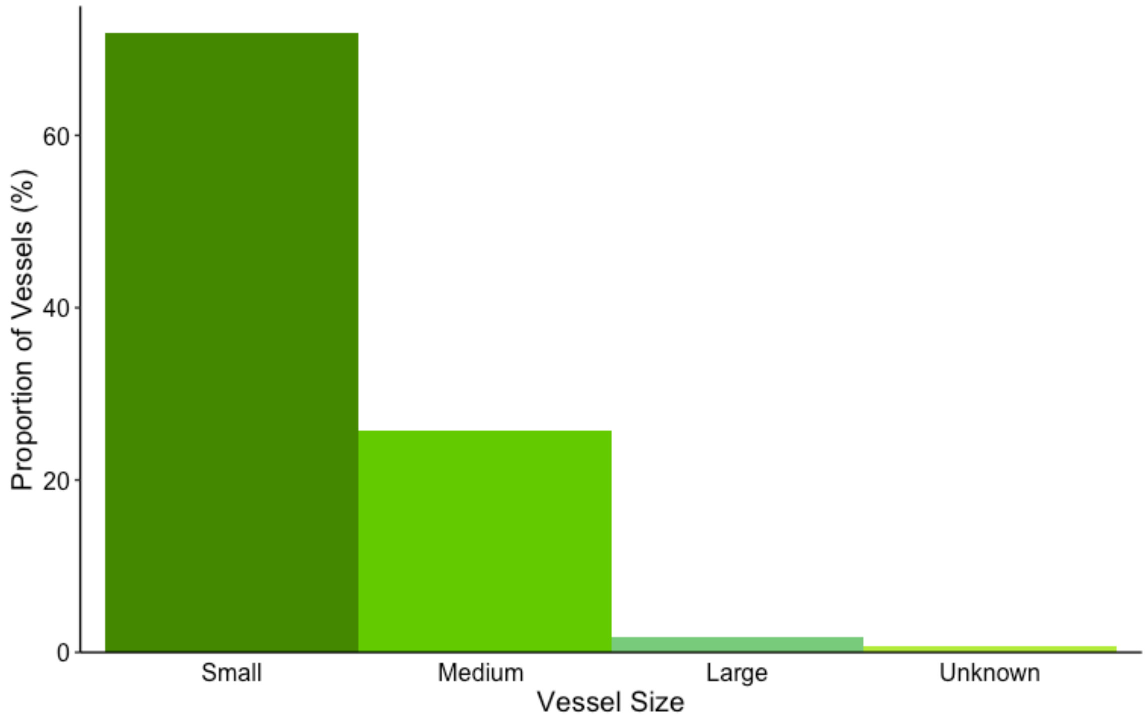

Figure 0.7 Frequency of the vessel size for each vessel sighting collected for the assessment of vessel noise impacts on NRKW communication while beach rubbing in the Johnstone Strait, British Columbia, Canada. The following definitions are used: large – >80 ft in length; medium – 30-80 ft in length; small – <30 ft in length.

Acoustic Data

A total of 271 .wav sound clips were acoustically analyzed over 20 beach rubbing events ($n_{Strider}$ = 15, $n_{Kaizumi}$ = 5). Rubbing events at Strider lasted an average of 75 ± 14.42 minutes, with the longest and shortest events lasting 225 minutes (5 September 2021) and 30 minutes (3 September 2021), respectively. Rubbing events at Kaizumi lasted an average of 42 ± 9.82 minutes, with the longest and shortest events lasting 80 minutes (21 August 2021) and 25 minutes (29 August 2021), respectively (Fig 3.5). Overall rubbing event lengths tended towards significance between the two beaches (W = 15.5, df = 18, p = 0.0595).

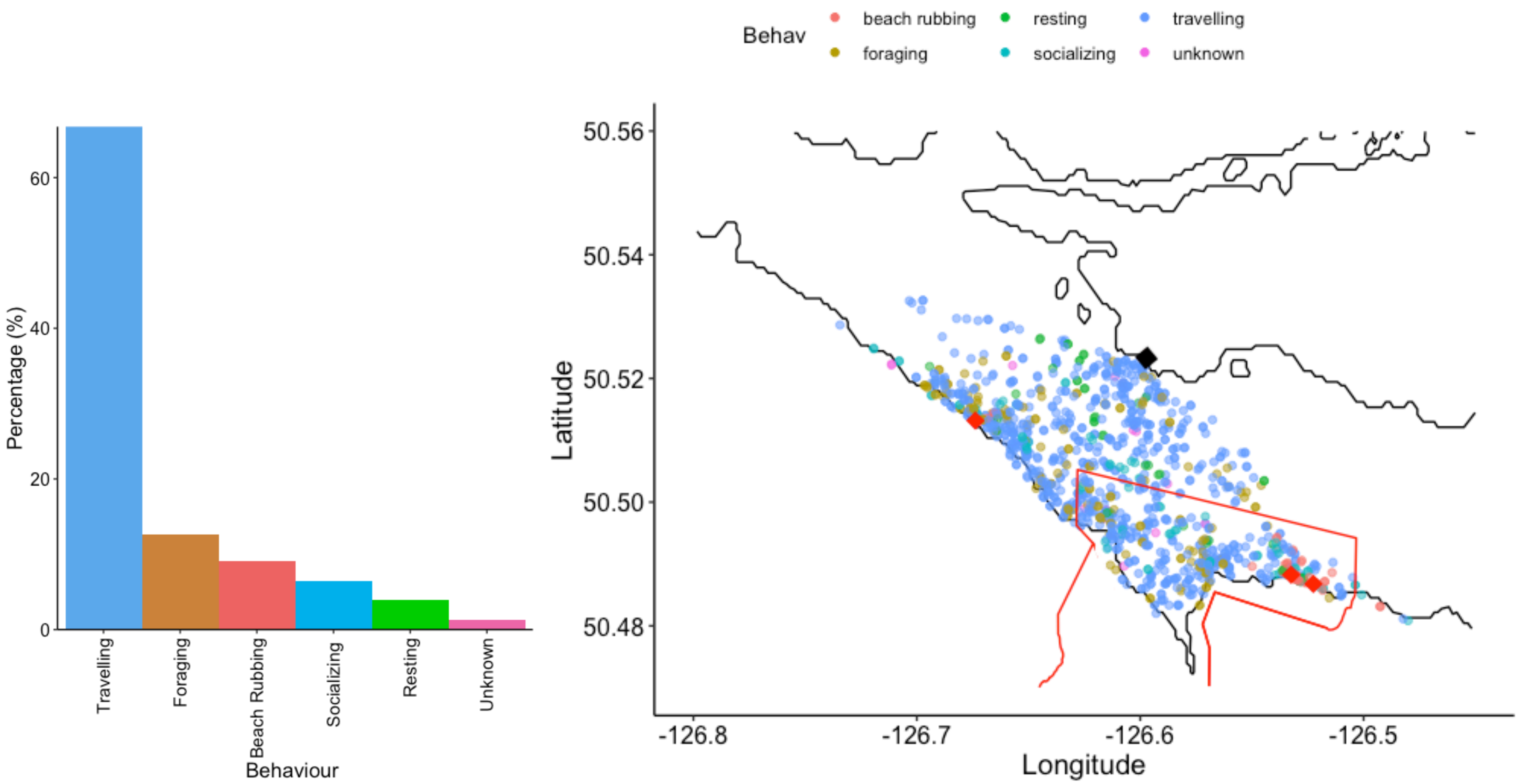

Figure 0.8 **Map of NRKW behaviour data collected for the assessment of vessel noise impacts on NRKW communication while beach rubbing in the Johnstone Strait and RBMBER (red outline), British Columbia, Canada. NRKW spent 66.8% of time travelling (n = 856), 12.6% foraging (n = 161), 9.0% beach rubbing (n = 116), 6.5% socializing (n = 83), 3.9% resting (n = 50), and 1.25% performing unknown activities (n = 16). Eagle Eye observation platform (black diamond), as well as the three rubbing beaches (red diamonds) are shown.**

A total of 13668 annotations were isolated. Of these annotations, 6559 were successfully identified discrete NRKW calls from the A (n= 4146) and G (n= 2143) clans. More calls were annotated at Strider (n= 5824) than at Kaizumi (n= 735) (Table 3.1).

