Exploring salmon reaction to playback noise exposures in Eagle River, Cook Inlet, AK

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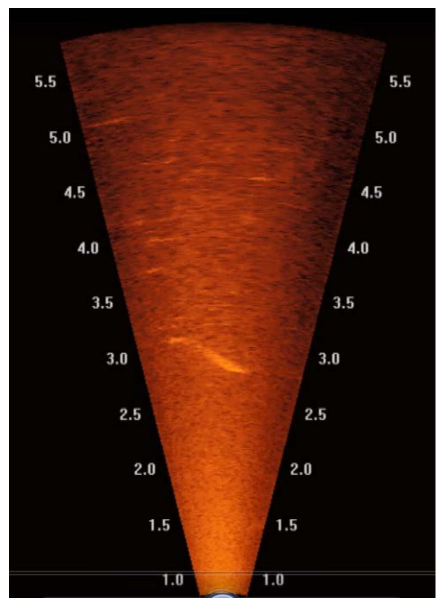

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1. Background

Following a dramatic decline, the Cook Inlet beluga (CIB) population was listed as endangered in 2008. A decade later, this population has shown no sign of recovery, and the causes of this lack of recovery remain unclear. One major threat to the population is anthropogenic noise (NMFS 2016). Studies on the type of anthropogenic noise and their levels within critical habitat have been recently completed (Castellote et al. 2018), and a research project on the effects of noise on CIB is undergoing (see below). However, to date there has been no effort to investigate the effect of anthropogenic noise on the main CIB prey, Pacific salmon species. NOAA Fisheries is currently regulating noise exposure to marine mammals under the Marine Mammal Protection Act and the Endangered Species Act. However, noise impact mitigation is focused on CIB independently of any potential effect on its prey. Research on the effects of noise on salmon species in other regions has been primarily focused on the near-field, where direct physiological impact occurs, aiming to understand survival to exposure, but not on behavioral responses (e.g. Caltrans 2010, Halvorsen et al. 2012, Bagocius 2015). Behavioral effects in other species, such as pelagic fish (sprat *Sprattus sprattus*, and Atlantic mackerel *Scomber scombrus*) can occur at much greater distances from the source than sound levels that can do physical harm, and they almost always involve a lower onset threshold than tissue injury or damage to the auditory system (Hawkins et al. 2014). These playback studies indicate that fishes can show strong behavioral reactions to impact pile driver strikes at ~163 dB_{peak}, and NOAA fisheries and US Fish and Wildlife Service currently defines an arbitrary threshold for behavioral response on ESA-listed fish species (salmon and bull trout) at 150 RMS dB.

Passive acoustic monitoring studies in Cook Inlet suggest anthropogenic noise has the potential to displace CIB (Small et al. 2017). Disturbance from anthropogenic noise may result in the spatial displacement of CIB or reduction in their feeding efficiency, and the consequent loss of foraging opportunities. This behavioral reaction could be caused by the direct harassment to beluga by noise exposure, or as an indirect effect by changes in behavior of their prey.

JISAO is directly involved in a NMFS funded research project to ADF&G (with M. Castellote as co-PI) with the aim to characterize CIB spatial displacement by anthropogenic noise in key foraging areas. This project started in 2017 and will be completed in 2020. Passive acoustic monitoring is applied to detect beluga and anthropogenic noise occurrence, and occupancy modeling is applied to investigate levels of displacement in monitored foraging grounds.

This research starts a new research line complementing the current efforts to understand the effects of anthropogenic noise on CIB, by incorporating CIB prey responses to noise. The study aim at testing the feasibility of monitoring salmon reaction to playbacks of anthropogenic noise using active acoustics techniques in one of the key CIB feeding grounds, Eagle Bay, in Knik Arm, northern Cook Inlet, AK.

2. Objectives

This feasibility study has 2 objectives:

1) Proof of concept: Testing the feasibility of using a dual-frequency identification sonar (DIDSON) to observe adult salmon behavioral reactions to pre-recorded anthropogenic noise (commercial ship and impact hammer pile driver) at the mouth of Eagle River.
2) Behavioral response: Testing if playbacks of ship noise and impact hammer pile drive strikes at source levels up to 170 RMS dB, generate any visible behavioral response in adult salmon.

3. Methods

3.1 Study area:

The mouth of Eagle River is located in Knik Arm, in an embayment heavily used by CIB in late summer and fall, when several adult salmon species are returning to spawn in natal rivers (Houghton et al. 2005). Adult salmon runs in Eagle River typically begin in May and peak in July (Satre et al., 2018), but during this period CIB focus their feeding efforts largely in the Susitna Delta region. By mid-August CIB shift their foraging efforts to Knik and Turnagain Arms (Castellote et al. 2016), thus early summer provides an opportunity to test salmon behavioral response in Eagle River with low risk of exposing CIB to noise. The mouth of Eagle River has been the base for extensive CIB behavioral observations by C. Garner, as it is adjacent to a live-ammunition firing range within the Joint Base Elmendorf Richardson (Fig. 1).

