Surface behaviors of Southern Resident killer whales: Are they responding to vessel noise?

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INTRODUCTION

The Southern Resident killer whales *(Orcinus orca)* were recently listed as endangered under the US Endangered Species Act (NMFS, 2005). They were declared "depleted" under the Marine Mammal Protection Act in 2003 and captures in the 1970s put a dent in population numbers. A combination of threats, such as contaminants, vessel traffic and prey availability have put these whales in a delicate position. A possible threat to the killer whales is the noise produced by vessel traffic because they use sound to communicate, navigate, and detect predators and prey (NRC, 2003). Marine mammals may try to avoid loud sound sources up to tens of kilometers away (Richardson et al. 1995). There is currently no data on permanent hearing loss due to reported and prolonged noise exposure in marine mammals (Erbe, 2002), but 195 dB re 1 mu Pa^{-2} s has been shown as a reasonable threshold for the onset of Temporary Threshold Shift (TTS) in dolphins and white whales exposed to midfrequency tones (Finneran et al. 2005).

Haro Strait, the primary summer region for Southern Resident killer whales, has relatively high vessel traffic due to a key-shipping lane. Commercially the Strait is serving the needs of two countries, Canada and United States. With that come high amounts of cargo ships for economic purposes: oil, clothing, automobiles, electronics, etc. National Security is present by the Navy from both countries. Sonar exercises are common from military vessels and have been known to affect cetaceans (Finneran et al. 2005). NRC (2003) has linked mass strandings of beached whales to high energy, mid-range, mid-frequency sonars. Other commercial vessels in the water come from the fishing industry, commuter vessels (ferry) and the whale-watching industry. There is also personal vessel traffic used for recreational uses and research. Whale watch guidelines have been put in place to assist in whale-watching vessels to view the whales at a 100 yard distance. These guidelines are voluntary and may not always be followed by personal or commercial vessels.

Marine Mammals ears physically bear a resemblance to land mammal ears except they lack the external fleshy lobes that land mammals tend to posses (NRC, 2003). The ocean has always had some amount of noise, which may have led to the evolution of marine mammal hearing to be toughened for ‘natural’ aquatic noise. That compensation has been shown in research that marine mammals have developed broader hearing ranges (NRC, 2003). Killer whales use high frequency echolocation to scout for prey and to sense their surroundings. When foraging on prey, the pulses are shorter and more frequent (Au et al. 2004). While foraging the whales can echolocate to navigate the bathymetry for vessels around them using pulses that go a further distance. Outboard-powered vessels operating at full speed produce estimated RMS sound-pressure levels of about 160-175 decibels with reference to one micro Pascal at one meter (dB re 1 _Pa hereafter) (Bain 2002, Erbe 2002). Inflatables with outboard engines are slightly “louder” than rigid-hull powerboats with inboard or stern-drive engines (Erbe 2002). Results from Grabstein (2006) showed that large vessels produce a significantly smaller fraction of their acoustic power at high frequencies than small craft, and that the shape of a vessel’s spectrum level (power vs. frequency) is more closely related to vessel type rather than weight or speed. A slow motorboat at 100m sounds the same as when it travels at a fast speed 500m away (Bain pers. comm.).

The indirect effects of anthropogenic sound on marine mammals via effects on their predators, prey and other critical habitat elements have only begun to be studied. Underwater sounds can be generated by engines, dredging, drilling, construction, seismic testing and sonar (Richardson et al. 1995). Anthropogenic sound has caused the killer whales to adjust their behavior to acoustically compensate once it reaches a threshold level (Foote et al. 2004). The NMFS (2005) summarized that some studies have linked vessels with short-term behavioral changes in Northern and Southern Resident killer whales. Avoidance tactics often vary between encounters and the sexes, with the number of vessels present and their proximity, activity, size, and "loudness" affecting the reaction of the whales (Williams et al 2002). Significant behavioral responses of male resident killer whales at received levels of approximately 116dB were demonstrated by Williams et al. (2002). Whether it is the presence and activity of the vessel, the sounds of the vessel or a combination of these factors it is not currently fully understood (NMFS, 2005). It is not known how current anthropogenic noise has affected the killer whales hearing and if it is stressing the whales to behave differently or if they have grown accustomed to a certain level. As a first step to addressing these uncertainties, I propose to consider descriptive studies of the relationship of vessel noise on surface behavior.