Table 0.1 Breakdown of identified NRKW discrete calls during beach rubbing events between 09:00-16:30, 1 July – 5 September 2021, in the Johnstone Strait, British Columbia, Canada. Note that the total overall rubbing time will differ from the sum of the total rubbing times at each beach, as there were three beach rubbing events in which A and G clan were present.

	Hydrophone					
	Strider		*Kaizumi*			
	Number of Calls	***Rubbing Time (min)***	***Number of Calls***	***Rubbing Time (min)***	***Total Calls***	***Total Time (min)***
A Clan	3878	720	268	65	4146	785
G Clan	1946	560	467	170	2413	730
Total per Beach	5824	1170	735	210		

Frequency of the annotated call types varied between beaches. The most annotated A clan calls were N04 (n = 1881), N03 (n = 545), and N09i (n = 505) (Fig. 3.6). This distribution was seen at Strider (n_{N04} = 1722, n_{N03} = 531, n_{N09i} = 490), but was not at Kaizumi, where the second and third most frequently annotated were different (n_{N04} = 159, n_{N05i} = 24, n_{N07i} = 19) (Fig 3.7). No significant difference was found between observed and expected values of A clan calls (x^2 = 15.804, df = 19, p = 0.6703). The most annotated G clan calls were N25 (n = 1083), N23i (n = 643), and N45 (n = 302) (Fig. 3.6). The same frequency was seen at both Strider (n_{N25} = 890, n_{N23i} = 506, n_{N45} = 233) and Kaizumi (n_{N25} = 193, n_{N23i} = 137, n_{N45} = 69) (Fig 3.8). No significant difference was found between observed and expected values of G clan calls (x^2 = 1.8821, *df* = 12, p = 0.996).

Ten-second ambient noise clips were isolated during instances of pre- (n = 221), during (n = 277) and post- (n = 267) beach rubbing. On average, ANLs between 500-15000 Hz for Strider and Kaizumi were 92.15 ± 2.74 dB re 1 µPa and 102.79 ± 6.89 dB re 1 µPa, respectively. ANLs at Strider tended to stay below 100 dB re 1 µPa, with three exceptions (21 July, 22 July, and 19 August). Comparatively, Kaizumi experienced ANLs above 100 dB re 1 µPa during three of five beach rubbing events. Daily ANLs at both beaches during rubbing (W = 58, *df* = 18, p = 0.08062) (Fig 3.9) and post-beach rubbing (W = 58, *df* = 18, p = 0.08062) tended towards being significantly different while ANLs at both beach pre-beach rubbing were significantly different (W = 59, df = 16, p = 0.006769). Comparisons at Kaizumi showed no significant difference between either the pre-beach rubbing and beach rubbing ANLs (V = 6, df = 4, p = 0.8125) or between the beach rubbing and post-beach rubbing ANLs (V = 11, df = 4, p = 0.4375). However, comparisons between pre-beach rubbing and beach rubbing ANLs at Strider were significant (V = 85, df = 18, p = 0.00341), and comparisons between beach rubbing and post-beach rubbing ANLs tended towards significance (V = 73, df = 18, p = 0.05737).

Instances of non-beach rubbing at Kaizumi were also analysed and annotated for 10-second clips (n = 144). The average ANL of non-beach rubbing events was 94.45 dB re 1 μPa. No significant difference was found between non-beach rubbing and pre-beach rubbing instances (W = 11, df = 12, p = 0.1469).

Correlations between ANLs and length of beach rubbing events (without pre- or post-beach rubbing ANLs) were not significant (S = 1695.7, df = 18, p = 0.2407, rho = -0.275), but a significant difference in the correlation between ANLs during beach rubbing and the average number of calls was found (S = 1970, df = 18, p = 0.03327, rho = -0.481) (Fig 3.10).

Discussion

Call Occurrence Frequencies

A Clan

Of the 4146 discrete A clan calls annotated, N04 (n=1881), N03 (n=545), and N09i (n=505) were the most frequently identified. These results are in line with those of previous studies. The A clan call distribution followed a similar pattern to the one described in Ford (1989), where the most frequently identified calls (n=578) from beach rubbing events between 1978-1983 were N04 (~22%), N07 (~18%), and N12 (~11%).

During all activity states besides multi-pod interactions, N04 has been historically reported as the most common call produced by the observed A clan pods (A1, A4, and A5), accounting for over 20% of the total calls identified (Ford 1989). In comparison, N04 accounted for 45% of the identified calls during this study (the 2021 assessment).

Differences in the call rate could be the result of the smaller sample size in the 1978-1983 assessment. However, this is unlikely given that calls with higher occurrence frequencies (i.e., >10%) in the 1989 assessment represented less than five percent each of the overall A clan calls identified in the 2021 assessment (e.g., N02, N08, N12) (Ford 1989).

While N03 was identified as the second-most common A clan call during the 2021 assessment, its identification rate during rubbing events between 1978-1983 was comparatively minimal (Ford 1989). N03 was historically thought to have been a "low-arousal" call used primarily during group resting or intermediary resting/foraging states (Ford 1989). However, the occasional inclusion of N03 calls during high-arousal activities such as travelling and foraging was considered interesting, and the frequency of N03 during beach rubbing between 1978-1983 was significantly higher ($p < 0.05$) than frequencies determined in both travelling and foraging (Ford 1989). The increase in N03 use during beach rubbing could be the result of a shift in call use by the A clan pods. Evidence has shown that pod-specific repertoires are retained for over 25 years (Ford 1991). However, dialect differentiation among resident killer whales indicates that not only will pods incorporate new and unique calls into their repertoire, but the rate at which they use established calls may change as well (Ford 1991). A marked decrease in N12 frequency was also noted between Ford (1989) and the current study. As N03 and N12 are both established A pod calls with near-identical characteristics (e.g., similar spectrographic shapes, harmonics, etc.), it is possible that this shift in call rates could be due to the change in matrilineal hierarchies as adult females die and are replaced by their daughters (Ford 1991).

Reasons behind the increased frequency of N09i are less distinct. N09 calls have been historically associated with instances of large aggregations or travelling, and accounted for 10% of beach rubbing identifications in 1978-1983 (Ford 1989). Comparatively, N09i accounted for 12% of identified calls during the 2021 assessment. This slight increase infrequency may be the result of behavioural changes occurring between Strider and Main. As visual scans were taken every fifteen minutes, shifts in behaviour that occurred between sightings were not recorded. This included NRKW travel between Main and Strider, which was often observed throughout the field season. Because changes in behaviour cannot be distinguished acoustically besides a lack of beach rubbing evidence,

