Effects of anthropogenic noise on fishes at the SCaan Kinghlas-Bowie Seamount Marine Protected Area

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Abstract:	Underwater noise from anthropogenic sources has been increasing dramatically for the past few decades and little is known about its effects on fishes. The objective of this study is to describe the occurrence and characteristics of fish sounds in the SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA, British Columbia, Canada) and to correlate them with the corresponding anthropogenic soundscape. Here we present preliminary results of the detection of fish sounds at SK-B MPA between July 2011 and July 2013. An automatic detector was used on nearly 40,000 acoustic samples (4,754.5 hours in total) to search for fish sounds. About 1.2% of the data were highlighted as containing fish-like signals. Manual verification of these detections revealed that 95.5% were false positives and the remaining sounds were of unknown origin. Eighty detections were highly stereotyped and are suspected to be produced by fish, but no identification has been confirmed yet. Systematic manual inspection of sub-sampled acoustic data is yet to be performed to determine if the detector missed any fish sounds. Future deployments should select areas based on the presence of known fish habitat occurrence, and install autonomous recorders optimized to reduce equipment self-noise and flow noise biases.
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Underwater noise from anthropogenic sources has been increasing dramatically for the past few decades and little is known about its effects on fishes. The objective of this study is to describe the occurrence and characteristics of fish sounds in the SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA, British Columbia, Canada) and to correlate them with the corresponding anthropogenic soundscape. Here we present preliminary results of the detection of fish sounds at SK-B MPA between July 2011 and July 2013. An automatic detector was used on nearly 40,000 acoustic samples (4,754.5 hours in total) to search for fish sounds. About 1.2% of the data were highlighted as containing fish-like signals. Manual verification of these detections revealed that 95.5% were false positives and the remaining sounds were of unknown origin. Eighty detections were highly stereotyped and are suspected to be produced by fish, but no identification has been confirmed yet. Systematic manual inspection of sub-sampled acoustic data is yet to be performed to determine if the detector missed any fish sounds. Future deployments should select areas based on the presence of known fish habitat occurrence, and install autonomous recorders optimized to reduce equipment self-noise and flow noise biases.

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1.INTRODUCTION

Underwater noise from anthropogenic sources has been increasing dramatically for the past few decades (McDonald et al., 2006). Its impacts on marine mammals have been widely studied, but little is known of the effects of noise on fishes and invertebrates (Popper and Fay, 2011; Popper and Hastings, 2009).

Marine anthropogenic noise at low frequencies overlaps with fishes' hearing range and peak sound production which can reduce their communication space and result in habitat loss (Hawkins et al., 2015). In addition to increasing stress levels and impairing the ability of fish to detect prey and predators, intense noise can cause temporary hearing loss and reduced survival (Simpson et al., 2016).

The main objective of this project is to study the effects of anthropogenic noise on fishes at the SGaan Kinghlas-Bowie Seamount Marine Protected Area (SK-B MPA). This is an offshore volcanic formation off the west coast of Haida Gwaii in the Pacific Ocean (Fig. 1) that rises from a depth of 3000 m to within 25 m of the surface (Canessa et al., 2003). The MPA encompasses three seamounts: Bowie, Hodgkins, and Davidson, and it is divided into three zones for management purposes (DFO, 2011); from the peak of the Bowie seamount to the 457 m bathymetric contour line (Zone 1), the remainder of the Bowie seamount (Zone 2), and the Hodgkins and Davidson seamounts (Zone 3). The value of the MPA for protection includes a rich, biodiverse, and productive ecosystem thanks to the surrounding oceanographic interactions such as upwelling and turbulent mixing of surface waters. It also serves the possible functions of biological oasis for unique plant and animal communities and of staging post for migrating marine mammals and seabirds (Canessa et al., 2003). The fish community is dominated by rockfish (25 species of *Sebastes sp.*), sablefish (*Anoplopoma fimbria*), and prowfish (*Zaprora silenus*). Some of these species are known to produce sound (Wall et al., 2014). Prowfish is a rare species that usually occurs in somewhat deeper water but is found in large numbers at shallower depth at SK-B MPA (Canessa et al., 2003).

