Employing Targeted Acoustic Startle Technology (TAST) to deter harbor seal predation on endangered salmonids at the Ballard Locks, Seattle, WA

Final Report

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Introduction:

Declines in marine survival of Salish Sea Chinook, coho, and steelhead have spurred significant research and management actions in Washington state over the past 5 years. Predation by harbor seals on out-migrating juvenile salmon and returning adult salmon, especially at bottlenecks (e.g., the Ballard Locks), has been identified as a significant obstacle to salmon recovery efforts. Broad estimates suggest harbor seals can consume large proportions of juvenile Chinook and coho out-migrants and adult returns (Chasco et al., 2017). In addition to the ongoing work of the Salish Sea Marine Survival Project, Governor Inslee's Orca Task Force recently identified pinniped predation as a priority issue to address in Puget Sound (Southern Resident Orca Task Force Report, 2018). Recovering Chinook stocks in particular, is essential to ensure the survival and recovery of endangered southern resident killer whales (Williams et al., 2011; Lacy et al., 2017).

It is highly desirable to find non-lethal mitigation options as alternatives to culling pinniped predators of salmonids. Acoustic deterrent devices (ADDs) have been employed in the Ballard Locks area with mixed success. Targeted Acoustic Startle Technology (TAST) is a new method which has been used in the UK to deter harbor and grey seals from salmon farms, thereby successfully reducing predation events (Götz and Janik, 2015; 2016). Rather than relying only on high sound levels to deter seals, the TAST elicits a startle response and has been shown to be highly target-specific— it can deter seals within confined ranges while not adversely affecting harbor porpoises. Due to the significantly lower sound exposure levels used (compared to conventional ADDs) and signal frequency bandwidth, the TAST mitigates for a range of environmental side effects such as the risk of hearing damage in target species and disturbance of non-target species (Götz and Janik, 2015). The TAST also operates at a low duty cycle (~1%), making it less likely to lead to habituation than traditional ADDs (Götz and Janik, 2016).

The Salish Sea Marine Survival Project lists several overarching hypotheses, three of which address the effects of predation on Chinook and coho survival. This adaptive management project focuses primarily on the hypothesis that an increase in predator intensity (from harbor seals) is affecting the marine survival of Chinook, coho and sockeye salmon. The focus is on a known local hotspot where

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[1] www.marinesurvivalproject.com

there is clear evidence of predation by harbor seals. The aim of this project was to test the effectiveness of the TAST in deterring harbor seals from predating on adult salmon at the Hiram M. Chittenden (Ballard) Locks (Figure 1 E). This was accomplished by collecting behavioral observations and fish counts, and estimating the effect of the TAST on four response variables: 1) Seal presence (counts), 2) Seal distance from the device, 3) Predation events, and 4) Fish passage through the ladder. Although the main focus of this study was to measure the TAST's effect on harbor seals, observational data was also collected for sea lions observed at the Locks during the study period.

Field Methods:

The TAST (Figure 1 A, B, C) was deployed near the entrance to the Ballard Locks fish ladder from August 14 to September 12, 2020.[2] The transducer was lowered into the water using a pulley system at the end of a 3 m aluminum pole which was secured to the yellow safety platform above the fish ladder (Figure 1D). The transducer was submerged at depths ranging from approximately 9 - 30 ft depending on tidal cycle. Operation of the TAST followed a three-day on (experimental condition), one-day off (control condition) schedule for the remainder of the Chinook run (August 14 - 21) and for the duration of the coho run (September 2 - 12).

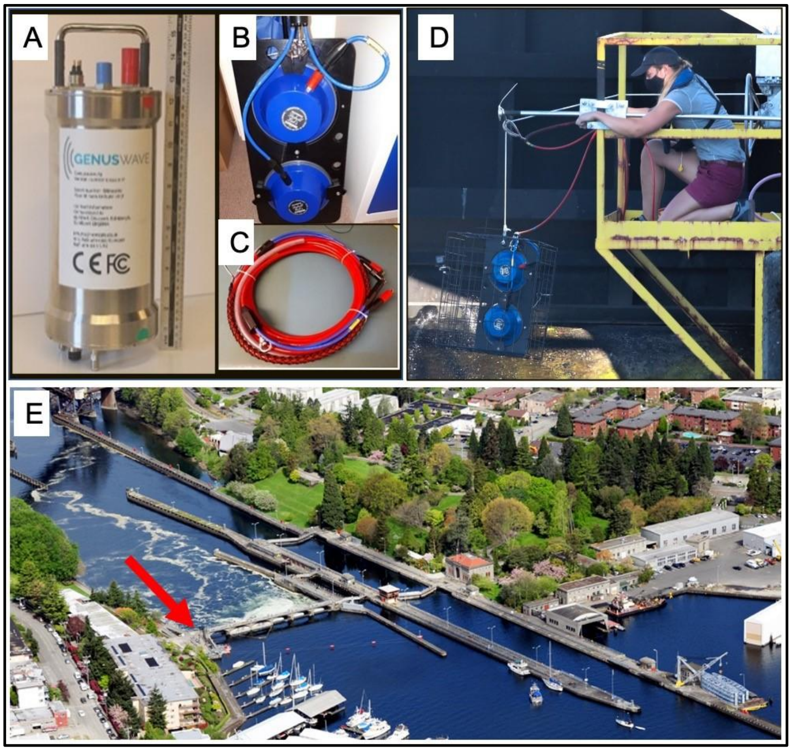

Figure 1. TAST device components: A) Control pod; B) Lubell underwater transducers; C) Power cable. TAST deployment: D) Observer deploying the transducer from the observation platform; and E) Aerial view of the Ballard Locks, red arrow points to the deployment site adjacent to the fish ladder entrance. Photo credit: Genus Wave (A, B, C), Oceans Initiative (D), US Army Corps of Engineers (E).

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[2] The field season for this project began two months behind schedule due to a combination of COVID and permitting delays. We were unable to deploy the TAST as early as initially planned, so we were unable to observe its effects during the sockeye run. Despite these delays, an observer surveyed for seal presence from the adjacent public park for 10 days in July and early August, which provided the opportunity to collect 14 hours of baseline data before deployment, and during a portion of the sockeye run.