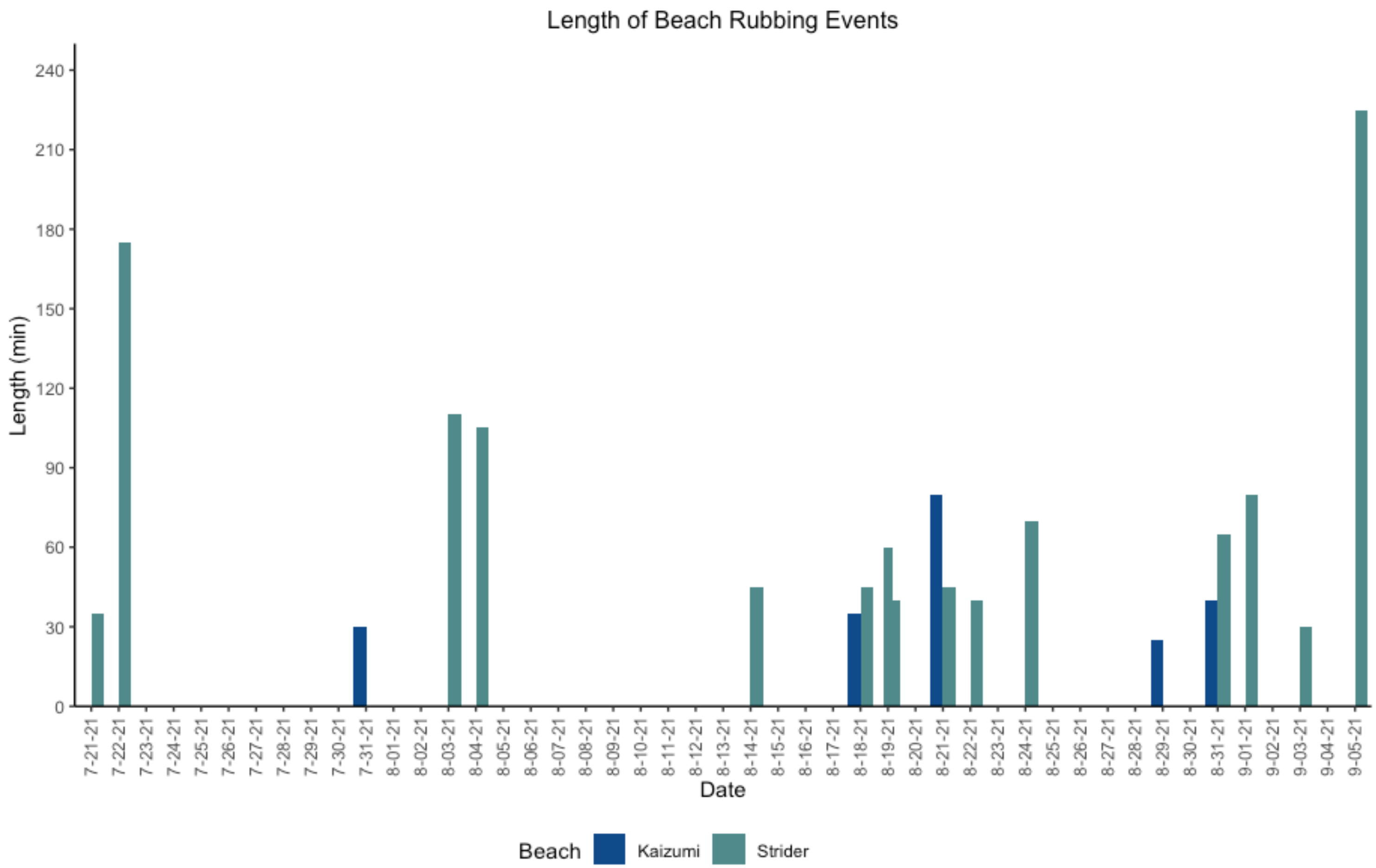

Figure 0.9 **Length of NRKW beach rubbing events at Strider and Kaizumi between 21 July and 5 September 2021 in the Johnstone Strait, British Columbia, Canada. Dates between 1 July and 20 July are not presented as no beach rubbing events occurred during that time.**

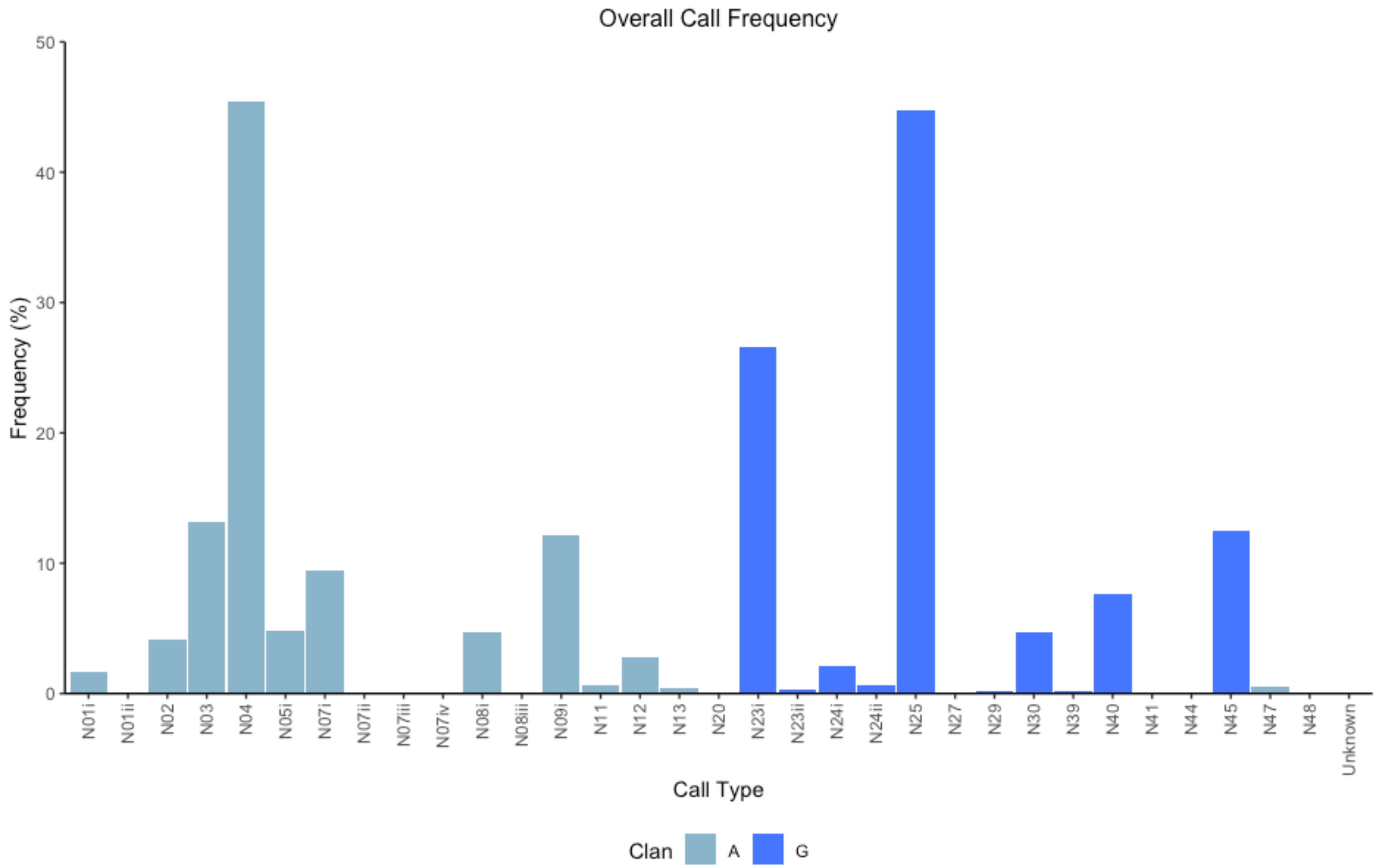

Figure 0.10 **Overall discrete call occurrence frequency identified during beach rubbing events between 1 July and 5 September 2021 at Strider and Kaizumi rubbing beaches in the Johnstone Strait, British Columbia, Canada. Graph is organized by associated clan and is arranged in alphanumerical order by the discrete call name.**