To investigate the effects of anthropogenic noise on fishes, we first need to determine the presence of fish sounds and their temporal distribution at this location. Patterns in fish sound production will then be compared to patterns in ocean vessel traffic and associated noise exposure. This will be done in collaboration with the ongoing MEOPAR-funded (Marine Environmental Observation Prediction and Response) NEMES (Noise Exposure to the Marine Environment from Ships) project that is mapping ocean vessel traffic and modeling associated noise exposure to predict gradients/spatial distribution of noise along the BC coast, including the SK-B MPA. Here we present preliminary results of the detection of fish sounds at SK-B MPA between July 2011 and July 2013.

2.METHODS

A.BOWIE SEAMOUNT ACOUSTIC RECORDINGS

Acoustic data were collected at SK-B MPA (Fig. 1) by means of three consecutive AURAL M2 acoustic recorder (Multi-Electronique Inc., Rimouski, QC, Canada) deployments between July 2011 and July 2013. Details for the three acoustic deployments are provided below in Table 1.

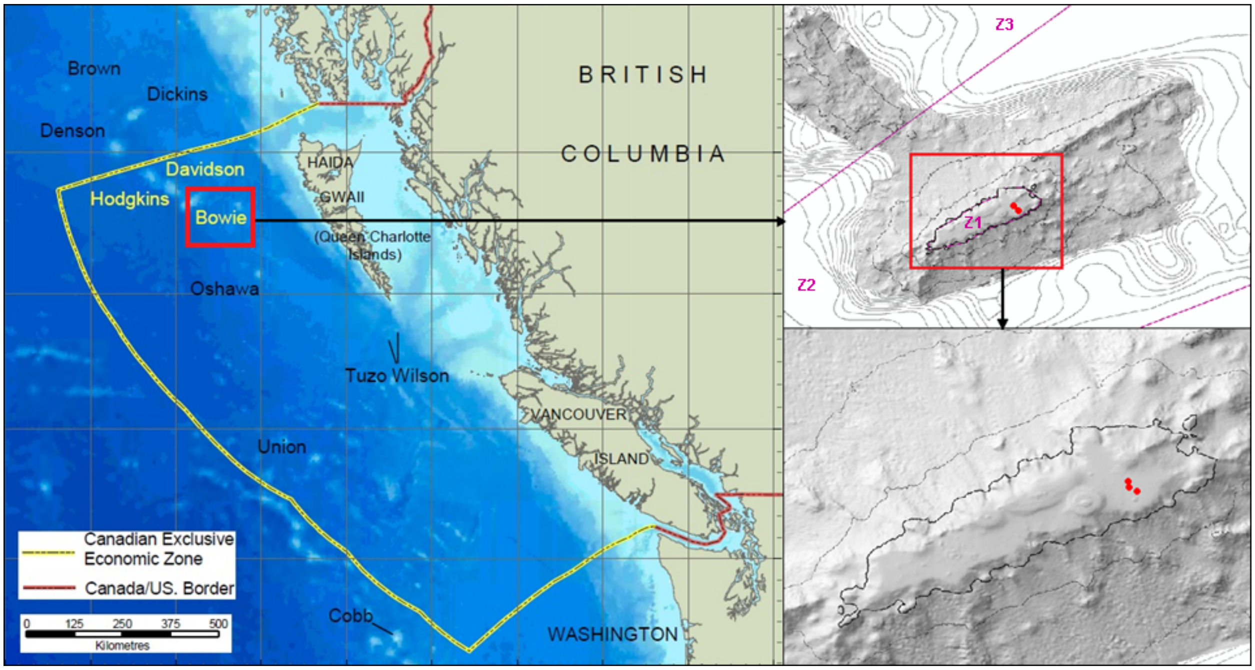

Figure 1. Location of Bowie Seamount in relation to other seamounts in the Northeast Pacific Ocean (left, adapted from Canessa et al., 2003). Top and bottom right show the location of the three deployments (red dots) in relation to the seamount bathymetry, with increased resolution (bottom right).The purple lines on the top right figure delineate the MPA's three zones: Zone 1 where the acoustic recorders were moored, Zone 2 for the rest of Bowie Seamount and Zone 3 showing part of the Hodgkins Seamount.

Table 1. SK-B MPA acoustic data.