The study area, which extended down the locks canal approximately 400 m from the TAST, was divided into eight blocks (Figure 2). During each 30 min observation session, observers continuously scanned the blocks with binoculars looking for pinnipeds in the following order: 4N, 4S, 3N, 3S, 2N, 2S, 1N, 1S. When a seal or sea lion was sighted, the observer recorded the observation and resumed scanning in the same order. Each sighting was recorded on a digital Google Form as one of three behavioral categories: 1) Foraging (fish visible), 2) Normal surfacing, and 3) Crash dive (a behavior usually associated with foraging). These observations were used to calculate predation rate and estimate animal distance from the TAST device. For each sighting, the observers also recorded distance from the TAST using a laser range finder, and angle relative to the TAST using an angle board mounted to the observation platform. In addition to surfacing events and location data, observers recorded the total number of individual seals, sea lions, and predation events observed for each species during each session. Weather conditions, as well as any other relevant behavioral observations were recorded in a field notebook following each session. Photos and videos of the pinnipeds and predation events were opportunistically taken each day using a high-quality camera and telephoto lens.

Each time the device was switched on or off, the transition period was recorded on a tripod-mounted DSLR camera, and observers conducted a 30-minute observation session (both before and after) so that data was collected during each transition period.

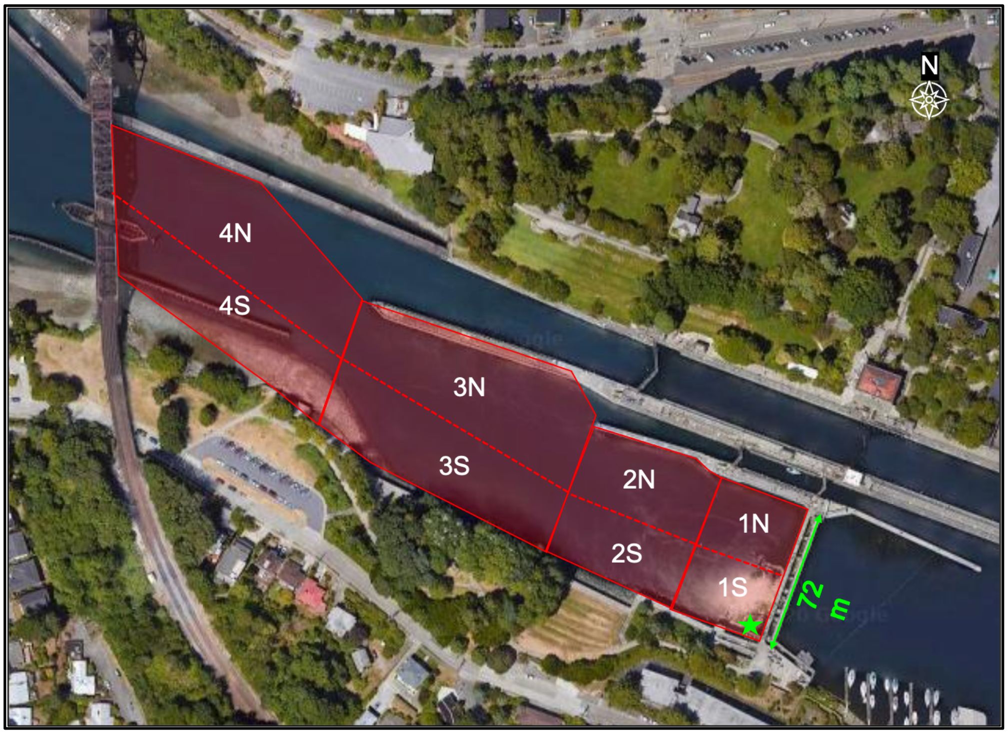

Figure 2. Map of the survey area divided up into observation blocks. Green star indicates location of the TAST and observer.

Underwater recordings of the TAST signal were collected at the locks canal so that received levels could be measured and sound propagation within the study area could be characterized. A Cetacean Research Technology (CRT) C75 hydrophone and a Tascam DR-100MKIII recorder (44 kHz sampling rate) were used to collect the recordings at 18 locations ranging from approximately 50 – 530 m from the TAST (see Figure 7). Recordings were taken in approximately 50 m increments at different locations relative to the shoreline, with most collected in the center of the canal (direct path to TAST), and some taken along the canal edge, and the lock wall. At each location the hydrophone was lowered to 3 m depth from a small boat that was drifting in the canal with the engine off. A range finder was used to determine the distance to the TAST from each recording location.

Analysis Methods:

General Analysis

Seal and sea lion presence as a function of treatment condition (experimental (TAST on) vs. control (TAST off)) was calculated by averaging the number of each species counted within a survey session and dividing by observation time. Seal distance from the TAST was initially explored visually by plotting the comparative distributions of seals occurring in a series of distance bins (See Figure 3). Predation rate was calculated by dividing the number of observed predation events for each species ("foraging (fish visible)" behavioral category) occurring in a survey session by the number of seal-hours (seal frequency × hour). The "crash dive" behavioral category was often an indication of foraging activity, although this was only included as a predation event when seals were observed with a fish in their mouth. Data for fish passage through the locks was provided by MIT and WDFW and were compared to historical (10-year average) data. The R language was used to run all statistical analyses in R 4.0.3 (R Core Team 2020).

Modelling Procedures

GLMMs: Distance and predation rates

Generalized Linear Mixed Models (GLMM) were used to analyze both seal distance (in meters) from the TAST and predation rates (count data with an observation time offset) using the "glmmTMB" package in R (Brooks et al. 2017). The distance analysis included both harbor seals and sea lions, as the sample sizes for surfacing events were sufficiently large. The predation rate analysis only included harbor seals, due to the limited sample size for sea lions. The distance model constitutes a GLMM with a Gamma error distribution, logarithmic (to the base of e) link function, and distance in meters from TAST as the response variable. The predation rate model uses a Poisson error distribution and logarithmic link function. The number of predation events in each observation period was used as the response variable and the logarithm of observation time (observation effort) was included as an offset (due to the log link).