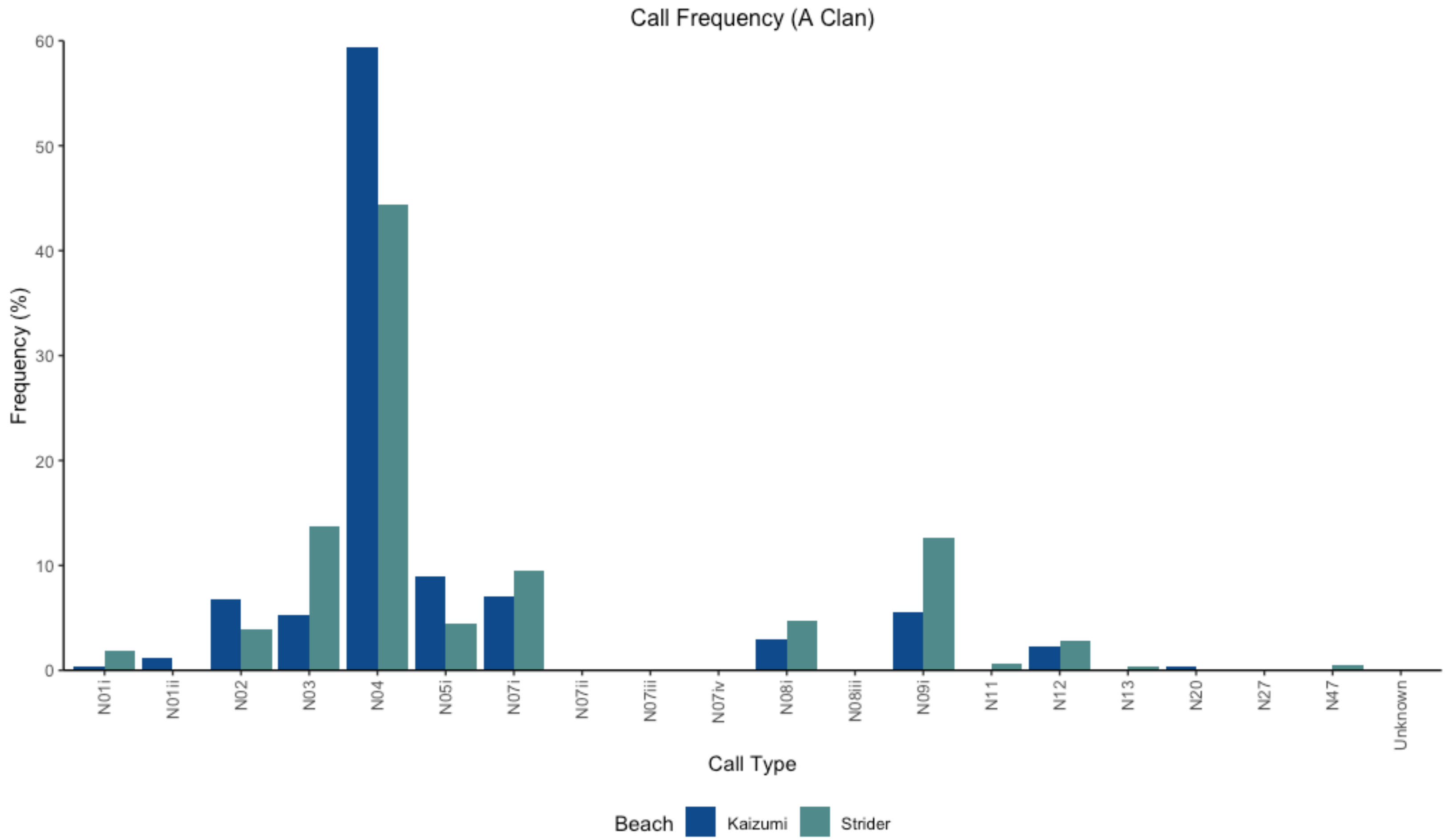

Figure 0.11 **Discrete call occurrence frequency identified for A clan during beach rubbing events between 1 July and 5 September 2021 at Strider and Kaizumi rubbing beaches in the Johnstone Strait, British Columbia, Canada. Graph is organized by the beach where the call was identified and is arranged in alphanumerical order by the discrete call name.**

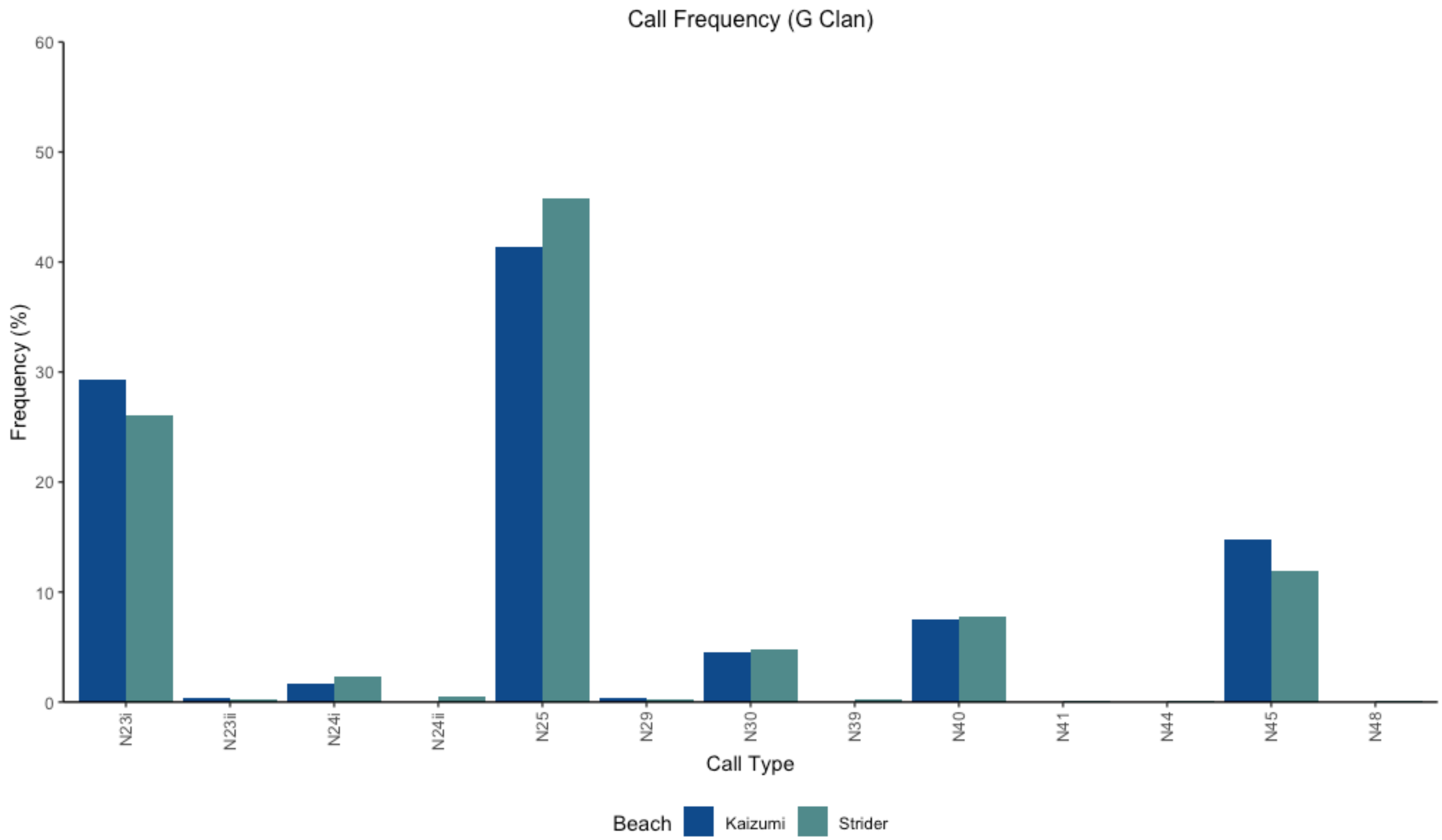

Figure 0.12 Discrete call occurrence frequency identified for G clan during beach rubbing events between 1 July and 5 September 2021 at Strider and Kaizumi rubbing beaches in the Johnstone Strait, British Columbia, Canada. Graph is organized by the beach where the call was identified and is arranged in alphanumerical order by the discrete call name.