METHODS AND MATERIALS

Study Area

During the month of October 2006 a randomized survey was conducted in the Salish Sea surrounding the San Juan Islands and South Vancouver Island aboard the 'Gato Verde', a 42-foot catamaran, powered by wind and a quiet electric/biodiesel engine. Commercial tugboats, tankers, commercial fishing vessels, commercial whale watch vessels and personal vessels to name a few use this area. I physically recorded surface behavior, number of boats off, motored or idling and total number of whales.

Definitions

Surface behavior is to include all actions performed by killer whales during visual time at the surface of the water, including but not limited to states (foraging, play, etc.) and events (breaching, tail slaps, pectoral slaps, synchronous swims, spy hop, rollover, porpoise and cartwheel). A behavioral event was taken as a secondary source of data, depending on what the sample size was to become. Foraging is characterized by a loose forward orienting formation with subgroups and individuals occasionally varying their progress and engaging in non-directional milling activity (Osborne, 1986). Long, dorsal ended dives with non-directional travel will also be considered as foraging, especially in males. Vessel is referred to as all man-made devices that have the ability to make noise in the water (this excludes sailboats under sail, kayaks and aircraft). Inactive is characterized by a tight, slow moving individual or group (1-2 kts) with all individuals simultaneously surfacing within a few meters of immediate neighbor or touching. Socialize is characterized by touching an object or another individual while not inactive and is not in accord with any other category. Travel directional is characterized as directional movement at a steady energetic pace (+3.5 kts) and an absence of any novel surface events. Travel non-directional is characterized as non-directional movement at a unsteady pace opposing the direction of the groups general direction.

Selection of Data

A PDA (Palm Tungsten E) with software provided by James Ha of University of Washington was used to record all observational data. Once whales were in observable range (~600m), a count was done of vessels. Vessel count was categorized by off, motoring or idling within 800m of the Gato Verde. A motoring vessel was shown as moving forward at a steady pace with a visual of heavy prop wash. An idling vessel was distinguished by smoke coming from the engine area. In some cases idling could be heard from the 'Gato Verde' with a visual lack of forward movement. A vessel categorized as off failed to display moving or idling characteristics. This 800m distance allowed whales to be 400m from the 'Gato Verde' and up to 400m from another vessel. Large ships were counted once in visual range and at any distance from the whales. All vessel data was time stamped with the initial data entry. The distance of whales closest to the 'Gato Verde' was recorded as 0m-100m, 101m-200m, 201m-400m, 400m+. An identification of the individual pod and/or members was taken when possible.

Once vessel counts had been done, two consecutive five-minute intervals of whale behavior were taken. Timed intervals were initially timed with a kitchen egg timer until a digital timer became available. Behavioral states and events were observed with the definitions from above. States and events were collected as counts as well as the number of individuals being counted. A single hydrophone array was pulled at the stern end of the 'Gato Verde' to capture all noise from whales and vessels and recorded onto a Marantz Recorder Model PMD660 and a pre-amplifier (Military box). Time was manually recorded with a synchronized watch once recorder had started recording and stopped. Whales were observed until they were unable to be followed accurately through binoculars (Leupold Wind River Mesa 10x23). Canon Rebel 2000 digital camera with a 70-300mm lens and JVC video camera was used to help identify the whale pods when possible.