We conducted a two step model selection process to select the optimal combination of fixed and random effects using the Akaike Information Criterion, AIC (Zuur et al., 2009). The AIC balances model fit and parsimony and in each step the model with the lowest AIC was selected. In the first step the optimal combination of random effects and potential benefits of a zero-inflation argument were evaluated while keeping the fully populated fixed effects term constant. In a 2nd step the previously selected random effects combination was carried forward and the optimal model fixed effects combination was selected (Zuur et al., 2009).

For the predation model, only treatment was considered as a fixed effect which was always included as it was of primary interest in this study. We assessed the following simple random effects (random intercept): Julian day, primary observer ID and observation location.

For the distance model we considered the following random effects: a nested random effects structure of 'observation session ID within date' and additionally observation location (platform versus gate) and foraging behaviour observed (yes or no). The ‘glmmtTMB’ function fits nested random effects with an unstructured correlation structure. Hence, the term ‘session ID within date’ was also beneficial as it addressed potential autocorrelation issues (i.e. distances within each observation session can be correlated). Candidate fixed effects (predictor variables) were treatment (On/Off, always included), species and the interaction term between the two (which represents species responding differently). The final selected seal distance model included the interaction term between treatment and species, the nested random effects structure of ‘session ID within date’ and observation location as a single random effect (random intercept).

The coefficients for all models are presented on the scale of the response variable to allow an intuitive interpretation of effect size. The ‘confit’ function was used to calculate confidence intervals for the model coefficients. The ‘emmeans’ package (Lenth, 2019) was used to calculate predictions and 95% confidence intervals for mean predation rates/hour as mean distance from TAST.

Model assumptions were assessed by qualitatively evaluating residual plots (e.g. residuals vs predicted values) and assessing the auto-correlation function of the residuals.

GAMM: Fish passage

Daily passages were variable and the relationship between Julian day and fish passage is non-monotonous across the whole season. Hence, a polynomial smoother instead of a monotonous link function is required to adequately describe this data set. Therefore, a Generalized Additive Mixed Model (GAMM) was used to analyze the fish passage data. The GAMM was fitted using the ‘gamm’ function in the “mgcv” package (Wood 2017). The objective was to allow for a comparison between predicted fish passage for the two treatment levels (On/Off) and the 10 year average. However, this can only be reasonably done for the period of time for which sufficient data is available for both treatment levels (On and Off). Therefore, only a date range from 2 days prior to deployment to 2 days after TAST was used for the last time, was included.

The GAMM included daily fish passage (count data) as the response variable and a polynomial smoother for julian day by a three-level treatment factor (ON 2020, OFF 2020, and 10 year average) as variables. Fish passage numbers on consecutive Julian days are likely to be highly correlated. Therefore, a moving average auto-correlation structure (CorARMA) with the term julian day by treatment was included in the model. The autoregressive order was set to 1 while the moving average order was set to 2. This was decided based on an assessment of the auto-correlation and partial auto-correlation function of the residuals for few possible combinations. The k-value (basis dimension) of the GAMM was 9 and the gam.check function did not reveal any issues.

Predicted values for the GAMM and 95% confidence intervals were plotted using the ‘ggpredict’ function in the “ggeffects” package (Lüdecke, 2018). The fish passage predictions were obtained by creating a data frame with the predicted values from the model for all days within the time modelled period for all three different levels (on, off, 10 year average). These numbers were then summed up (~area under curve) for each treatment and constitute the expected fish passage if the same treatment had been applied to the whole modelled periods (e.g. TAST on or off for the whole period).

Acoustic Analysis of the TAST signal

SpectraPlus sound analysis software (Pioneer Hill Software, LLC) was used to calibrate each sound recording (according to a full-system calibration factor provided by CRT) and measure sound pressure levels (SPL) in dB re 1µPa of the TAST signals in each recording. Received levels (in root mean square (RMS) SPL) were determined for each of the recording locations. These levels were compared to levels calculated from the transmission loss equation assuming spherical spreading, according to: $TL = 20 \log_{10} R$, where TL is the transmission loss (dB), and R is the distance (m) from the source.

Results:

Survey Effort

Observers spent 14 hours over 10 days conducting baseline monitoring from Commodore Park, approximately 50 m west of the fish ladder, before site access was granted by USACE and prior to deployment of the TAST. Observers then spent 30 total days at the locks while the TAST was deployed, resulting in 102.5 hours of total surveying effort (42.5 with TAST off and 59 with TAST on) during the second half of the August Chinook run and the early September coho run. The treatment schedule followed a 3-day on, one-day off cycle during behavioral data collection, with two exceptions when we had to deviate from the schedule. Following the end of the Chinook run on the 21st of August, we were asked by WDFW to keep the TAST on for the week between our monitoring phases in order to assist in managing seal predation during a tribal fishing opening and state-led PIT tagging efforts. Behavioral observations were not collected during this time period. For the last three scheduled observation days of the coho run, wildfire smoke caused unsafe conditions for observers, so our monitoring effort was reduced and the final control day of the coho run was canceled.

Seal Presence

When the TAST was on, seal presence in the overall survey area declined by 25% compared to when it was off, and sea lion presence declined by 21%.

Seal Distance

Descriptive Statistics: When the TAST was on, seals were observed at a mean distance of 109 m (median 87m) from the device. When the device was off, seals were observed at a mean of 84 m (median 64 m) from the device. As seen in Figure 4, there was a shift in seal distribution around the device. At distances from 10 - 40 m seal numbers dropped by more than half during 'on' periods while only a slight drop was observed at distances of 40 - 60 m. More seals were observed at a distance of >70m during 'on' periods which indicates a shift away from the device. However, further analysis is needed to determine the significance of this shift.