Deployment	Period	Coordinates	Depth (m)	Duty cycle (min on / off)	Sampling rate (KHz)
D1	Jul 2011- Jan 2012	53.305 135.623	235	9 / 6	16
D2	Jan - Apr 2012	53.307 135.627	233	9 / 6	16
D3	Jul 2012- Jul 2013	53.308 135.627	232	4.5 / 10.5	16

B.AUTOMATIC DETECTIONS OF FISH SOUNDS

An automated detector developed by JASCO Applied Sciences was used to detect potential fish sounds from these data. The algorithm employed is similar to the one described in Moloney et al. (2014) and Dewey et al. (2015). The various processing steps of the detector are indicated in Figs. 2 and 3.

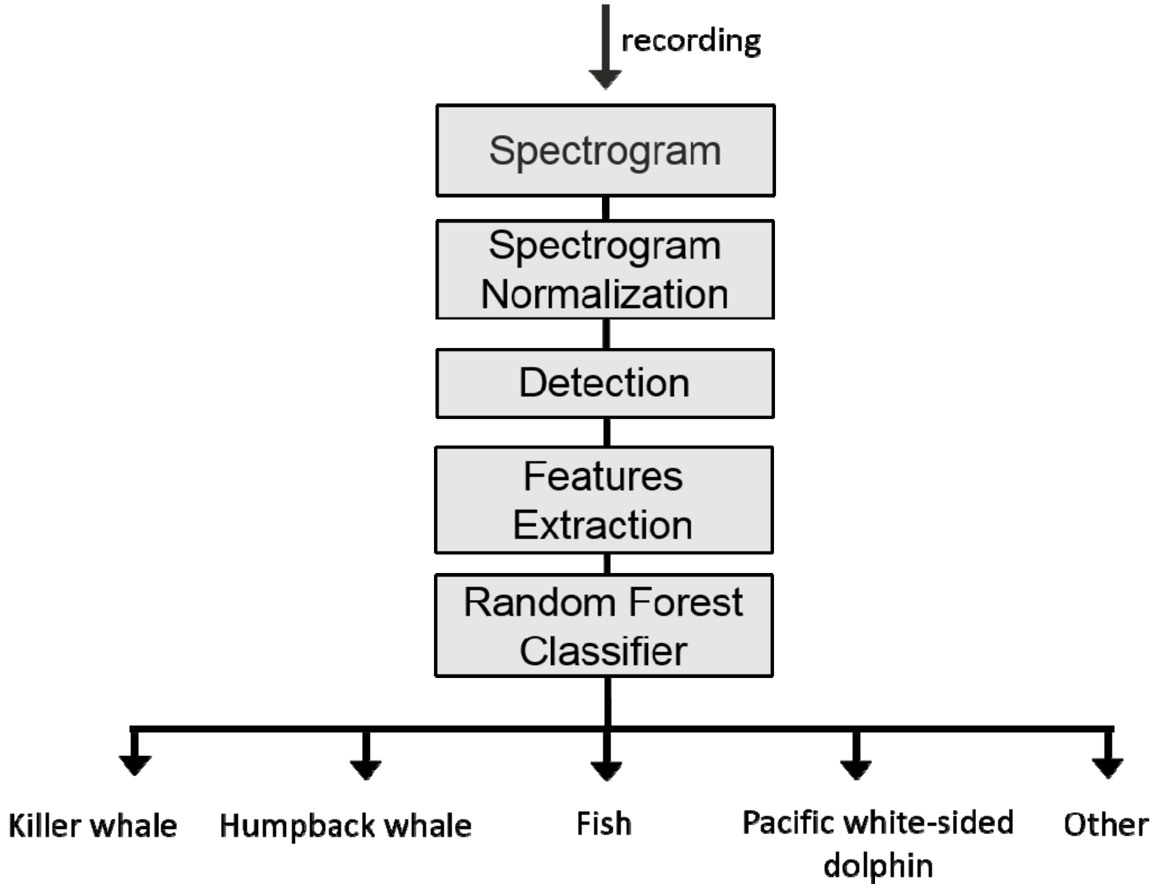

Figure 2. Automatic detection of fish sounds: diagram of the automated processing.