Acoustical Monitoring

Files were recorded in ten-minute increments. Acoustical data was analyzed using Raven 1.2 software to produce spectrograms of vocalizations and vessel noise with a sampling rate of 44.1 kHz. A one-minute time sample was taken to coincide of the start time from the vessel count. Whale vocalizations will be split from the one-minute sample in order to receive root-mean-square (RMS) amplitude of vessels only. Root-mean-square refers to a common way of defining the effective voltage. Only whale vocalization that could be seen above background noise was split out. The one-minute sample was extended beyond and before (two and a half minutes each way) the vessel count time to ensure 60 seconds of vessel noise has been obtained. A maximum of five random single echolocation clicks were included into minute samples of vessel noise. The one-minute un-split sample was the ideal sample because it would give an exact relation in time to the vessel count. The vessel noise was then converted to dB by adding the calibration to the $20\log_{10}(RMS)$.

Data Analysis

I wanted to see if there is a relationship with the number of moving vessels and the amount of vessel noise. The statistical test regression was done to see if there is a linear relationship between vessel noise and the number of moving vessels. To test surface behavior against vessel noise, a calibrated weighted mean on the RMS observed was tested against the behavioral states. The type of test was determined on if the data was normally distributed. I am expecting to show a significant difference in the behavioral state travel directional and vessel noise. All data was tested for normality. Overall, I expect to show that vessel noise has little if any relationship on the Southern Resident killer whales behavior.

RESULTS

All whales were identified with photo identification to be members of J-Pod. There were no significant relationships between behavior states and vessel noise. I was able to analyze over one hour of individual minute samples to determine the vessel noise. We had six days with the whales and only four of those days were used (67%). Out of 59 observational samples to be matched to one minute of vessel noise, only 44 were used due to electrical noise and orca communication interference. In analyzing vessel minutes I had to filter out all noise above 19500 kHz on all files due to a 20 kHz band that was on 90% on the recordings. The filter dropped the RMS amplitude roughly 13 mV. A filter done on a recording without the 20 kHz band only dropped to RMS amplitude by 0.2 mV. Once all the RMS amplitudes had been calculated, I was able to add the calibration number of 66.42176937 and give the new units of vessel noise in dB RMS re 1 _Pa.

All data was tested for normality using the variance ratio test. Travel directional (P=0.26, n=44), total number of vessels (P=0.24, n=44), total numbers of vessels on (P=0.24, n=44) and vessel noise (P=0.51, n=44) were normally distributed. Travel non-directional (P =0.03, n=44), socializing (P=1.9x 0^{-13}, n=44), foraging (P=5.1x10^{-4}, n=44), inactive (P=5.6x10-6, n=44), and total number of vessels motoring (P=0.049, n=44) tested not normally distributed.

A regression test was done between number of vessels while motoring or idling and vessel noise (dB RMS re 1 _Pa.) and results showed no relationship (Fig.1, P=0.44, R^2=0.014, n=44). The same test was done on total number of vessels and vessel noise and the results did not show a significant relationship (Fig.1, P=0.60, R^2=0.007, n=44). A linear regression was done on travel directional behavior state against the vessel noise (Table1, P=0.16, R^2=0.047, n=44) and there was no significant relationship found. However, I was able to show a negative trendline of higher vessel noise with less directional traveling (y = -0.0129x + 2.1195). A Spearman Rank Correlation was done on all other behaviors with vessel noise and no significant relationship was found (Table1).

DISCUSSION

The boat-based study revealed that none of the vessel noise tested against the surface behaviors showed a significant relationship. The expectation of seeing the Southern Resident killer whales travel directionally more often during high vessel noise was not shown. In coming up with my prediction, I was thinking of travel directional to be used as an escape from high vessel noise. Movements of killer whales have also appeared to be affected by boats within 100m and 400m (Bain, pers. comm.). I was able to show a negative trendline of higher vessel noise associated with less directional traveling. A previous study by Williams et al (2002) showed that male resident whales swam steady with a less direct path when vessels were in the area. Females reacted differently to vessels by swimming faster and increased the angle of successive dives. Whether there is a relationship between the vessels and the whales or the vessel noise and the whales is yet to be seen. Additional analysis may be done to identify all individuals and test females and males differently.