Model Results: The best distance model (GLMM) showed that there was a highly significant effect of treatment condition on mean distance ($p < 0.001$), a significant difference in mean distance between species ($p < 0.001$), and a significant difference in the responsiveness between the two species (interaction term between species and treatment, $p < 0.001$). The model coefficients, which provide a measure of effect size, show that seals surfaced 1.35 times (35%) further away from the TAST when it was on, while sea lions surfaced 2.58 times (158%) further away when it was on. Predicted values from the model of mean distances of surfacings for both harbor seals and sea lions are visualized in Figure 4. The predictions for mean distance from the model shows that when the TAST was on, seals were on average, 118 m away and sea lions were 158 m away. However when the device was off, sea lions were on average 61 m away from the device and seals were 88 m away.

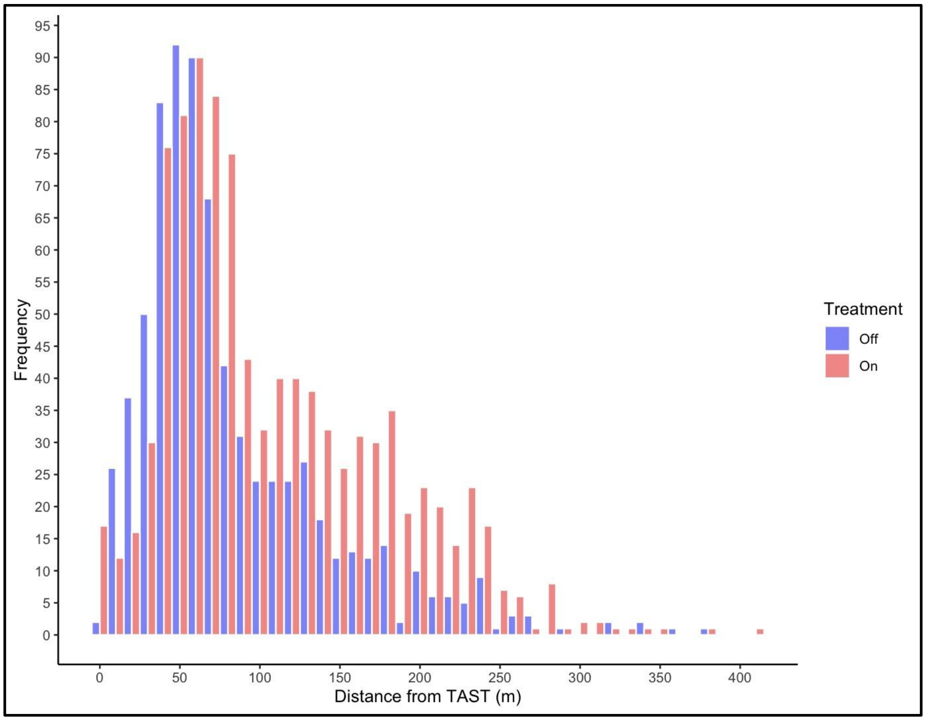

Figure 3. Harbor seal distance from the TAST is shown as a function of surfacing frequency for both treatment control (blue) and experimental (red) conditions. The bin width (distance) is 10 meters. There appears to be a shift away from the TAST when it is turned on, especially within the 50 m range, where we expect the effect to be strongest.

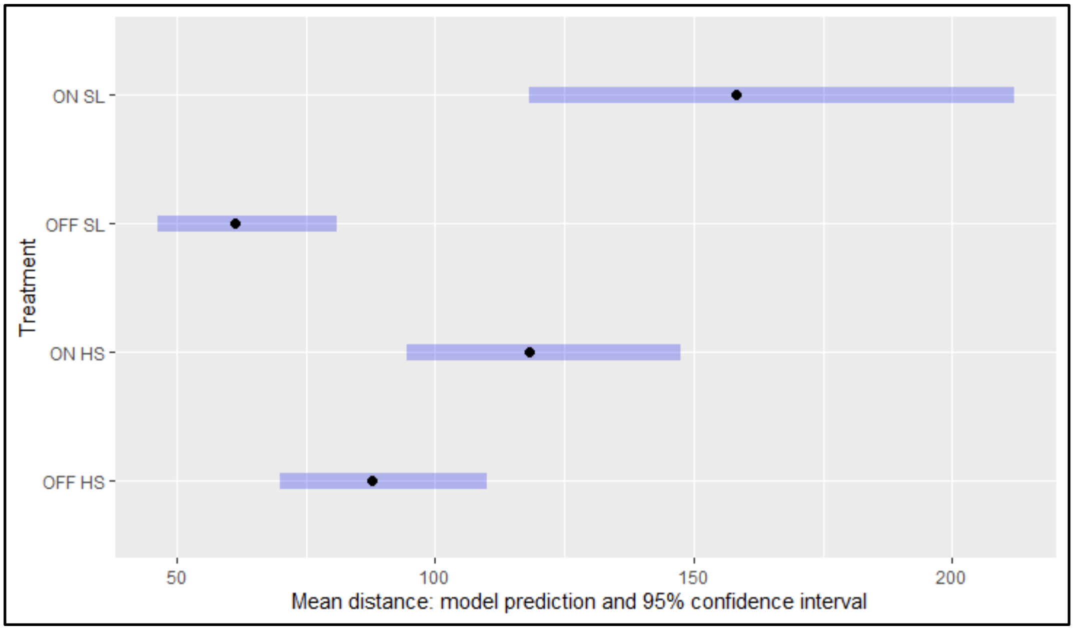

Figure 4. Mean distance predictions and confidence intervals are shown for experimental (TAST on) and control (TAST off) treatment conditions for harbor seals (HS) and sea lions (SL).

Predation Rate

The mean observed predation rate (# of predation events observed / hour) was 0.92 when the TAST was on and 1.67 when it was off during baseline and control observations. There was a significant decrease in the observed predation rate during the experimental condition (TAST on) compared to the control condition (TAST off, p=0.03). The estimates for effect size obtained from the model suggest a 49.3% (Figure 3, p=0.03) reduction in the predation rate when TAST was on (coefficient: 0.517, 95% CI:0.285/0.959). The model predicted the mean predation rate as 0.754 events per hour when the TAST was on and 1.460 events per hour when it was off (see Figure 5, for mean predation rate and 95% confidence interval).