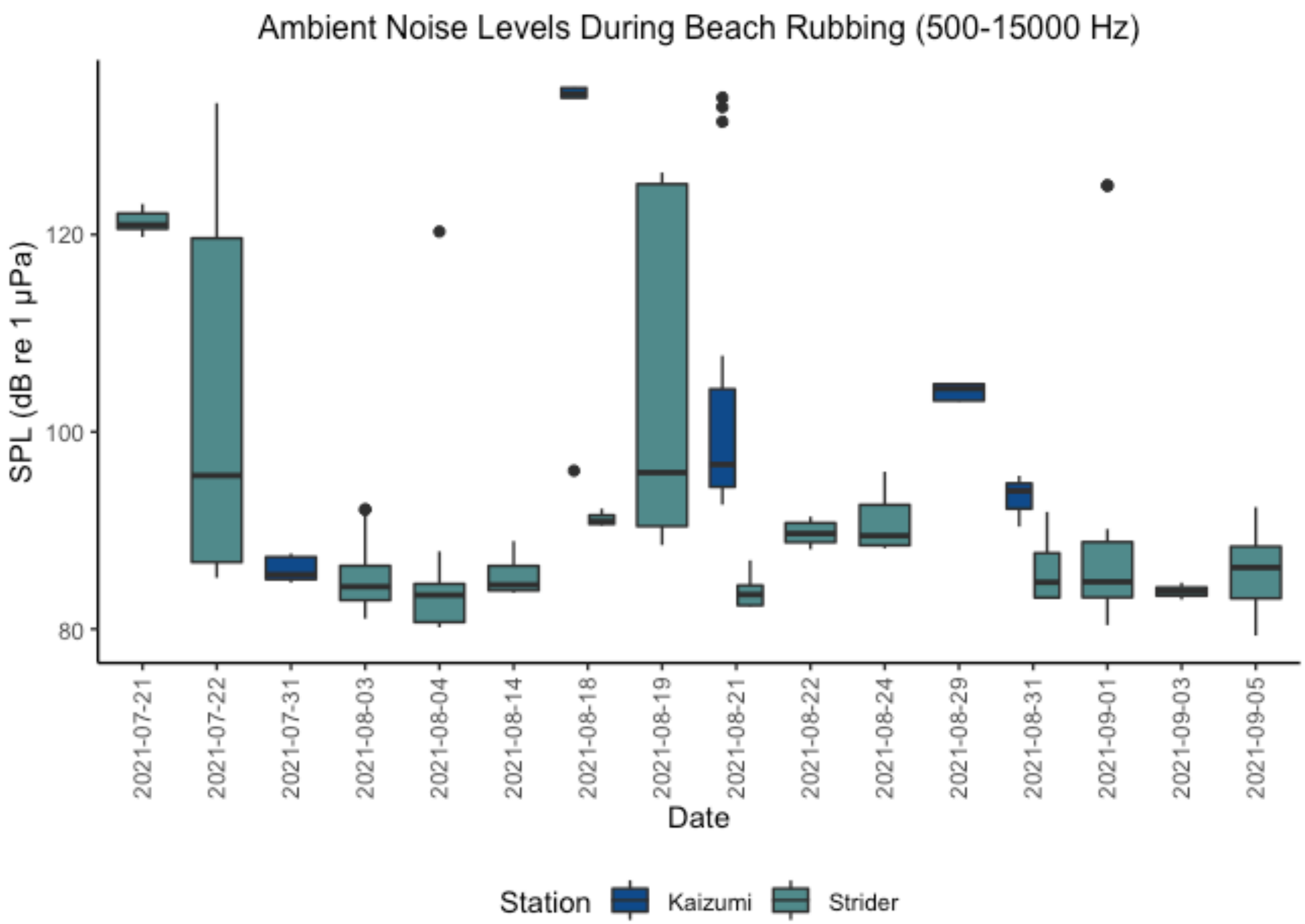

Figure 0.13 **Ambient noise levels analyzed at Strider and Kaizumi during beach rubbing events between 1 July and 5 September 2021 in the Johnstone Strait, British Columbia, Canada.**

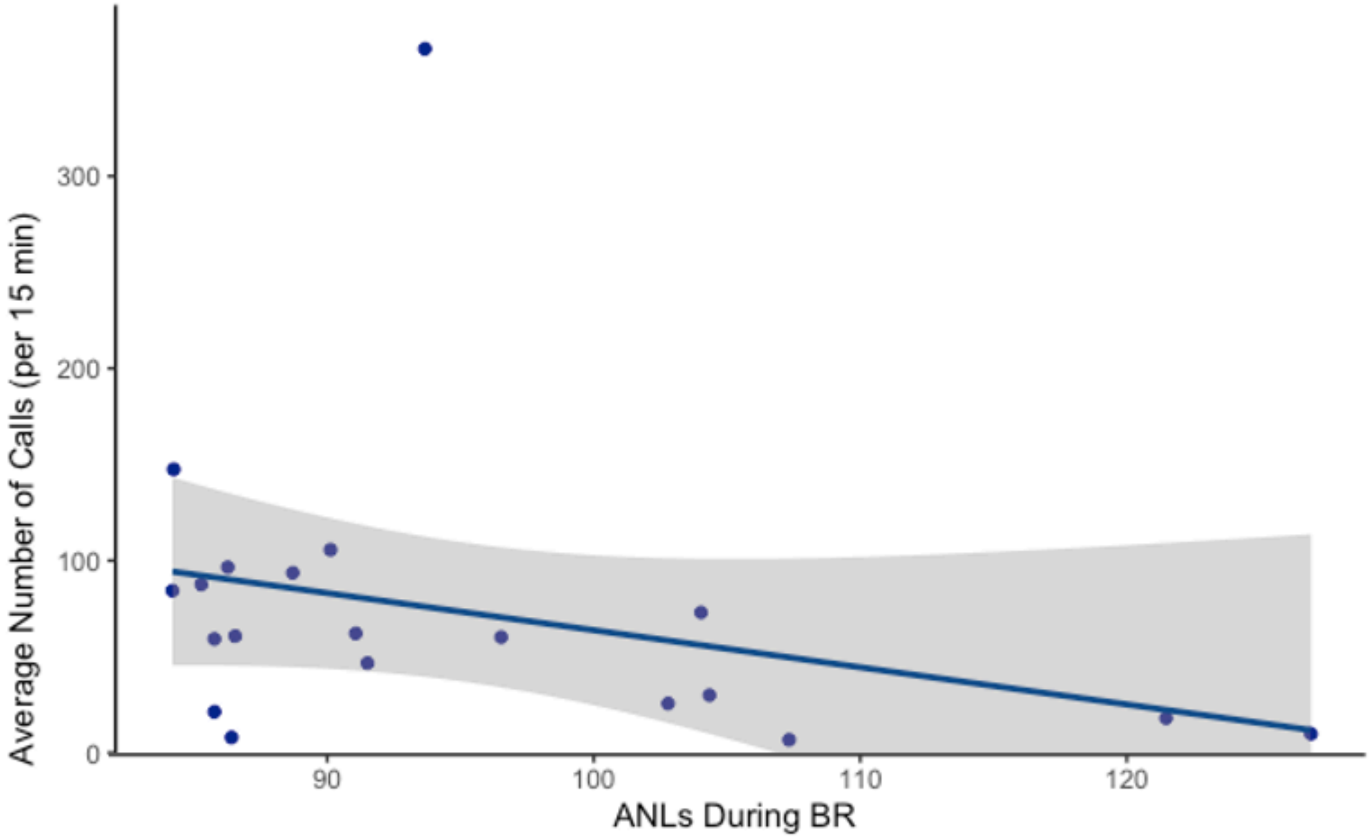

Figure 3.10 **Correlation between average ambient noise levels (dB re 1 μPa) and average call rates (per 15 minute interval) at Strider and Kaizumi during beach rubbing events between 1 July and 5 September 2021 in the Johnstone Strait, British Columbia, Canada. The Spearman rank correlation coefficient indicates a negative relationship, where as ambient noise levels increase the average call rate decreases (*S*=1970, *df*=18, *p*=0.03327, *rho*=-0.481).**

it is possible that calls from NRKW that were travelling towards or away from Strider were identified as well.

No significant difference was found in the observed and expected frequencies between Kaizumi and Strider (p=0.6703). Acoustic data showed that while nine A clan beach-rubbing events occurred at Strider, only one occurred at Kaizumi on August 31. This event identified higher frequencies of N05 and N07 calls compared to N03 and N09 calls, but the low sample size at Kaizumi makes it inappropriate to discuss reasons for this difference. Further research is needed to determine if there is a true difference in A clan call occurrence frequencies between beaches within and outside of RBMBER. These studies may need to expand their methods to include multi-year data, or to expand the study periods to times outside of the 09:00-16:30 range.

G Clan

Of the 2413 discrete G clan calls annotated, N25 (n=1083), N23i (n=643), and N45 (n=302) were the most frequently identified during beach rubbing. Unfortunately, while previous studies on G clan vocalizations have focused on overall call frequencies, there is minimal discussion on the rates of individual calls for various behaviours. Results from the 1978-1983 assessment (n=821) found that in general, N23 (~35%), N25 (~25%), and N24 (~22%) were the most frequently identified calls across the I11 pod (Ford 1991). Based on the 2021 beach rubbing assessment, both N25 and N23i (which comprised approximately 45% and 27% of all identified G clan calls, respectively), have remained important for the I11 pod. N24 calls, however, made up less than 3% of the total 2021 beach rubbing calls (N24i = 2.2%, N24ii = 0.3%) compared to the approximate 22% in 1978-1983 (Ford 1991). These results may indicate that N24 calls are used during lower-arousal circumstances. Furthermore, while N45 was frequently identified during beach rubbing in 2021 (~13%), it was minimally identified in the 1978-1983 assessment (<5%) (Ford 1991). Similar to the A clan N03 call, N45 was strongly associated with instances of low arousal rather than high-arousal activities such as beach rubbing (Ford 1991). This increase could be the result of matrilineal hierarchy changes, but further inferences cannot be made because of the different scale size between studies.