Other possibilities as to why I was unable to show any significant relationships may be my sample. I had intended to look at all three Southern Resident pods. I had one good day of observational data from K & L pods. When I went to analyze the data, it had been filled with electrical noise and was not able to be used. The fifteen minutes of files that lacked electrical noise was filled with echolocation and orca communication and I was unable to get one minute of only vessel noise. It would have also been viable to see if the vessel noise had any relationship to the behavior state observed for these pods. A possible future study could be done to see if there is any pod variation in regards to vessel noise.

Early analysis of finding a relationship between number of boats and vessel noise was used to find out whether or not it would be suitable to test vessel numbers with surface behavior states. Finding the lack of significance, all the relationship testing was done with the vessel noise and the surface behavior states. Since vessels were taken within a certain range from the vessel, and not from the whales, could help explain the lack of significant relationships. Another possibility of finding a significant relationship could have been to take a count of vessels that were in a closer radius to the hydrophone. Tankers and other large ships were counted once in visual range. Sound may still be heard from a large ship to the hydrophone from far distances, but at lower frequencies. This was shown during analysis of the acoustic recordings. Tankers, noted as an aside during observation in close distance to the research boat, was notably louder. There were not many vessels in the water on the K & L pod day (max=4) and with no significant relationship of more vessels giving more noise one could not assume the noise would have been less than a busy whale watch day.

Southern Residents K & L may be showing the same compensation that the Northern Residents have shown when being introduced to Acoustical Harassment Devices (AHD). According to Morton et al (2002) the Northern Residents left common used region when AHDs were commonly used and returned to the area after the AHDs usage was stopped. Tolerances of noise may not be as accustomed for K & L pod.

My received sound levels ranged from 118.32 to 140.03 dB RMS re 1 _Pa (Fig.2). Range of received sound levels from Griffin and Bain (2006) was 106 to 146 dB RMS re 1_Pa. Their study helped to show a 15% to 20% average annual decrease in foraging space due to increased noise levels. The peak values observed on a fixed array on the westside of San Juan Island has been about 130dB when either a small powerboat passes nearby (order 100m) or a large vessel passes in the distant shipping lane (order 1000m). That can be translated by the typical received level of common noise the southern residents likely experience is about the same – regardless of the source being a single powerboat, single ship, or a fleet of whale watch operators (Veirs and Veirs, Pers. comm..). In taking counts of vessels, the vessel was not characterized as type of vessel and it's mode of operation. Although samples with high amounts of electrical noise were not used (Fig.3), some samples did have faint electrical noise that showed at a certain level of kHz (Fig.4).

A study is currently being done on dive duration for the Southern Residents to see if they are expending more energy to stay below the surface. A vertical avoidance has been shown in other cetaceans and been known to come with a physiological cost. Dolphins breathing synchrony has been documented to show it is clearly influenced in the presence of boats (Hastie et al. 2003).

Lusseau (2003) found that dolphins showed a vertical avoidance and therefore had less rest periods. The vertical avoidance of boats was also occurring prior to the boats being in visual range. A cetaceans hearing has evolved to peak in the water environment and may be able to pick up the sound of a motorboat prior to it being in visual range.

Whale watching boats have increased over the years and so has the acoustical compensation from killer whales to account for it. The three Southern Resident pods have shown an increase (in seconds) of mean call duration over three decades (Foote et al. 2004). Since I did not look at any call rate associated during these behavior states, I cannot conclude any association between call rate and vessel noise or states. A prediction to why the whales were moving less often with more noise may be that the increase in noise causes situations in which it is harder to communicate with other members in the pod as a whole. Southern Resident killer whales are known to be social animals and communication it part of being social.

J-pod is the more likely of the resident pod to be seen in the Salish Sea and may have become accustomed to the noise. Sticking to quieter refugia of the Straits may be an option for these whales. Knowing that matrilineal units are close nit, with family members staying around for lifetimes, it is interesting to have more research on the increase of vessel traffic and any affect on them. Another opinion is that they have learned to compensate for the noise and are introducing new cultural transmission to the next generations. Acoustical compensation has been seen in other species, such as the great tits overcoming urban noise with a higher minimum frequency song (Slabbekoorn and Peet, 2003). As stated before, Foote et al. (2004) found that the Southern Resident killer whale population increased the duration of their calls by 10-15% as vessel traffic increased over three decades. Overcoming noise for species may help with continued success in breeding.