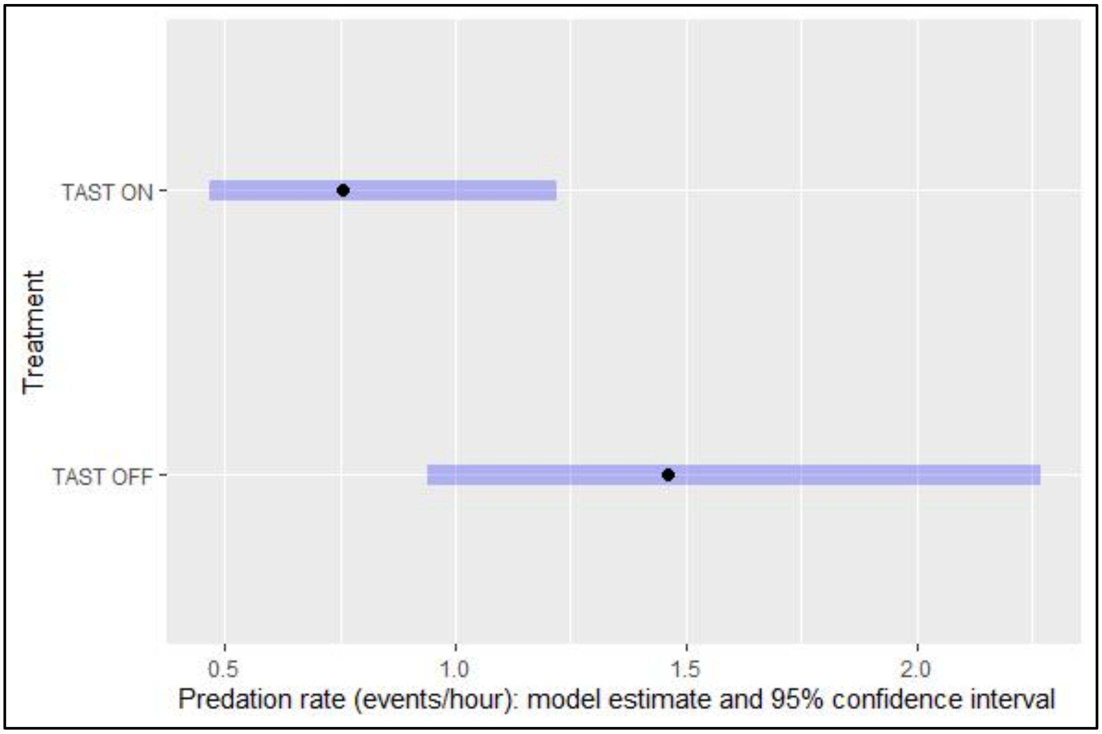

Figure 5: Predicted harbor seal predation rates (shown as events per hour) and 95% confidence intervals are shown for experimental (TAST on) and control (TAST off) treatment conditions. There was a 49.3% reduction in observed predation events per hour during experimental days.

Fish Passage

Given the underlying dynamics of salmon returns, it is difficult to ascertain a direct effect of the TAST on fish passage through the locks when purely looking at the raw data. Point estimates of the fish passage data as a function of whether the TAST was on or off (Figure 4), descriptive statistics point towards an increase in mean number of fish observed passing through the ladder when the device was in operation, resulting in a rise of 17% for Chinook and 34% for coho.

Given the challenges encountered when evaluating the raw data, we used a GAMM with polynomial smoothers to analyze the data. The smoothers for all three factor levels (‘TAST on”, “TAST off”, “10 year average”) as well as the parametric coefficients were highly significant at p<0.0001. The model’s prediction for the number of fish passing through the fish ladder during the selected time period (August 12th - September 16th, 2020) was 14,109 fish with the TAST on, vs. 9,660 fish with the TAST off and 5816 for the 10 year average. If the TAST had been turned on for the entire duration of the deployment period, the model predicts that 4449 more fish would have passed through the Ballard Locks in 2020, compared to if it was off. This translates to a potential of 46% more fish “saved” with the TAST on. When these data are compared to the 10-year historical average, fish passage was at a 142% gain with TAST on, which translates to 8,292 more fish passing the locks than the 10-year average.