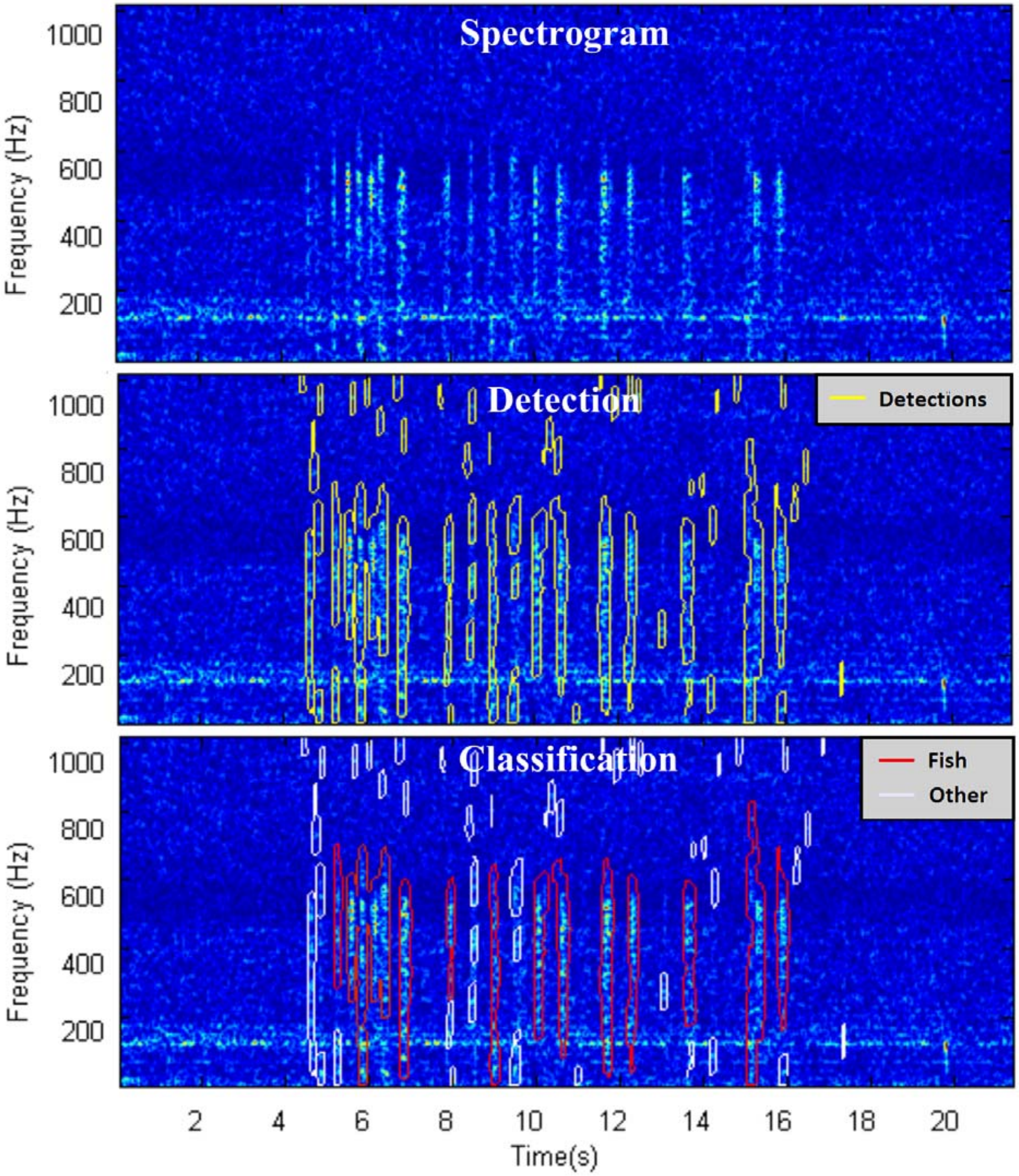

Figure 3. Automatic detection of fish sounds. Top: example of spectrogram with fish sounds, center: detection of acoustic events in the spectrogram, bottom: classification of fish sounds using a random forest classifier.