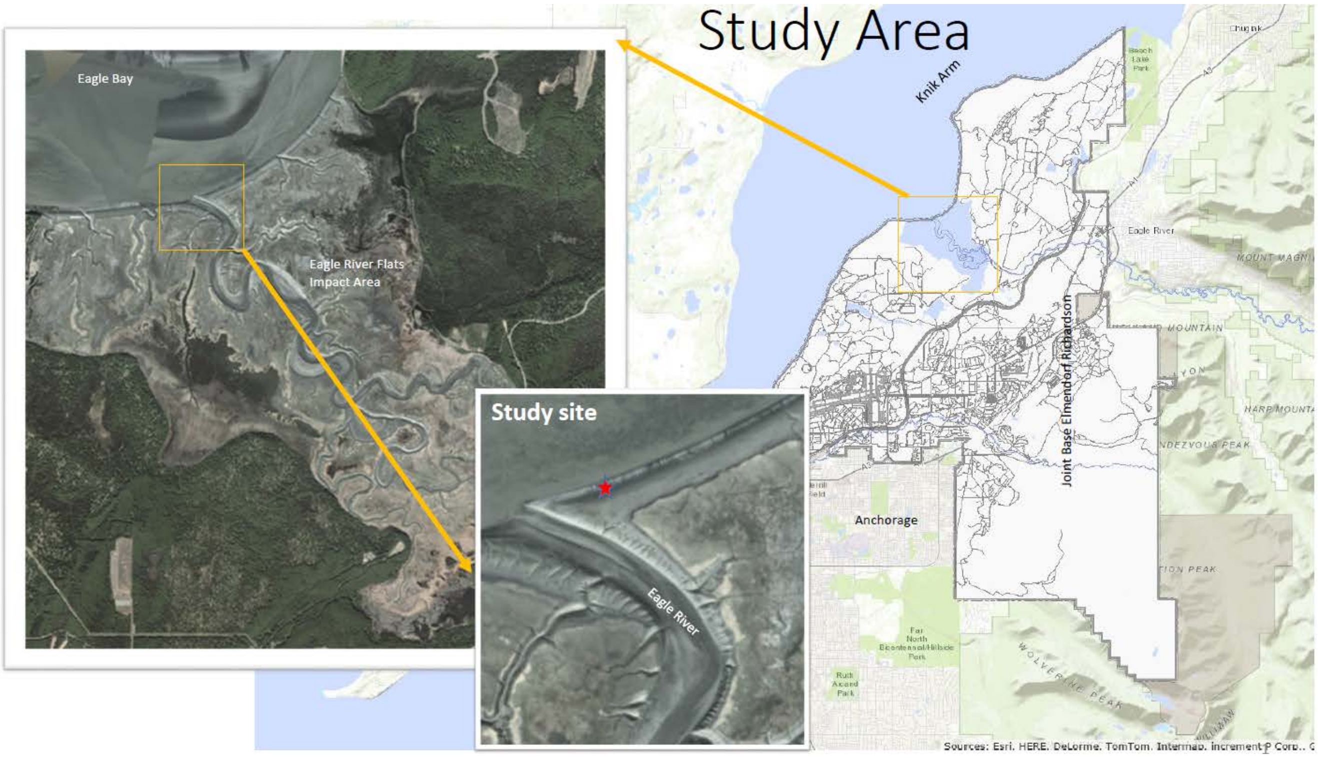


Figure 1: Eagle Bay in Knik Arm, Upper Cook Inlet, AK, with a satellite view of the Eagle River flats that are part of the U.S. Army fire range zone. The red star in the close-up image of the mouth of the river indicates the study site where the DIDSON and underwater speaker where placed.

The site was selected after testing several locations at the east river bank, both towards the river channel and towards the bay. The steepness of the bank, mud consistency, as well as its topography, was better suited on the bay side, thus the study was conducted projecting noise and observing salmon passing eastwards with the incoming tide, and westwards with the ebbing tide.

3.2 DIDSON transducer and speaker system setup

In order to adjust the position and the inclination of the projetion and field of view, the system was mounted on a custom made platform that allowed continued adjustments while running trials (Fig. 2). Because the tidal swing in this area of Knik Arm is extreme, the platform needed to be mobile, but heavy enough to be stable and resist the current drag. We used a large game sled where we built a fortified wood frame to support a aluminum tripod. We installed a car jack underneath the proximal leg of the tripod, with the purpose to allow adjustement of the angle of view and projection. A custom built 8 feet long handle connected to the car jack allowed us to adjust the angle of view while the tripod was submerged. Initial tests showed that the platform was a little light, and therefore unstable in the current flow, thus we added two pieces of railroad truck weighting 40 lbs each that we attached to the proximal end of the sled to solve the problem.

Figure 2: Custom built sled and adjustable tripod to deploy the DIDSON and underwater speaker system in the beach, allowing adjustments while submerged. The sled was pulled or lowered every few minutes to follow the tide.

A DIDSON 300 m transducer, with telephoto lens, and a Lubell LL916C-025 underwater speaker were mounted on a plate and attached to the tripod. We fixed the DIDSON and speaker in a slightly convergent angle to maximize the overlap between the field of view and the sound projection zone (Fig. 3). The instruments were screwed in the plate to make sure the angle would not change throughout the experiment trials, and the field of sound projection within the field of view was calibrated once all trimmings in the customized set up were complete (see calibration section below).

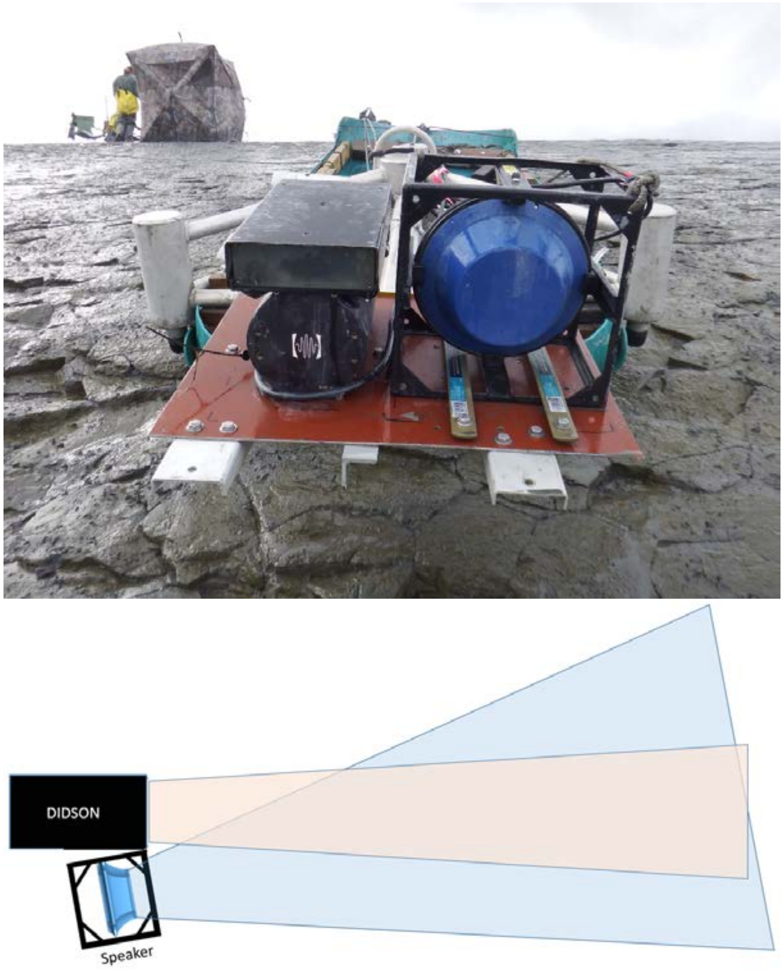


Figure 3: Picture - Frontal view of the plate holding the DIDSON (left) and underwater speaker (right) system. Drawing – Schematic of the overlap in field of view and field of sound projection (overemphasized for simplicity in representation).