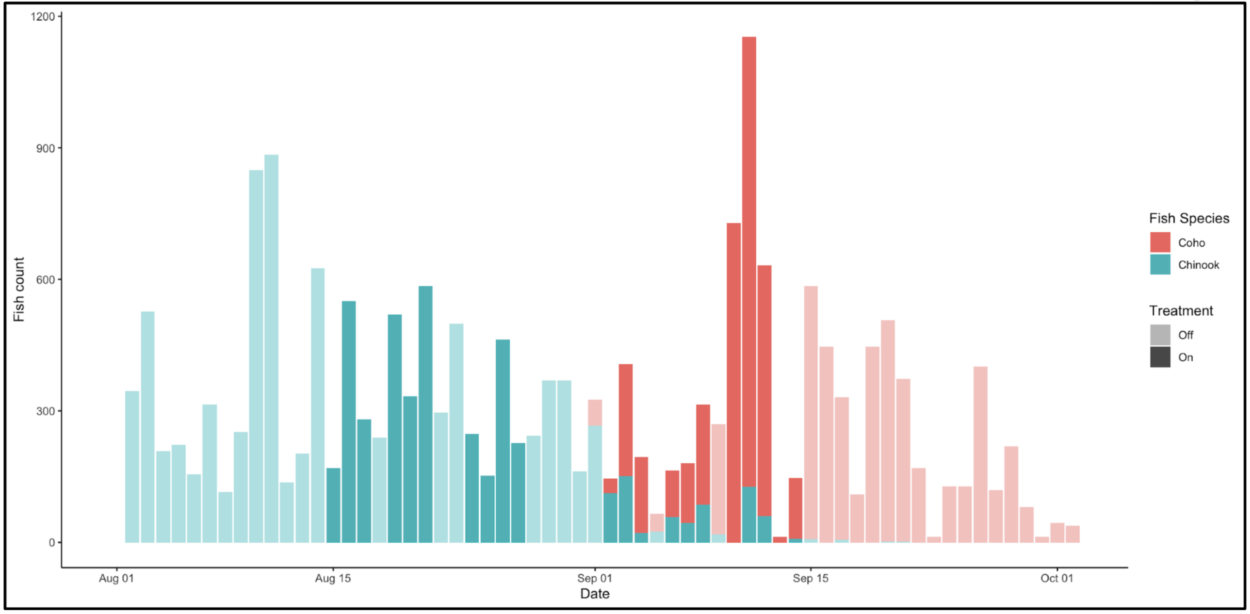

Figure 6. Daily counts of coho (red) and Chinook (blue) salmon passage through the Ballard Locks fish ladder are shown as a function of 2020 count date (data provided by the Muckleshoot Indian Tribe). The TAST treatment condition is shown using bar opacity, with lighter bars indicating the control condition (TAST off) and darker bars indicating experimental condition (TAST on).

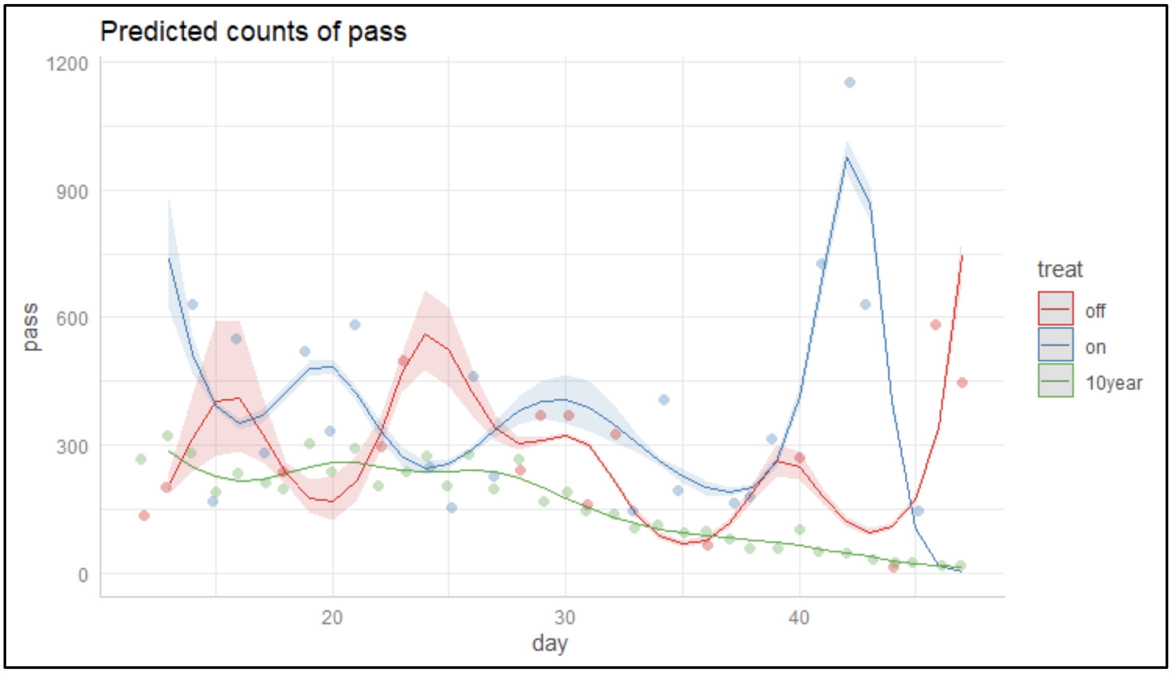

Figure 7. Fish passage data (pass, provided by MIT) is shown for experimental (blue) and control (red) conditions along with the 10 year historical average data for each day of the TAST deployment.

Acoustic measurements and propagation

TAST received levels in blocks 1 - 4 of the survey area ranged from 129 - 145 dB, 119 - 135 dB, 115 - 128 dB, and 115 - 125 dB, respectively. Received levels measured outside the survey area (>400 m from TAST) ranged from 106 - 110 dB. As expected, the TAST received levels decreased sharply with increasing distance from the device, however the observed transmission loss of the signal was slightly higher than predicted simply from spherical spreading (Figure 8). Overall, received levels measured in the center of the canal were higher than those measured at the edge, in much shallower water (Figures 8, 9). As recordings were being collected, the TAST signal was audible above background noise to a human listener out to approximately 450 m from the device.