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Appendix 1

Table 1. The normality, sample size, probability value, coefficient of determination, and the Spearman rank-order correlation coefficient of the vessel noise analysis.

Beahvorial State	Normal	n	P-value	R^2	r_S	Significant
Travel Directional	Yes	44	0.1578	0.0469		No
Travel Non-Directional	No	44	0.734		0.0546	No
Socialize	No	44	0.776		0.0457	No
Foraging	No	44	0.961		0.0078	No
Inactive	No	44	0.1635		0.22	No

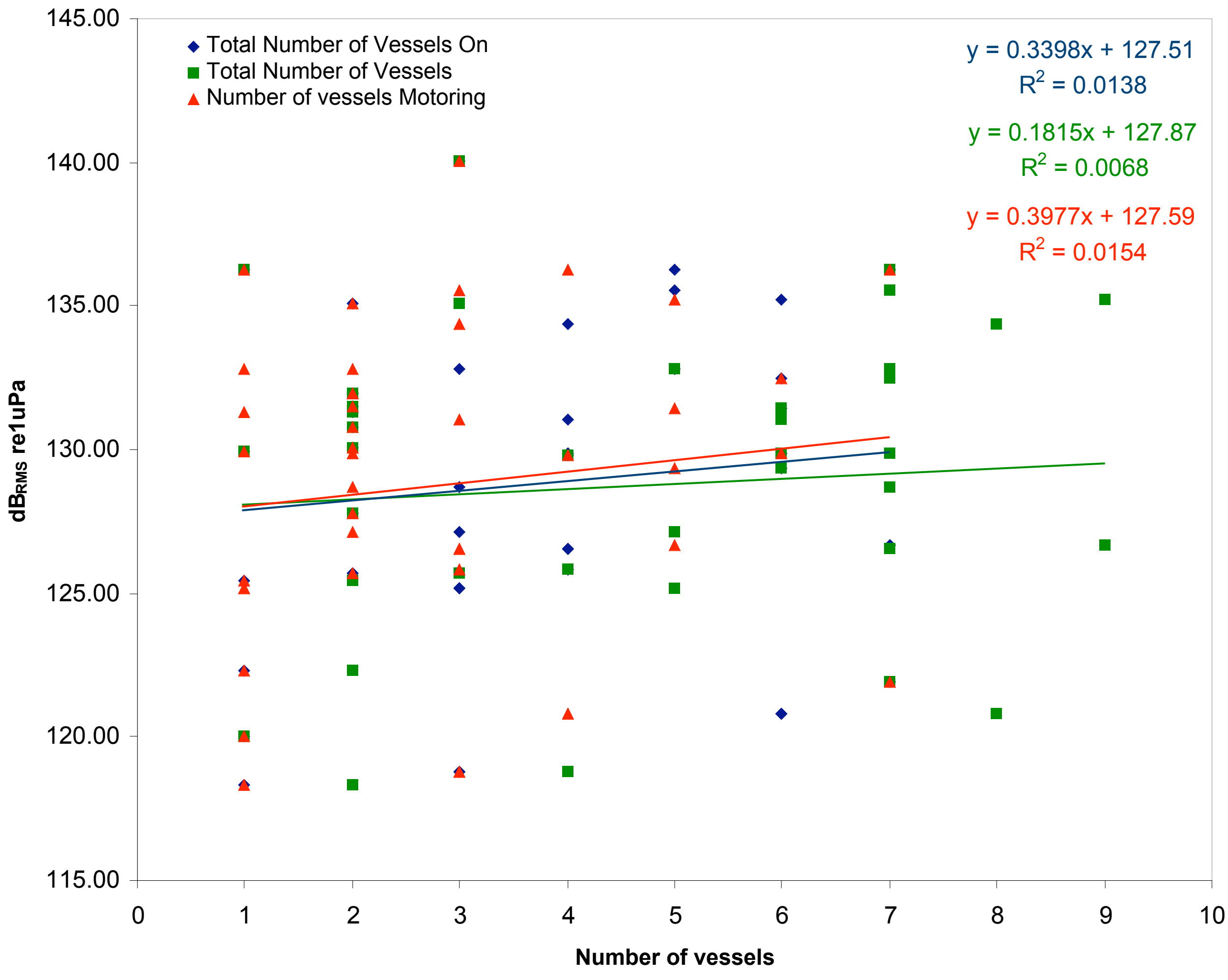

Figure 1. Relationships of vessel noise and the different category states of vessels.

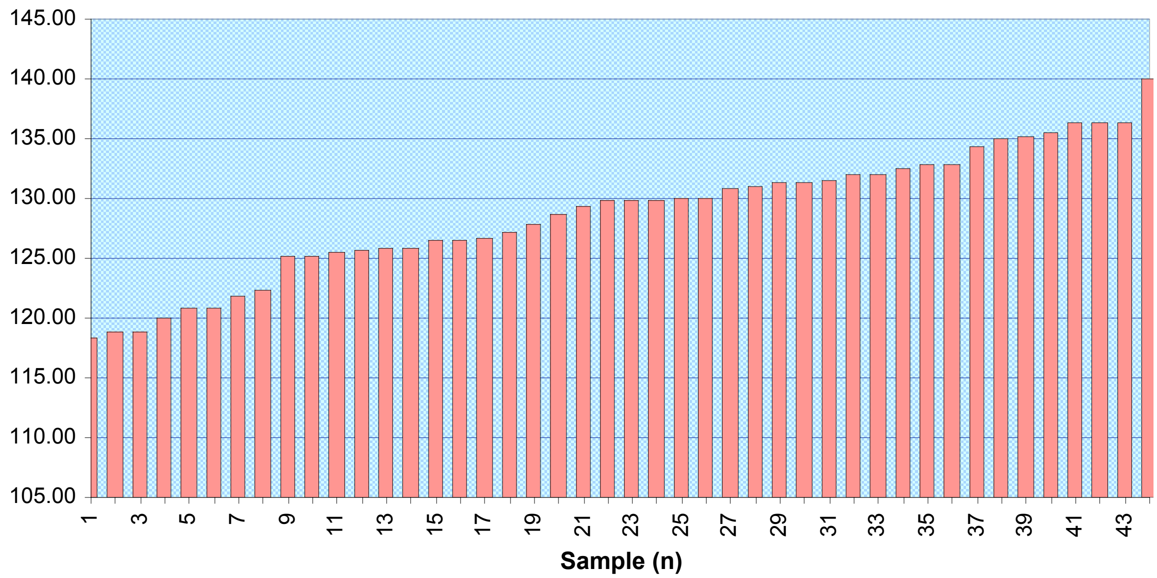

Figure 2. Received sound level recorded per sample. Samples are not shown in sequential time but rather in order of increasing sound level.