The computer running the DIDSON software, and the sound production system were placed in a smaller game sled to keep the equipment away of the mud, and the sled was placed inside a pop-up hunting blind to protect the equipment from the rain and provide shadow to the DIDSON screen (Fig. 4).

Figure 4: Pop-up hunting blind protecting the laptop and sound system. The sled is semi submerged on the left placing the DIDSON transducer and speaker underwater.

3.3 Sound playbacks

Four types of sound files were included in this study:

1) Noise of a common containership operating in Cook Inlet (Matson Anchorage, crossing CIB critical habitat twice per week year-round) recorded with a bottom-mounted acoustic recorder in Cook Inlet. Ship distance was approximately 1.5 km from the recorder.
2) Strikes from an impact hammer pile driver (Delmag D62-22, 13.5 ton) on a 36 inch diameter pile from Port McKenzie (adjacent to Anchorage) recorded with a bottom-mounted acoustic recorder in Cook Inlet. Pile driver was 1.4 km from the recorder. These are labeled as “round pile” in the analysis.
3) Strikes from an impact hammer pile driver (Delmag 62 single-action, 7.6 ton) on a sheet pile from the Port of Anchorage recorded with a bottom-mounted cable hydrophone array in Cook Inlet. Pile driver was 16 m from the recorder. These are labeled as “sheet pile” in the analysis.

We used 2 additional sound files, on an exploratory basis:

4) Echolocation click trains of a beluga whale recorded with an acoustic suction cup tag in Bristol Bay.
5) Beluga calls recorded with a bottom-mounted acoustic recorder in Cook Inlet.

These recordings were conditioned to be played back using an underwater speaker Lubell LL916C-025, AC205C transformer, Rolls RA2100b Power Amplifer, and TASCAM DR100 MKIII portable player/recorder. The playback system had a frequency response of 200 Hz to 23 kHz (+/-3 dB) and maximum output level of 180 dB re 1 µPA @ 1kHz.

3.4 Sound playback system calibration

Prior to any trial exposing fish to noise, the system was calibrated to obtain precise information on the received levels at different distances from the speaker, and both on axis and at the edge of the DIDSON field of view at 4 different distances (Fig. 5). Measurements were done at multiple gain levels. Calibration was completed using a hydrophone RESON TC4034 and amplifier VP2000 connected to a sound acquisition board I/O Tech DAQ3000 operated from a laptop PC.

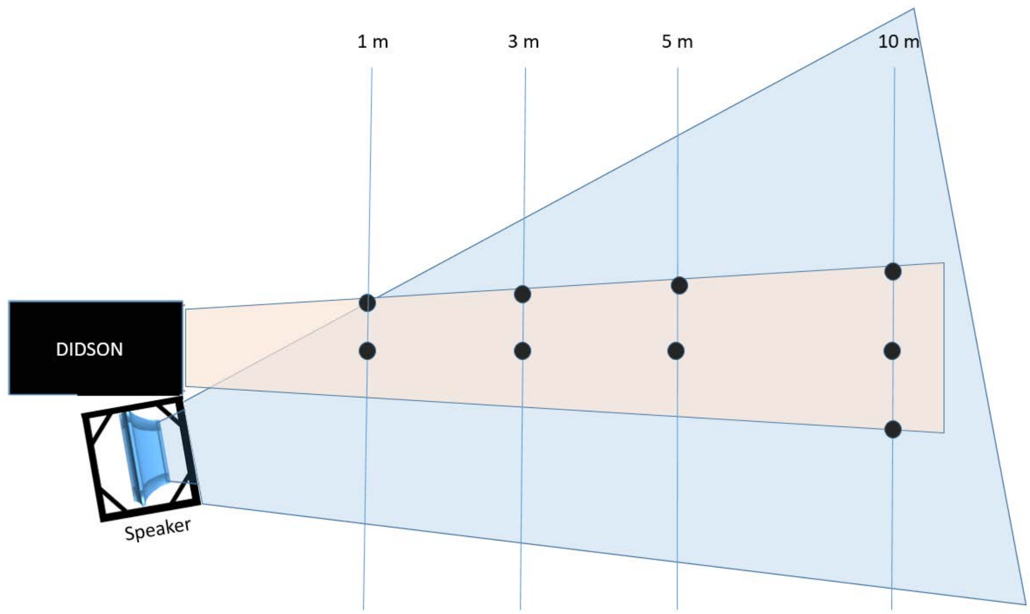


Figure 5: Calibration set up showing the sampling design to obtain received levels within the DIDSON field of view. Black dots denote the locations were received levels were measured.

3.5 Analysis of behavioral response to playback exposures

Salmon behavior was recorded with the DIDSON software for post-processing. Observations and notes were taken in field, but behavioral analysis was completed in the laboratory after the field work was completed doing a thorough review of the DIDSON files. Two experiments were completed:

1) Sudden onset: 15 s of noise playback precisely started when salmon were observed in the DIDSON field of view. The aim was to observe any sudden reaction at the onset of noise playback.
2) Continuous exposure: Alternating 15 minutes of noise playback and 15 minutes of no playback. The aim was to observe any difference in fish passing rates.

In order to analyze salmon behavior, an ethogram of behavioral events was established. The next variables were measured in the DIDSON imaging:

- Fish start and end times: Time when fish enters and leaves the DIDSON field of view.
- Number of fish: If fish was alone or if more than one fish entered the DIDSON field of view.
- Distance: Distance from speaker at start and at end times of fish in the DIDSON field of view.
- Direction: Direction of fish while crossing the DIDSON field of view.
- Playback noise type, on and off times.
- Playback gain level, and calculated corresponding received level based on distance to speaker.
- Distance at exposure: Distance from speaker at start of playback.
- Ethogram behaviors: Behaviors observed while fish in screen.

- Reaction: Assessment of reaction to noise playback. Two rounds were done, and initial blind assessment where playback info was hidden. A second assessment knowing the playback details. Three categories were used, no reaction, possible reaction, reaction.

Each fish observed in the DIDSON field of view was considered a trial during the experiments. If more than one fish entered the field of view, each fish was assessed independently. While playback source levels remained constant throughout each trial, the levels used varied for each trial from gain 5 to gain 8. These gain levels were selected after obtaining calibration results.