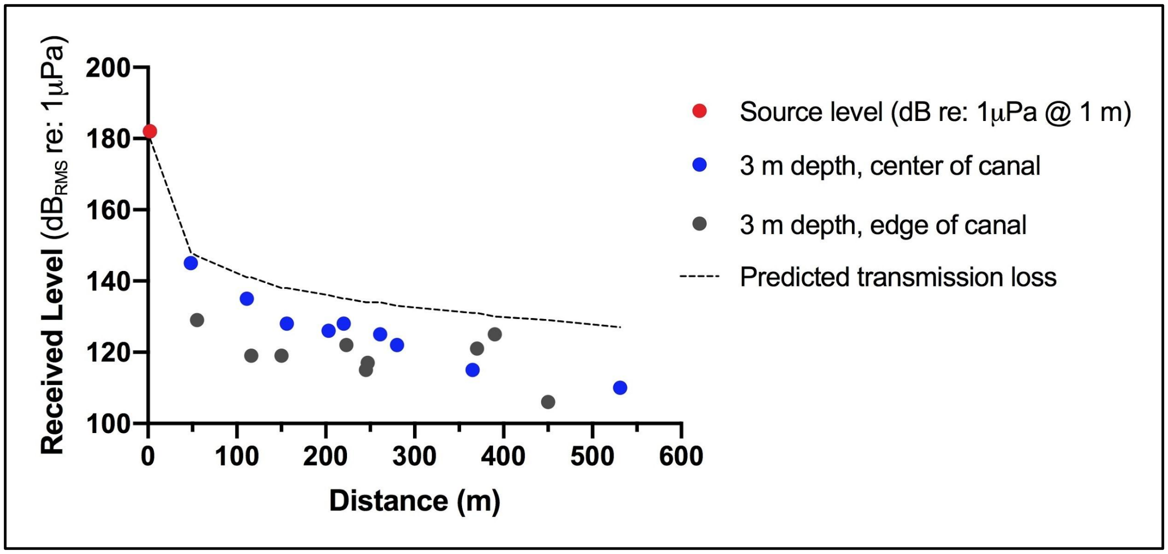

Figure 8. TAST underwater signal levels measured in the locks canal. Root mean square (RMS) received levels are shown in dB SPL with corresponding distance from the TAST device. Received levels measured in the center of the Ballard Locks canal are shown in blue, and those measured along the canal edge are shown in grey. The TAST source level (measured prior to deployment at the locks) is shown in red, and provided for comparison. A curve showing sound pressure levels predicted from the transmission loss equation assuming spherical spreading is also shown as a reference.

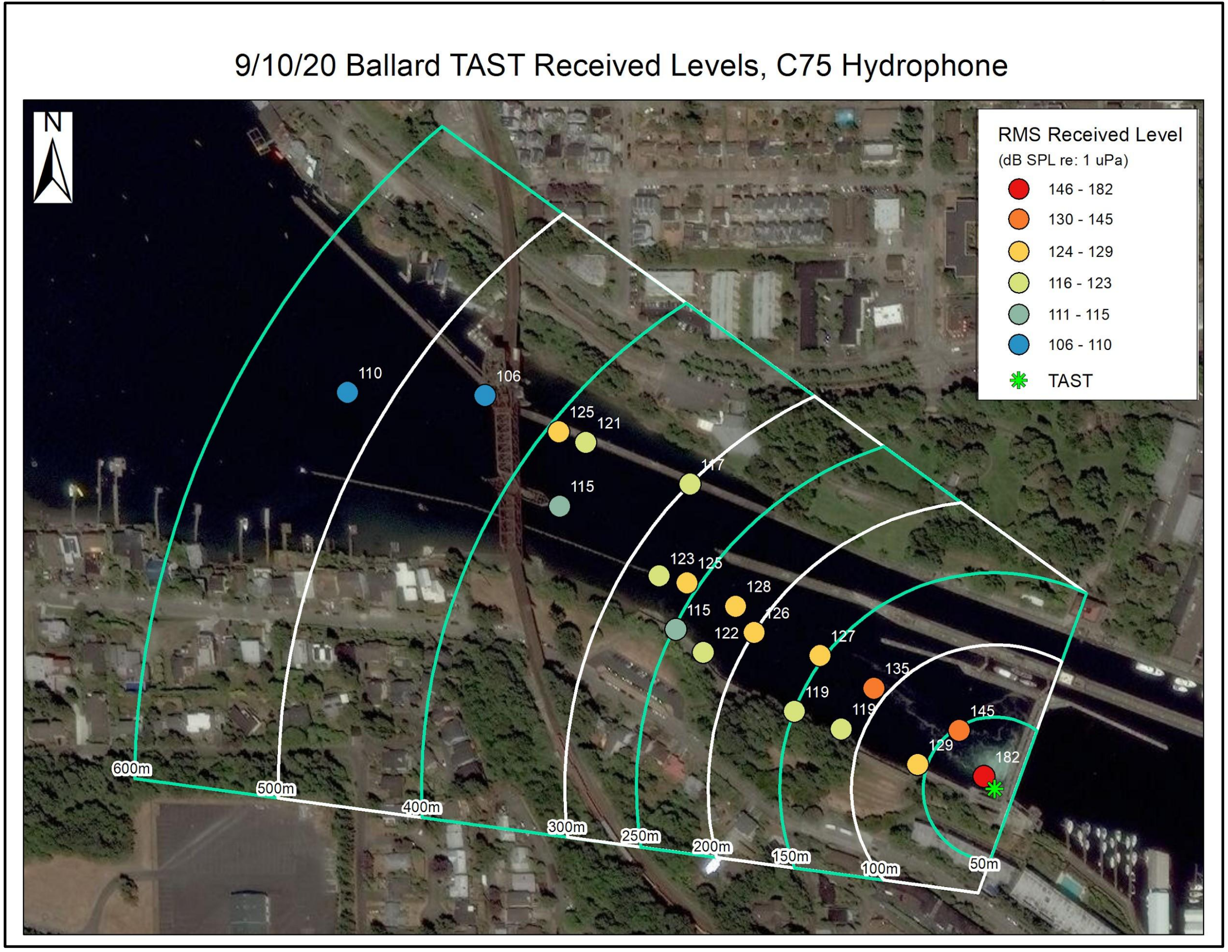

Figure 9. Map of the Ballard Locks study site showing measured received levels of the TAST signal at each recording location. The source level measurement (shown in red) is provided for comparison. There were 16 recording locations within the survey area (Blocks 1 - 4) and 2 locations outside the survey area (>400 m from the TAST) which can be seen West of the train bridge. The location of the TAST device is shown as a green star.

Discussion

Our analyses revealed that when the TAST was turned on, there was a significant increase in both seal and sea lion distance from the device (35% and 158% respectively) and a 49.3% reduction in observed predation rates. Modelling suggests a 46% increase in fish passage (4.5k additional salmon) when TAST is on compared to when it is off. If fish passages with 'TAST on' in 2020 are compared to the previous 10 year average the model suggests a 142% increase.

The data on seal distances (Figures 4 & 5) shows that deterrence ranges in harbour seals were fairly limited. Transmission loss of the TAST signal was relatively high and the received level measured at 50 m was only 145 dB re 1 μPa dropping to < 130 dB at the edges of the canal. The former number is just below the startle threshold in seal with good hearing (Götz, & Janik, 2020) which explains the limited range. However, there is potential for investigating improved coverage by using a network of coordinated TAST units while keeping the overall duty cycle low.