No significant difference was found between G clan call types performed at Strider and Kaizumi. Similarities in call frequencies could be the result of the data being isolated to one G clan pod, I11. Overall observations of I11 pod showed variations of matrilineal groupings between the I4, I27, and I65 matrilines only. Studies on variations of A clan matrilineal unit interactions have shown that vocal behaviour, including the use of discrete call types and subtypes, is more affected by which matrilines are present during the encounter than by the behaviour being performed (Weib et al. 2007). Though an assumption can be made that the same is true for all NRKW clans, studies focusing on G clan vocalization patterns should be performed to better understand the relationship between activity states and call type frequencies.

Effects of Ambient Noise Levels

Differences in the ANLs between the beaches during rubbing and post-rubbing tended towards significance, while pre-rubbing ANL differences were significant. Furthermore, Kaizumi ANLs were, on average 10.64 dB higher. This difference in dB levels indicates a ten-fold increase in sound intensity, as it is measured on a logarithmic scale, and a 3 dB increase alone indicates a doubling in sound intensity (Katz et al. 2010). The large discrepancy in ANLs is likely the result of RBMBER, which creates a half nautical mile (0.5 nm) long 'voluntary no-go zone' around both Strider and Main. Despite RBMBER being a voluntary no-entry area with no legal repercussion for entry, majority of private vessels during the 2021 assessment and in previous years remained outside of the boundaries (V. Rani, pers. comm). Additionally, because most ecotourism vessels promote environmental education and sustainability (Kur and Hvenegaard 2012, Wearing et al. 2014), crossing the boundaries of a killer whale sanctuary can have negative consequences on marketing and business. As a result, once NRKW enter RBMBER, whale watching boats tended to leave the area given the distance between the boundary and rubbing beaches (N. Rammell, pers. comm). When coupled with the BeWhaleWise guidelines that state that vessels should proceed at speeds of less than seven knots when within 1000 m of whales (BeWhaleWise.org, n.d.), decreased ANLs are more likely within RBMBER than in other coastal areas of BC. Average ANL differences between baseline and vessel slowdown periods off the coast of the San Juan Islands, for example, marked only a -2.1 dB decrease (Joy et al. 2019). Given that international directives recommend that ANLs remain below 100 dB re μPa (Tasker et al. 2010), and that average levels in Strider are well under this (92.15 ± 2.74 dB re 1 μPa), the preference that NRKW exhibit towards beaches within RBMBER compared to Kaizumi both in total event occurrences

($n_{Strider}$=15, $n_{Kaizumi}$=5) and event lengths between beaches (*W*=15.5, *df*=18, *p*= 0.0595) is clear.

Increases in ANL, especially within the same frequency range of NRKW vocalizations, can have detrimental effects. A ten dB difference equates to a ten-fold increase in energy levels (Erbe 2011), and the 11 dB difference between beaches within and outside RBMBER can cause shifts in behavioural patterns and auditory capabilities. Auditory threshold shifts are a large concern for cetacean populations, as they can cause temporary or permanent hearing loss and subsequently alter both physical and acoustic behaviours (Erbe 2011). Southern resident killer whales, for example, are shown to increase their call amplitude by one dB for every equal increase in ANL (Holt et al. 2009). If ANLs between beaches remain significantly different, a similar shift in acoustic effort may be seen by NRKW rubbing at Kaizumi. Correlational results between ANLs and average call rates show that NRKW used less discrete calls at higher ANLs, though further research should be done to determine if causation is present. Given that the current theory on beach rubbing functionality is primarily cultural, it is possible this decrease is a mechanism to save energy for other vital behaviours. Increased effort will likely cause a shift in NRKW bioenergetics and create long-term consequences for vital behaviours such as foraging and reproduction (Holt et al. 2009).

Vessel noise clearly plays a role in the ANL differences between beaches, as the majority of 2021 vessel sightings complied with the RBMBER boundaries in 2021 (V. Rani, pers.comm). The majority of vessel sightings (71%) taken within the study site were of small boats that emit noise in the same frequency band as NRKW communication. This proportion may under-represent the true number of vessel presence contributing to increases in the 500-15000 Hz range, as relevant literature on the effects of vessel noise fails to provide exact definitions of “small” vessels (Erbe 2002, Erbe et al. 2019). Small vessels in this study were defined as those less than 30 ft in length, but it is possible that vessels up to 50 ft in length may be included in other datasets. It is also important to note that there are many variables besides vessel noise that contribute to mid-frequency ANLs, such as weather patterns, depth, and overall sea-surface agitation (Morris 1978, Farmer & Lemon 1984, Dahl et al. 2007, Hildebrand 2009). Because vessel sightings were used primarily as a summary statistic to determine what vessels were present the most within the study site, the relationship between ANLs and number of vessels present per encounter were not studied. Future acoustic studies should focus on the proportion of noise that each variable contributes at beaches within and outside RBMBER to achieve a clear understanding of the role vessel noise plays in these differences.

The significant differences ANLs seen at Strider between pre-beach rubbing and during beach rubbing (V=85, df=18, p=0.00341), as well as the trend towards significance in between beach rubbing and post-beach rubbing activities (V=73, df=18, p=0.05737), show different trends than expected. In 84% of Strider events, ANLs were seen increasing between pre-beach rubbing and during beach rubbing instances and decreasing in 73.3% of events between during and post-beach rubbing events. These results, coupled with low correlational levels between ANLs and the length of beach rubbing events (S=1695.7, df=18, p=0.2407, rho=-0.275), indicate that once NRKW make the decision to rub within RBMBER, changes in background noise do not carry a significant effect on how long they beach rub or when they decide to stop. Tandem studies found similar results, where decreasing distances between vessels and Strider had no effect on NRKW beach rubbing probability (V. Rani, pers. comm).

No significant differences were found at Kaizumi between either the pre-beach rubbing and beach rubbing ANLs (V=6, df=4, p=0.8125) or between the beach rubbing and post-beach rubbing ANLs (V=11, df=4, p=0.4375), likely because of small sample sizes (n=5). Interestingly, while the trend downward in ANLs observed at Strider was seen in four out of five Kaizumi events from during to post-rubbing instances, the trend upward in ANLs between pre- and during rubbing instances was not seen. Because Kaizumi is located outside of RBMBER, vessel restrictions and guidelines are limited to the BeWhaleWise guidelines, which requires vessels to maintain only a 200-m distance from NRKW rather than the 926-m distance imposed by RBMBER (BeWhaleWise.org n.d.). As vessel distances decrease from 1000 m to 200-400 m within Kaizumi, the probability of beach rubbing decreases (V. Rani, pers. comm). These results are similar to previous modeling where killer whales exhibit behavioural changes at close-range (i.e., <400 m) vessel presence (Erbe 2002).

It is likely that since the creation of RBMBER in 1982, NRKW have developed a cultural or behavioural preference to the lower levels of vessel presence and subsequent ANLs within the killer whale sanctuary. Rubbing beaches within the Johnstone Strait have long been considered important sites for the NRKW population, with seasonal returns to the area for foraging and beach rubbing (Ford et al. 2017). Deterrence from habitat because of increased ANLs have been shown in other areas like the Broughton Archipelago, where significant decreases in whale occurrence occurred during fish farm implementation of acoustic harassment devices (Morton & Symonds 2002). While multi-year studies should be performed to increase the sample size of Kaizumi beach rubbing events, the obvious preference for beaches within RBMBER, such as Strider, may be an indication of an acoustic stressor presence at Kaizumi.

Next Steps

There are many factors besides increased ANLs that may contribute to the preference that NRKW have for rubbing at the Strider beach within RBMBER. Because data from the Main rubbing beach could not be analyzed, it is important to note that there are many opportunities for future research to strengthen the findings reported here. A study using night-time beach rubbing events at Kaizumi, for example, may show lower ANLs due to the decreased vessel presence within the Johnstone Strait and provide a comparative study on how ANLs affect beach rubbing at Kaizumi. Studies on how other environmental factors, such as beach composition and structure, bathymetry, tidal heights, and weather patterns affect beach rubbing events and acoustics at all three beaches is imperative to determine if the correlation between increased ANLs and beach preference is equal to causation. Regardless of the need for further studies, however, the high ANLs recorded at Kaizumi should be mitigated to prevent the marine soundscape from further degradation.