4. Results

4.1 Calibration results

We calibrated the sound field projected by the speaker within the DIDSON field of view up to 10 m distance at the small boat launch ramp in Anchorage, AK (Fig. 6). The floating dock running parallel to the ramp made the operation much simpler than attempting the calibration at the beach in Eagle Bay. We calibrated the system around the low tide to allow us positioning the speaker and DIDSON system by the end of the concrete floor of the ramp. Thus, the area of sound propagation ahead of the speaker was exclusively of mud as in Eagle Bay. In order to evaluate if the differences in environments had any effect in the results, we also collected some noise samples while at Eagle Bay, but limited to 1 m distance to the speaker.

Figure 6: Left - Calibration procedure at the small boat launch ramp in Anchorage, AK. Hydrophone is placed on axis guided by the DIDSON field of view at different distances. Right - the DIDSON transducer and underwater speaker system, attached to their tripod plate, are placed at the end of the concrete ramp at low tide, with the center axis of the field of projection parallel to the dock.

Comparison of obtained dB values at 1 m distance from the speaker at the small boat launch ramp and from the study site indicated an average difference of -2.4 dB across all gain levels and noise classes. Therefore, a correction factor of this amount was added to all the received levels obtained at the ramp to account for the propagation differences between the ramp and the study site. We presume this difference might be due to the softer mud at the ramp in comparison to the mud in Eagle Bay, that was very compact and hard.

The calibration results show we attained a maximum source level of 171.2 RMS dB re 1 µPa @ 1m for ship noise when using a gain level 7, Two examples of the equivalence from distance to the speaker and received level are presented in Figure 7. These are calculated for each noise type at the 4 distances on axis and the 10 m distance off axis at the edge of the DIDSON field of view. A best fit trendline is applied to allow calculating the distance to dB equivalence for any distance in the range.

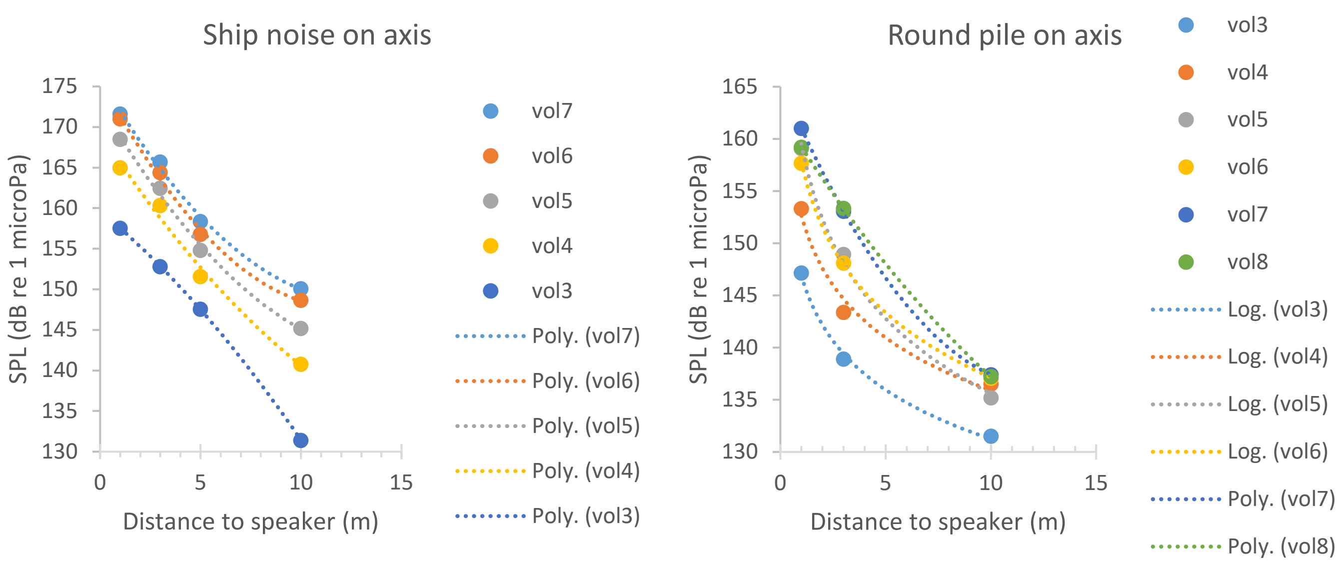


Figure 7: Equivalence from distance to the speaker and received level, and best fit trendline for two examples of noise type, ship noise (left), and round pile (right).

4.2 Feasibility of using DIDSON to observe salmon behavioral reactions to playbacks of anthropogenic noise

Our study successfully achieved the first objective, testing the feasibility of this methodological approach. The platform built to maintain the DIDSON transducer and speaker underwater was stable, and allowed adjusting both the position along the intertidal zone and the angle of projection without problems. At times, the platform became heavy to handle when the drag in soft mud was high, but anchoring the sled with a screw-in anchor and using the anchor line to help pulling it up or down was effective. The platform was stable except during the ending period of the decreasing tide cycle, prior to low tide. The decrease in beach steepness by the lower end of the intertidal section forced us to place the sled platform almost entirely into the water, which in combination with strong ebbing currents, made it unstable and unsafe. However, during the end period of the decreasing tide cycle, the fish density was drastically reduced in the study area, and thus fighting with the current to keep the platform stable was not worth the effort.

4.3 Salmon ethogram

A total of 11 behavioral events were identified in the DIDSON imaging files. Table 1 provides the list and definitions. This ethogram was applied in the analysis of the DIDSON files, and was sufficient to describe all the observable behaviors.

Table 1: List of all the behavioral events identified in the study and their definitions.

Behavior	Description
Traveling	No response observed. Fish maintains same speed and direction. Fish usually traveling against current.
Drifting	Fish moves quickly through frame with current as result of little to no tailbeats, for duration close to 1 second.
Increased tailbeat	Fish increases number of tailbeats
Decreased tailbeat	Fish decreases number of tailbeats
Minor change in direction towards speaker	Fish displays decisive minor change in direction towards speaker after body orientation creates angle from head to center of mass to tail
Minor change in direction away from speaker	Fish displays decisive minor change in direction away from speaker. Body orientation creates angle from head to center of mass to tail
Perpendicular change in direction towards speaker	Fish turns 90 degrees and swims straight towards speaker
Perpendicular change in Direction away from speaker	Fish turns 90 degrees and swims straight away from speaker
Major change in direction	Fish makes a major change in original path of travel
Paused	Fish stops swimming momentarily, body becomes rigid
Collision	Fish collisions with another fish

Examples of each of these behavior events have been extracted from the DIDSON files and converted into mpeg movie clips. These are available online at Google Drive for Fish Behavioral Response.