Surprisingly, at distances of < 10 m more seals were seen during "on" periods. This could be the result of seals spending more time swimming on the surface and diving less (Götz & Janik, 2011). This could potentially be mitigated by "in air" playbacks in future developments. Although in-air playbacks were beyond the scope of this study, there are several applications where deterring sea lions from hauling out (e.g., on public docks) may be of interest.

When the difference in seal distance from the TAST observed during control and experimental conditions is considered with respect to the received sound levels, there was a dramatic shift in seal numbers in the 10 - 40 m range from the device when it was on. Compared to the control condition, the number of seals in this range dropped by half, whereas only a slight drop in seal numbers was observed at distances of 40 - 60 m. Although we were unable to measure received levels closer than 50 m to the TAST, those collected just beyond this distance suggest near cylindrical spreading loss within close range (< 50 m). We can therefore estimate received levels within the 10 - 40 m range to be approximately 162 - 150 dB, and those in the 40 - 60 m range to be 150 - 146 dB. This difference in seal distribution within the study area suggests that the TAST device was effective at displacing many seals at received levels greater than 150 dB. This signal level is 9 dB lower than the published startle threshold for harbor seals (estimated from harbor seal audiogram and grey seal sensation level startle threshold) of 159 dB (Götz & Janik, 2011). However, this visual assessment method of startle may have overestimated the thresholds in grey seals aas thresholds measured using more sensitive accelerometer methods can be >10 dB lower (see Götz et al. 2020). Received levels exceeded this startle threshold in blocks 1N and 1S only. Harbor seals showed a much less dramatic shift in distance between the two experimental conditions than was observed in sea lions, although these results are difficult to interpret due to the limited sample size for sea lion observations. However, this difference could be explained by the difference in timing of arrival to the Locks—harbor seals were already present and foraging when the TAST was first deployed, while sea lions were not observed at the Locks until September when the TAST was in place and emitting sound. Sea lions did not have the same history of food reinforcement in 2020, prior to the area being ensonified.

Unfortunately, we were unable to measure received levels within the 0 - 50 m range of the TAST because boat passage was restricted within 50 m of the Locks spillway. If possible, future deployments would benefit from finer-scale acoustic measurements (e.g., in 10 m increments) closer to the TAST (< 50 m) in order to get better resolution of the received levels in the areas where our results show the largest shift in pinniped presence.

While we were conducting baseline observations prior to deployment, it became clear that concurrent efforts to manage seal predation using underwater firecrackers (or "seal bombs") was a regular occurance. Available data on source characterization of seal bombs estimate the sound exposure level (SEL) of an explosive with charge weight of 2.33 g to be 197 dB re: 1μPa^2·s (Wiggins et al., 2019) which is loud enough to cause hearing loss in a harbor seal at close range (Kastak et al., 2005). Therefore, it is possible that the use of these explosives as a management strategy at the locks could have resulted in seals with hearing loss which would render any acoustic deterrent much less effective. We did collect several hundred photographs that could be used for individual photo-identification of harbor seals (Thompson and Wheeler, 2008). With additional funding, it would be possible to investigate site-use of the study area to investigate whether individuals photographed on days when firecrackers were in use and may have compromised hearing were subsequently documented inside the fish ladder during the TAST use. The ability to recognize individual seals may be necessary for management options (e.g., hazing or translocation) that hinge on identification of "nuisance seals."

The delayed start to the season resulted in a number of disadvantages in the data collection process. The first was the reduction of our expected sample size by 50%, as we missed the entire sockeye run and the first half of the Chinook run. Additionally, the delayed start time resulted in a missed opportunity to deter naive seals at the beginning of the season. Any "young of the year" or seals new to the area that arrived at the locks in the spring would have had two months of "normal" foraging activity. Introducing the TAST in August instead of before the salmon run was likely to result in a reduced effect on seals that already had an established reinforcement history of successful foraging at the Locks.

The presence of sea lions at the Locks during the coho run may have had an influence on fish passage and predation rate, however this relationship will be difficult to explore further given the limited amount of data collected for sea lions this year. The signal emitted by the TAST was initially designed to target harbor and grey seals, but anecdotally, observers noted multiple instances of avoidance behavior from sea lions during the Chinook and coho runs. This is supported by the modelling effort which points towards stronger deterrence effects in sea lions. Our observer documented the first instance of a Steller sea lion returning to the Locks for the 2020 season. The large male swam in from Puget Sound, directly towards the ladder without making any deviations from his course. When the animal reached about 50 m distance from the TAST, he promptly turned 180 degrees and proceeded back out to the Sound. Over the rest of the season, when sea lions became more prevalent, observers noted that they would typically spend time in the closest observation block if the TAST was turned off, then immediately after turning it on, they would leave the area. Schakner et al. (2017) has demonstrated that similar applications of startle stimuli have been effective in sea lions, though the TAST technology for use with this species is still in the research and development stage. Nevertheless, these observations suggest that this technology could also be useful in deterring other species of pinnipeds in regions where food motivation and over-predation is an issue.

Conclusions:

The TAST achieved four primary objectives: reducing the number of seals in the immediate vicinity of the TAST; displacing the seals away from the ladder; reducing observed salmon predation rate by seals; and increasing fish passage through the ladder. Modelling suggests that 4449 more fish (representing a 46% increase) may have passed through the locks if TAST had been on for the whole period (between August 12th - September 16th, 2020). There is some indication in the data that TAST has also deterred sea lions from preying on salmon in the immediate vicinity of the TAST.

There are many other interesting ways this technology could be applied in other conservation contexts where previous attempts at using ADDs have not been successful (Gotz & Janik, 2013). For example, mitigating predation on out-migrating juvenile salmonids or keeping animals away from harmful activities such as marine construction or oil spills. While our results are promising, we are limited in what we can claim due to small sample size and hope to continue this work in the future given additional funding.

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