Given the lower ANLs observed at beaches within the RBMBER and the preference of NRKW to these beaches, it is recommended that the boundaries of RBMBER be expanded to include the Kaizumi rubbing beach. Expanding RBMBER by approximately 4.5 km to the west will not only incorporate Kaizumi within the 'voluntary no-go zone', but it will also provide a sufficient buffer zone (i.e., ~800 m to the west, 926 m to the north) between the beach and RBMBER's boundaries to deter vessels from approaching rubbing NRKW. Access to the Vancouver Island shoreline within the expansion should also be restricted to prevent the public from camping on Kaizumi. To increase awareness of the new boundaries, a one-year "pre-expansion" campaign should be carried out to provide sufficient notice to vessels. This campaign may include installing informative signs at nearby marinas (e.g., Telegraph Cove, Alert Bay, Port McNeill), sending out notices to ecotourism companies, and educational "dock talks" performed by members of relevant non-profits such as the CETUS Research and Conservation Society or OrcaLab. Following the expansion, a one-year “grace period” where no fines are provided should be considered for those camping on Kaizumi; however, because the marine portion of RBMBER is a ‘voluntary no-go zone’, no grace period is necessary for vessels that cross the boundary. Educational interactions between these vessels and the Robson Bight Marine Warden Program should continue in the same manner as previous seasons.

It is also recommended that the BeWhaleWise guidelines are modified to increase the suggested distance between vessels and NRKW from 200 m to 400 m, similar to the current guidelines set out for SRKW. Results of this study and others have shown the increased ANLs have a significant effect on the life history and behaviours of killer whales (Erbe 2002, Morton & Symonds 2002, Holt et al. 2009, Williams et al. 2009a). As such, minimizing these effects as soon as possible may mitigate severe long-term impacts on the acoustic capabilities of NRKW. Furthermore, engine disengagement rules are currently only set in place by the Washington State government; no rule or guideline about engines exists for Canadian waters (BeWhaleWise.org n.d.). Canadian government regulations should be amended to include mandatory engine disengagement if killer whales appear within 400 m of the vessel.

Modifications to both RBMBER and the BeWhaleWise guidelines are not easily carried out. Provincial and federal legislation, as well as opposition from ecotourism industries and public opinion, are all things to consider should these recommendations be accepted. However, the amelioration of the marine soundscape is a necessary treatment to restore NRKW critical habitat and should be prioritized.

Conclusion

Resident killer whales are complex, cultural animals that rely on the marine soundscape as a critical component of their habitat (DFO 2018, Riera et al. 2019). As the popularity of observing charismatic megafauna in captive settings declines (Wassermann et al. 2018), the potential rise in demand for eco-tourism will increase ambient noise levels off the coast of BC. Rubbing beaches within RBMBER are protected by a ‘no-go zone’ that is respected by the majority of ecotourism and private vessels. As a result, the marine soundscape of these beaches and surrounding area experience lower levels of acoustic degradation. Beaches that lie outside RBMBER, however, are subjected to increased vessel exposure and noise, degrading the acoustic environment of a traditionally important NRKW site. An expansion of the RBMBER boundaries by approximately 4.5 km westerly to encompass and adequately protect the Kaizumi rubbing beach would result in the long-term decrease of the area’s ambient noise levels. It is likely that this expansion would cause a shift in the use of Kaizumi by NRKW in a similar way that the removal of acoustic harassment devices in the Broughton Archipelago re-established baseline use of the habitat (Morton & Symonds 2002). The functional use of beach rubbing remains poorly understood, but regardless of its purpose, the intrinsic value that comes from protecting culturally relevant behaviours in a complex population is important.

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Appendix A. Supplementary Methods

Table A5 A list and description of vessel data collected.

Vessel Data	***Description***
Vessel Type	
Size	*Small*: <30 ft.
	Medium: 30-80 ft.
	Large: >80 ft.
Hull Type	*Monohull*: Single hull (e.g., kayaks and most motor vessels).
	Catamaran: Two hulls.
	RHIB: Rigid-hull inflatable boats (e.g., zodiac vessels).
	Landing craft: Lowerable ramp, often at the bow. May be flat-bottomed.
	Other: Specified in the 'Notes' column.
Engine Position	*Inboard*: Engine located inside the boat.
	Outboard: Engine located outside and visible on the boat.
	None: No engine on the vessels (e.g., kayaks and canoes).

Table A6 **A list and description of killer whale data collected. Descriptions taken from DFO (2021) and CETUS Research and Conservation Society (N. Rammell, pers. comm.).**

Killer Whale Data	***Description***
Group Size	The best guess at the number of killer whales in the group
Group Spread	*Alone*: Solo animal *Tight*: Within one body length of each other. *Loose*: Within five body lengths of each other *Dispersed*: Within ten body lengths of each other.
Group Configuration	*Flank*: Whales arranged side-to-side. *Linear*: Whales arranged head-to-tail. *Non-Linear*: Whales arranged in no particular orientation within the group.
Behaviour	*Traveling:* Killer whales swim consistently in the same direction for three or more surfacings, often grouped up and moving quickly to their destination. *Foraging:* Killer whales are loosely organized and show frequent directional changes. *Resting:* Killer whales form a resting line, and their speed slows to approximately 1 knot. *Socializing:* Killer whales show frequent signs of surface-active behaviours which may include spy-hopping, beaching, pectoral fin slapping, or tail lobbing. *Beach Rubbing:* Killer whales enter on of the known rubbing beaches or are within 50 m of a gravel beach; bubbles, splashes, and circling fins are observed.

Table A7 **Relevant GPS coordinates.**

Characteristics	***Latitude***	***Longitude***
Theodolite (Eagle Eye)	50.52328° N	-126.5974° W
Main Hydrophone	50.48678° N	-126.5225° W
Strider Hydrophone	50.48825° N	-126.5324° W
Kaizumi Hydrophone	50.51319° N	-126.6738° W

Table A8 A list and description of all measurements collected.

Measurement	*Description*
Begin File	Includes the name of the sound clip the annotation is associated with.
Begin Time (s)	Where the annotation begins relative to the entire clip.
End Time (s)	Where the annotation ends relative to the entire clip.
Dur 90% (s)	The sound pressure levels that are exceeded 90% of the time of the measurement period (Shore Gold 2010).
Low Freq (Hz)	The lowest limit of the annotation's frequency.
High Freq (Hz)	The highest limit of the annotation's frequency.
Freq 25% (Hz)	Frequency levels that are exceeded 25% of the time of the measurement period.
Freq 75% (Hz)	Frequency levels that are exceeded 75% of the time of the measurement period.
Avg Power Density (dB FS)	Average amplitude levels of the measurement period.
Peak Power Density (dB FS)	Peak amplitude levels of the measurement period.
Energy	The energy of the isolated acoustic wave.
Overlap	Filled in: Y = if there was overlap with another call, or if there was overlap with a distinct non-call.
Call Type	Filled in with the name of the NRKW call annotated.
Call Certainty	Filled in: 0 = if uncertain about the call type, and 1 = if certain about the call type.
Non-Calls	Includes sounds that are not defined as calls, where: B = NRKW Buzz, BR = Beach Rubbing, W = NRKW Whistle, S = NRKW "Squawk" VN = Vessel Noise, Y = Undefined Non-Call.
To Verify	Filled in: 1 = if calls needed to be verified with the DFO, and 2 = if they had been verified. If calls did not need to be verified, this section was not filled in.
Vessel Noise	Filled in: Y = if vessel noise was present at the time of the call. If vessel noise was not present, this section was not filled in.
Comments	Any extra comments, for example: the potential pod or matriline call type.