4.4 Sudden onset response

A total of 1815 trials were obtained for the sudden onset experiment. Of these, 372 trials were not of quality enough to characterize the fish behavior while crossing the DIDSON field of view (poor DIDSON image quality, or fish exited the field of view short after the onset of playback). Final sample size for this experiment was 1414 trials, 598 of them exposed to playback noise, and 816 trials as control (playback system on but in pause). Total number of trials per condition, and their reaction classification are presented in table 2.

Table 2: Total number of trials per condition, and their reaction classification.

Behavioral reaction	Playback	Control
No reaction	513	761
Possible reaction	43	19
Reaction	42	36

When the proportion of trials with and without observed reaction was compared across conditions (playback or control), there was a clear dominance of no reaction for both conditions (85.8% for playback, 93.3% for control). However, more trials were classed as reaction or possible reaction during playback than during control. Figure 8 provides the proportions of trials by condition.

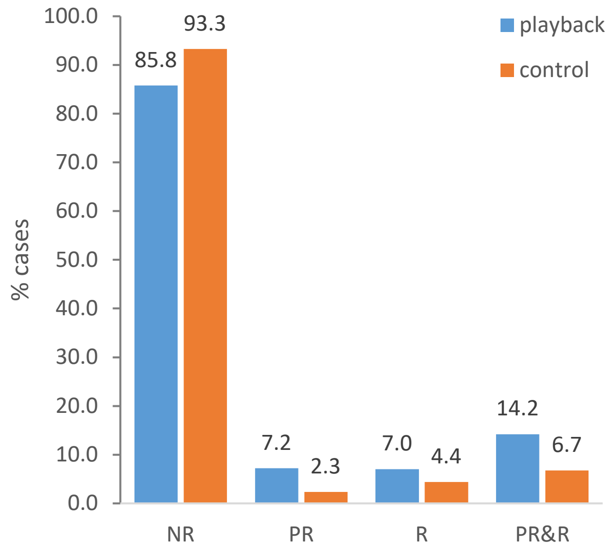


Figure 8: Proportion of trials per condition (control or playback) that were classed as no reaction (NR), possible reaction (PR), and reaction (R), as well as reaction plus possible reaction together (PR&R).

A Pearson Chi^2 test was used to assess whether the obtained proportion of response trials differ from a random process. The analysis was made both excluding and including the possible reaction trials. When the possible reaction trials were added to the reaction trials, results were highly significant (Chi-Square = 12.47018 df = 1 p = .000414), however, when excluding the possible reaction cases, results were non-significant (Chi-Square = 3.301600 df = 1 p = .069213).

When trials were grouped by noise class (ship, round pile, etc.) to explore significance of results, not all the noise classes showed significant differences from a random process. When possible reaction trials were excluded, only ship noise showed a significant p value (Chi-Square = 2.180231 df = 1 p = .139794). When possible reaction trials were combined to the reaction trials, sheet pile noise also became significant (Chi-Square = 4.279085 df = 1 p = .038585). Therefore, only two types of anthropogenic noise triggered significant behavioral reactions in our study, ship noise and sheet pile strikes.

Sample size for the opportunistic sound files from beluga echolocation and calls was too small to run any significance test, but the majority of trials were classified as no response (192 out of 255, Fig. 8) and only 2 trials for each sound type triggered reactions. Note that most of these trials were played at the maximum gain level 7 supported by the system, equivalent to 154.1 RMS dB re 1 µPa @ 1m for click trains and 180.9 RMS dB re 1 µPa @ 1m for beluga calls (both measured at the click or call with highest amplitude of the looped recording).

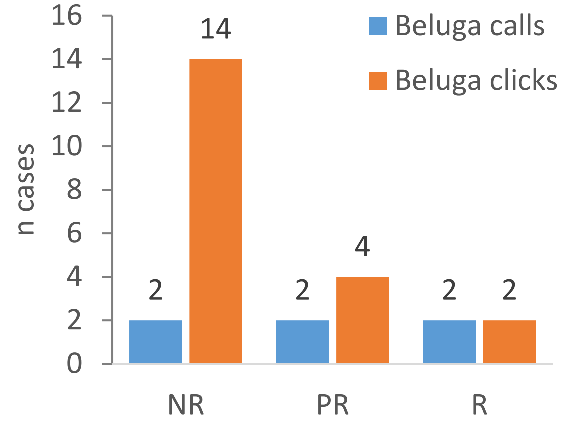


Figure 8: Number of trials and their behavioral reaction classification (NR – no response, PR – possible response, R – response) for the 2 opportunistic sound types.

When evaluating the received levels for all exposures in trials classified as reaction for ship noise, round piles, and sheet piles, we found highly significant differences ($F(2,25) = 85.6912$, $p = 0.0000$; $KW\text{-}H(2,28) = 21.0542$, $p = 0.00003$, Fig 9). Reactions occurred at higher RLs for ship (median of 168.2 dB) than for any of the two piles (median of 155.2 for sheet piles and 151.3 dB for round piles).

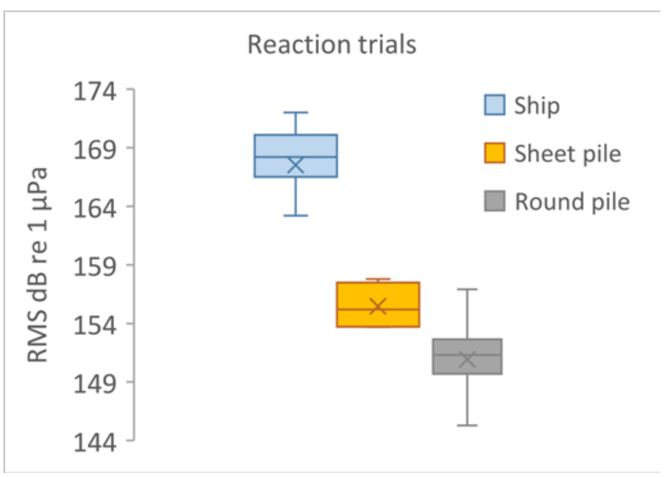


Figure 9: Box and whisker plot with received levels from reaction trials by noise type. X denotes the mean, line denotes the median, box denotes the 25^{th} to 75^{th} percentiles, and whiskers are maximum to minimum range.

When possible reaction trials were added to the received level analysis, little variation was found from the results shown above, thus they were not added to this report.