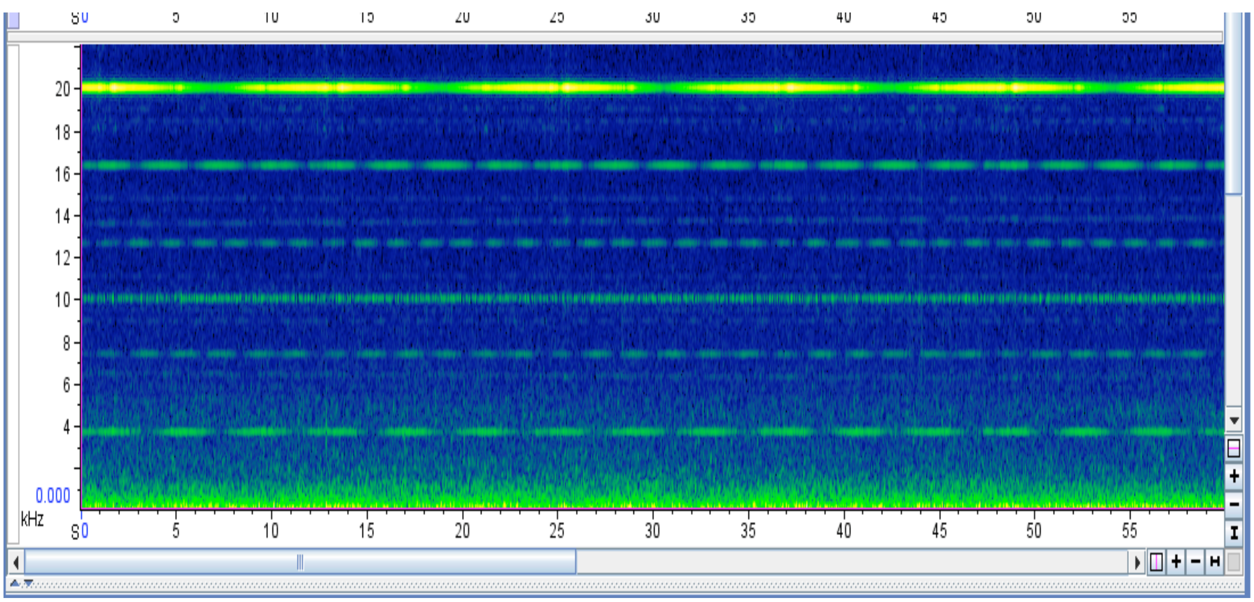

Figure 3. An example of electrical noise coming through the hydrophone recordings. Recordings like this were not used in the statistical sampling.

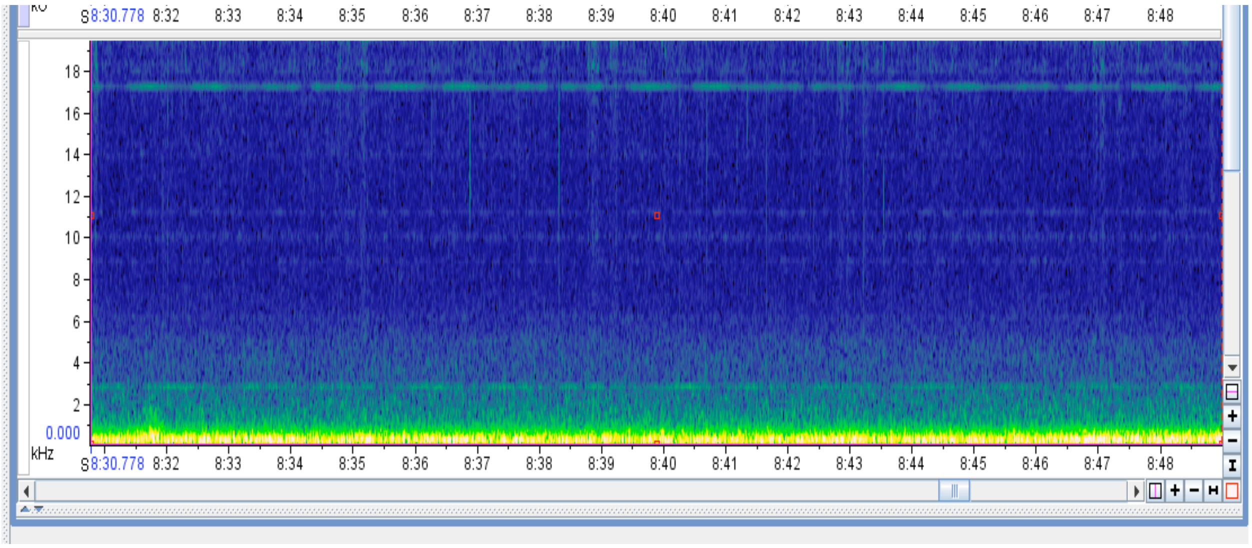

Figure 4. An example of light electrical noise coming through the hydrophone recordings. Recordings like this were acceptable for use in the statistical sampling.