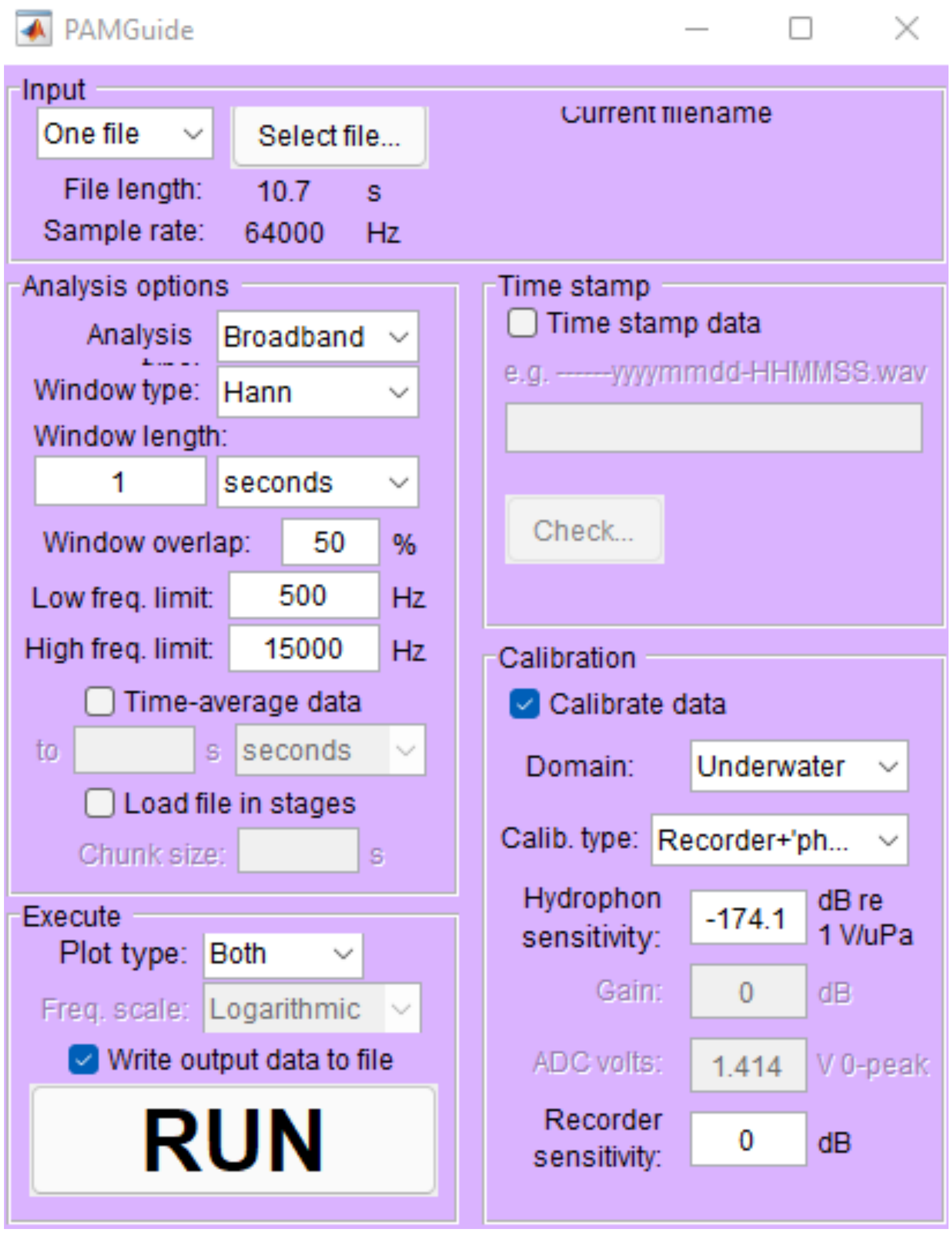

Figure A1 **PAMGuide window showcasing the settings for each .wav file analyzed for ambient noise analysis. Settings are based on desired output data and ranges, as well as calibration settings.**

Appendix B. Supplementary Results

Table B2 A breakdown of data collection, including the number of killer whales seen every day. Asterisks (*) represent sightings of transient killer whales, and days of no data collection (NDC) are recorded.

Date	*Number of KW Present*	*Date*	*Number of KW Present*
2021-07-01	0	2021-08-04	8
2021-07-02	0	2021-08-05	0
2021-07-03	0	2021-08-06	4
2021-07-04	4*	2021-08-07	0
2021-07-05	0	2021-08-08	7
2021-07-06	0	2021-08-09	0
2021-07-07	6*	2021-08-10	0
2021-07-08	9	2021-08-11	5
2021-07-09	0	2021-08-12	0
2021-07-10	0	2021-08-13	0
2021-07-11	0	2021-08-14	7
2021-07-12	0	2021-08-15	6*
2021-07-13	0	2021-08-16	2
2021-07-14	NDC	2021-08-17	7
2021-07-15	0	2021-08-18	8
2021-07-16	0	2021-08-19	11
2021-07-17	7	2021-08-20	NDC
2021-07-18	0	2021-08-21	7
2021-07-19	NDC	2021-08-22	10
2021-07-20	7	2021-08-23	NDC
2021-07-21	6	2021-08-24	10
2021-07-22	6	2021-08-25	6
2021-07-23	0	2021-08-26	10
2021-07-24	0	2021-08-27	25
2021-07-25	0	2021-08-28	5
2021-07-26	NDC	2021-08-29	8
2021-07-27	0	2021-08-30	0
2021-07-28	0	2021-08-31	16
2021-07-29	8	2021-09-01	20
2021-07-30	NDC	2021-09-02	8
2021-07-31	14	2021-09-03	27
2021-08-01	0	2021-09-04	NDC
2021-08-02	NDC	2021-09-05	13
2021-08-03	9		

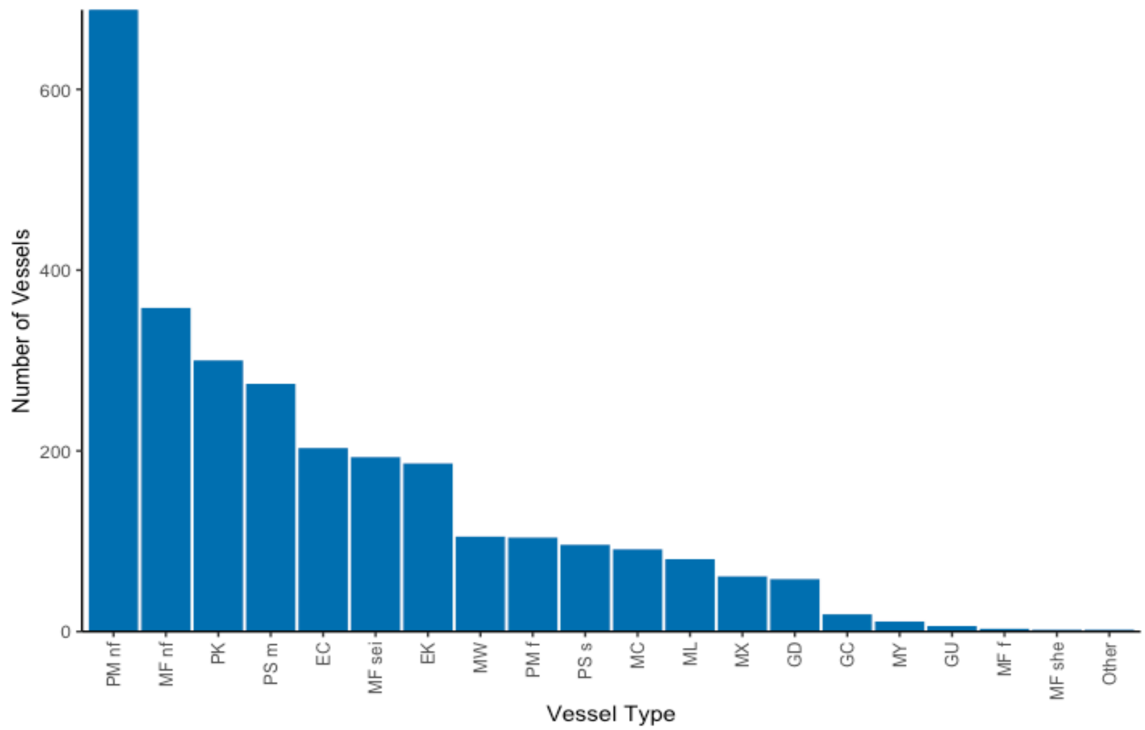

Figure B2 **Frequency of all vessel types sighted in the study site for the assessment of vessel noise impacts on NRKW communication while beach rubbing in the Johnstone Strait, British Columbia, Canada. The following shorthands are used: PM nf (private motor – not actively fishing); MF nf (maritime fishing – not actively fishing); PK (private kayak); PS m (private sail – motoring); EC (ecotour Canadian); MF Sei (maritime fishing – actively fishing, seining); EK (ecotour kayak); MW (maritime tug with tow); PM f (private motor – active fishing); PS s (private sail – sailing); MC (maritime charter); ML (maritime tug with log tow); MX (maritime cargo/shipping/tug, no tow); GD (government, DFO); GC (government coast goard, Canada); MY (maritime ferry); GU (government coast guard, USA); MF f (maritime fishing – actively fishing, type unknown/other); MF she (maritime fishing – actively fishing, shellfish).**