When evaluating the type and amount of behavioral reactions observed in trials, where noise was played back, independently of the noise type and playback gain level, the predominant behavior was traveling (no change in behavior) for all three behavioral classes (no reaction, possible reaction, and reaction) (Fig. 10). However, three other behaviors were relatively common, minor change in direction away from the speaker, drifting, and pause, which can be related to a sudden response to the noise exposure.

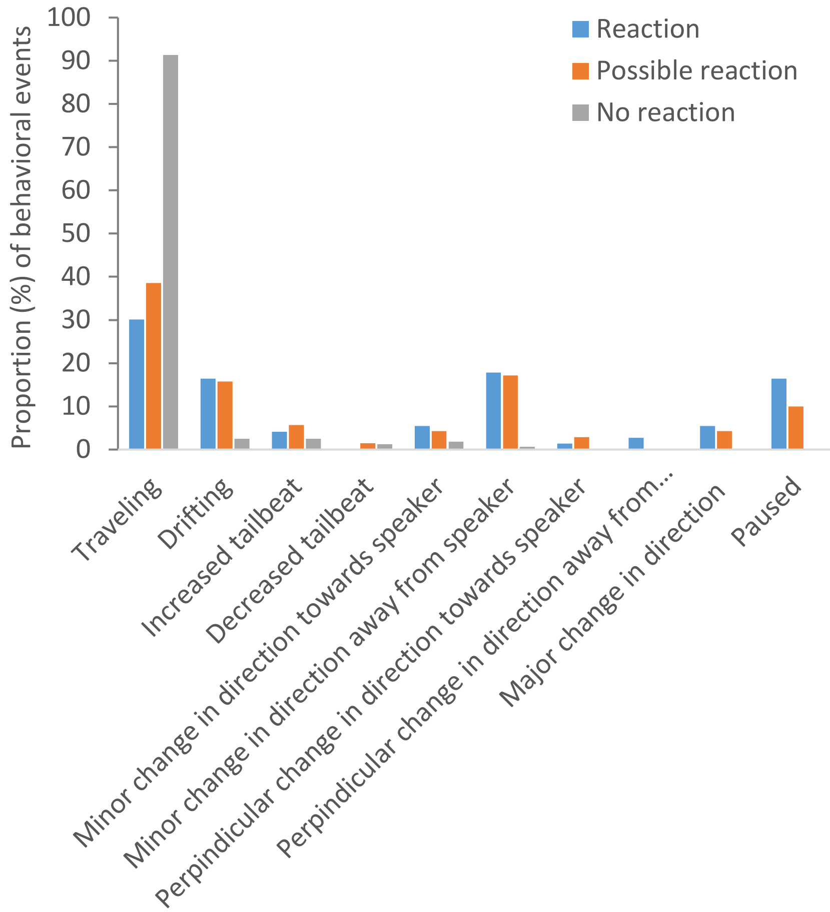


Figure 10: Type and proportion of behavioral reactions observed in playback trials (all noise types).

When these behavioral reactions were grouped by noise type, trials classified as reaction and possible reaction had to be grouped together due to the low sample size. In general, results by noise type were similar, with traveling, minor change in direction away from the speaker, drifting, and pause, as predominant behavioral responses (Fig. 11).

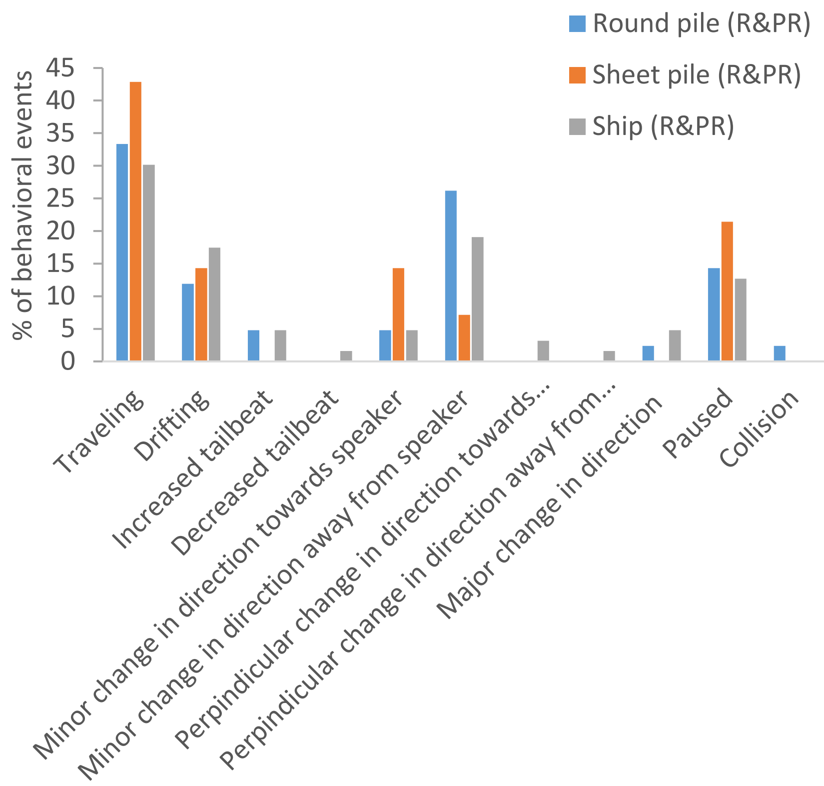
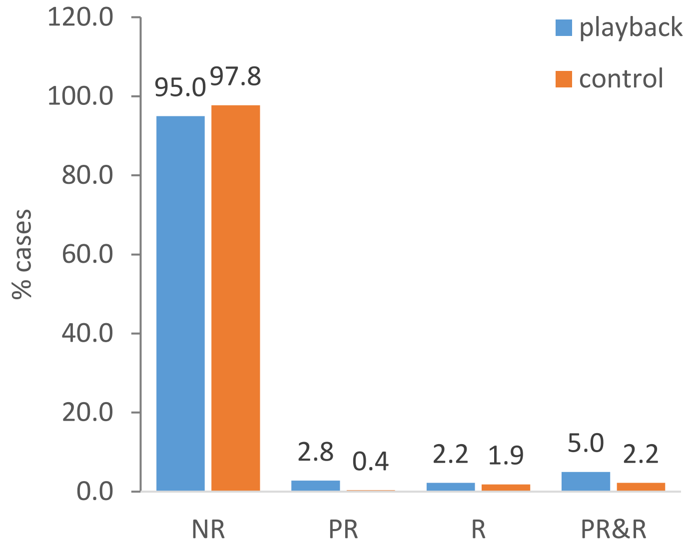


Figure 11: Type and proportion of behavioral reactions by noise type observed in playback trials, grouped by type of noise playback.

4.5 Continuous exposure response

A total of 14 control sessions and 19 playback sessions of continuous noise exposure experiment (15 minutes of continuous playback) were completed. We obtained 767 trials (fish passing through the DIDSON field of view). Of these, 139 were too low in quality to be evaluated, thus we got 359 usable trials with noise playback conditions and 269 as control with no noise playback. When proportion of cases per behavioral class were obtained, results were similar to the sudden onset experiment, with a predominance of no reaction, but slightly increase in trials with possible reaction during playback conditions when compared to the control condition (Fig. 12).



Fogure 12: Proportion of reaction, possible reaction and no reaction trials during sessions of continuous exposure and control, for all noise types.

A Pearson Chi^2 test was used to assess whether the obtained proportion of response trials differ from a random process. The analysis was made both excluding and including the possible reaction trials, but results were not significant in any case (Chi-Square = .0580952 df = 1 p = .809532 excluding no reaction, and Chi-Square = 1.388404 df = 1 p = .238676 when reaction and possible reaction were lumped).

When evaluating the fish flow rate during the two conditions of control and noise playback, we did not find any significant differences (normality test K-S p > .10, t-test = 0.08 df = 31 p = 0.93517)(Fig. 13).

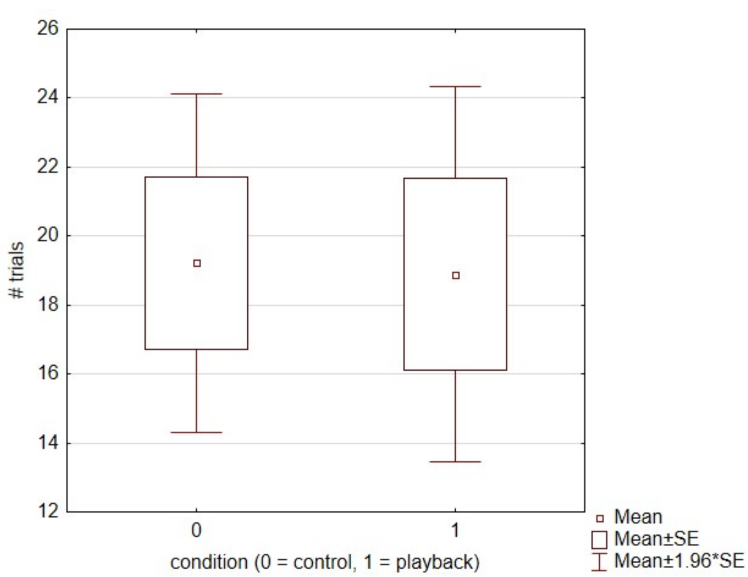


Figure 13: Box and whisker plot for number of trials (fish) during the 15-minute sessions for the two conditions of control and noise playback as part of the continuous exposure experiment.

5. Discussion and conclusions

5.1 Proof of concept

Overall, the methodology applied to observe the behavior of salmon while different noise files were played back was very successful. The platform to keep the DIDSON and speaker system in place was cumbersome but with 2 people it was easily handled, however it required more human power to drag it up and down the study site at the beginning and end of each sampling day. The capacity to adjust the angle of the field of view was critical. The design would not be appropriate for areas with low beach or bank steepness, as most of the platform would need to be submerged, generating too much drag to the current and becoming unstable and unsafe for the equipment. The DIDSON field of view, while narrow, allowed observing fish passing with time enough to decide when to start the playback for the sudden onset response experiment. The image resolution obtained allowed to identify subtle behavioral events up to 5 m of distance. When longer distances where tested (e.g., 10 m) we could not get a good focal point to allow observing good quality imaging along the full field of view for behavioral observation, but it could be potentially applied to continuous exposures where the aim is to count fish but not observe subtle behaviors. The platform was tested on different orientations, but when perpendicular to shore, with fish passing across the DIDSON field of view, the image quality and the capacity to identify behaviors was optimal as maximum backscatter was generated. During high current periods, the platform had a natural tendency to adopt an oblique angle, pushed by the current. The oblique angle slightly decreased the quality of the DIDSON imaging likely due to lower backscatter by fish crossing on a oblique angle, but in most cases it was of good enough quality for the objectives of our study. If the angle was too oblique compromising the DIDSON quality too much, we used a side anchor to provide stability at a closer angle to perpendicular, and even if the drag to the current increased, the anchoring system and the weight of the platform kept it stable.

5.2 Sudden onset and response to noise

Our study exposed salmon to playbacks of anthropogenic noise, and successfully observed their response. Results of the sudden onset experiment demonstrate that salmon showed a lower sensitivity for noise exposures than what we expected, as onset of reactions were not statistically significant until reaching received levels of 151.3 RMS dB (median for round pile). These results are strikingly close to the arbitrary measure by NOAA Fisheries and USFWS, of 150 RMS dB as threshold for behavioral effects on ESA-listed fish species (salmon and bull trout) for most biological opinions evaluating pile driving. This measure cites that sound pressure levels in excess of 150 RMS dB can cause temporary behavioral changes (startle and stress) that could decrease a fish's ability to avoid predators. However, this threshold has been criticized because neither NOAA Fisheries nor USFWS has provided any research data or related citations to support this threshold (Caltrans 2015).

When response to ship noise was evaluated, the threshold for reaction was higher, 168.2 RMS dB, which suggests that fish are less reactive to structured continuous noise than noise of impulsive nature. Another interesting result is the fact that trials classed as possible reaction were needed to obtain statistical significance on the reaction to noise from sheet pile strikes. Thus, the obtained threshold for sheet pile strikes is based on subtle (i.e., pause, drifting) and very subtle (i.e., minor change in direction) fish reactions. Similar behavioral events were common during the ship reaction trials, however for this noise type, possible reaction trials were not needed to reach statistical significance. This suggests that the fish reaction to ship noise, while based on same behavioral events, was more obvious to the observer.

After a few days of running trials, an in response to the observed subtle changes in behavior when sudden onsets of playback sound were played at high source levels (e.g., 160-170 RMS dB), we prepared some sound files of beluga calls and beluga echolocation for incorporation into the study. The rationale was that perhaps the lack of contextuality in the playback of ship noise would impede triggering a reaction. Ship noise would not be presented at high levels until after a gradual increase corresponding to the ship approaching the fish habitat, and the physical presence of the ship itself would likely trigger a different field of particle motion than a small diameter transducer statically positioned at the beach. Similarly, the pile drive strikes would not be presented without other industrial noises, such as engine or hydraulic noise and other mechanical sources that are normally occurring in construction sites, and the point source equivalent of our transducer is obviously very different in physical characteristics than a Mach cone acoustic field created by an impact hammer striking the top of a long pile (an acoustic field in the shape of an axisymmetric cone, Dahl et al. 2015). We wondered if the lack of additional cues would place our noise stimuli out of context and prevent stronger startle responses. However, beluga calls or echolocation click trains in particular, would be naturally presented without any other cues, and thus our set up would be realistic, and a startle reaction or flee response would be expected when a predator acoustic cue would be detected by a salmon. Nevertheless, our results did not show any evident strong reaction from any of the two beluga signals played back to salmon at distances less than 5 m from the speaker. Same subtle reactions as the ones observed with ship or pile drive exposures were observed in 10 out of 16 trials.

The most typical reactions to the noise exposures were to pause the locomotion, slowly move away from the speaker, or drift. These often occurred at the onset of the playback, thus suggesting that the exposed fish detected and reacted to the onset, or soon after the onset, of the noise stimuli. Our results suggest that the behavioral response to ship, sheet and round pile strikes, at the levels used in this experiment, are subtle or mild, and do not elicit startle or flee reactions. The study is too limited to allow interpreting how these behavioral changes might impact the survival or reproduction of salmon, but both during the field trials, and after the analysis of the collected data, we keep wondering how a reduction in tail beat, or even pause, could facilitate predation.

5.3 Continuous exposure response

The 15 minute exposures were targeted to understand if ship and pile driving noise disturbance, at the levels emitted in this experiment (i.e., 160 to 171 RMS dB), would elicit a temporary spatial displacement away from the source. This effect was not observed. Fish flow rate through the DISON field of view did not differ between control and playback conditions, and the amount of observed reactions was similar between the two conditions. The fact that only the possible reaction class (but not the reaction class) was slightly higher during the playback sessions than during the control sessions suggests that the response by salmon to longer duration noise exposures is less evident that to short and sudden exposures. This could be related to the fish being habituated to the increasing received level of the sound stimuli while swimming towards the disturbed area, in contrast with a sudden onset at high amplitude at near distance.

5.4 Further work and conclusions

This study has successfully proven the applicability of the DIDSON system to observe behavioral response of salmon exposed to noise playbacks in upper Cook Inlet, despite its challenges related to high tidal swings, currents, and heavy suspended sedimentation. Distances up to 5 m are good to observe the subtle behavioral changes described here, but further distances would be desired, especially in view of the interest to expand this research in the near-future to cover the prey-predation interaction in the presence of belugas. Perhaps the new system ARIS by Sound Metrics might allow extending the sampled distance. Increasing the angle of the field of view would also be desired if beluga observations are to be incorporated in a playback study. If ARIS is not providing a wider angle, perhaps a different set of lenses for DIDSON might be more suitable (i.e., spreader lens) as we used the 300 m version with telephoto lens in this study.

Another important unexpected result of this study was the substantial acoustic signature generated by the DISSON system (ran in HF mode for the entire study). When the signal output was measured at 1 m on the central field of view, we obtained differences with the background noise as high as 15 dB. Although the median difference was 2 dB across the full spectrum (50 Hz to 158 kHz), there were substantial segments of the spectrum (15-65 kHz, and 100-115 kHz) that exceeded the background noise in 5 to 6 dB (Fig 14). This acoustic signature requires further attention especially in the context of studies on behavioral response to sound signals for both salmon and beluga. Future work should evaluate if this signal is audible to these species.

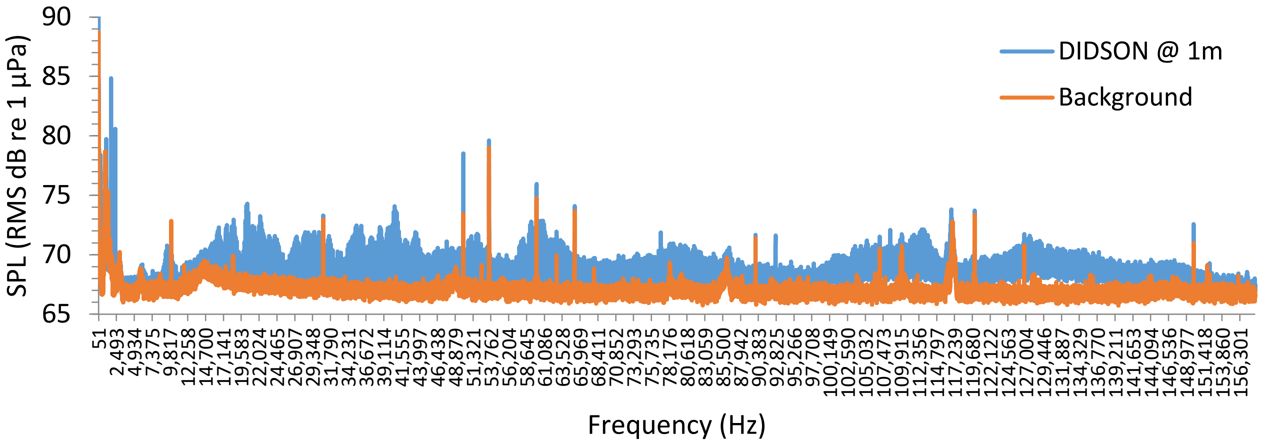


Figure 14: Frequency spectrum contents in RMS dB re 1 µPa/Hz of the background noise in Eagle Bay with DIDSON off, and the DIDSON spectrum level at 1 m distance center in the field of view.

A total of 16 h and 21 minutes of DIDSON data was collected and analyzed for this study. Increasing this sample size, especially in other areas and periods in Cook Inlet, aiming to expose salmon on a different life cycle (e.g., juveniles) would be of interest, as the tolerance for noise exposure might vary throughout the life cycle, in particular, tolerance to disturbances might increase when reproductions becomes the life priority.

Finally, the results presented here accomplished the second objective, to describe behavioral reactions to playback exposure of anthropogenic noise sources. This objective can now be expanded, to look into specific questions related to wildlife management and potential impact to salmon and beluga. Our initial exploration of this subject highlights how salmon reactions are subtle in nature when exposed to a downscaled version of the source, and thus future objectives should consider escalating the magnitude of the disturbance to levels similar to the real sources, or even coordinating with industry to sample real disturbances.

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