The algorithm first calculated the spectrogram and normalized it for each frequency band. Next the spectrogram was segmented to detect acoustic events between 10 Hz and 8 kHz. For each event, a set of 40 features representing salient characteristics of the spectrogram was extracted, several of which were calculated following Fristrup and Watkins (1993) and Mellinger and Bradbury (2007), and were based on the spectrogram, frequency envelope, and amplitude envelope of the signal. Extracted features were presented to a classifier to determine the class of the sound detected. The classification was performed using a random forest classifier (Breiman, 2001), which was trained using several thousands of manually annotated vocalizations in recordings collected at different locations in British Columbia (Mouy et al., 2015). The random forest was defined with five classes: “killer whale”; “humpback whale”; “fish”; “Pacific white-side dolphin”; or “other”. For this study, only fish classifications were analyzed. Fish sounds used for the training of the classifier were all collected in the Strait of Georgia in 2014 by a JASCO tetrahedral hydrophone array deployed on the Ocean Networks Canada VENUS observatory (Moloney et al., 2014; Dewey et al., 2015). Fish sounds included both pulses and grunts as illustrated in Fig. 4. Only about 100 fish sounds were used to train the fish class of the classifier due to the limited availability of the manually annotated fish sounds. Consequently, the fish classification is less mature than the other classes and needs to be improved. The present collaboration with JASCO Applied Sciences will provide feedback for the fish automated detector and any fish sounds that are positively indentified within the SK-B MPA acoustic data will be used to adjust the classifier.

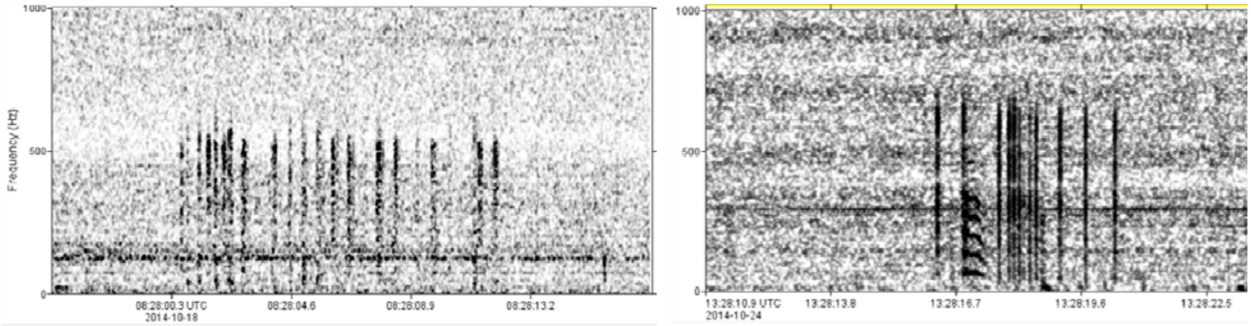

Figure 4. Examples of fish sounds collected in the Strait of Georgia that were used for training the random forest classifier.

C.MANUAL VERIFICATION OF THE DETECTOR OUTPUT

Manual verification of the signals highlighted by the automatic detector was performed with Raven Pro 1.5 (Cornell Lab of Ornithology, Ithaca, NY). Each sound was examined in 15-second spectrograms to provide context. Spectrogram parameters were 1024 samples FFT, 85% overlap, 51% brightness, 81% contrast. Default initial view displayed the first 2.8 KHz, the top part of the spectrogram (up to 8.2 KHz) being inspected only when needed. The first 200 Hz were filtered out for all of Deployment 3 due to intense flow noise that made aural verification difficult. This high-pass filter was applied only when needed throughout Deployments 1 and 2.

The automatic detector output was delivered in Selection Table format, which when opened in Raven Pro 1.5 displayed a selection box around each sound it identified as fish. Raven Pro 1.5 allows toggling between selection boxes within a set of open WAV files. This made it possible to move quickly between selections that were separated in time throughout the data. Each selection was reviewed manually and annotated with a general “Class” (Unknown, Noise, Humpback Whale, Sperm Whale, Fish) and “Sound Type” for a more specific and variable description of the sound (e.g., “Bump”; “Current”; “Seismic”; “Biological?”; “Beginning of call”; “Mooring noise”; “Vessel noise”; “Possible Fish”; “Echolocation Click”).

3.RESULTS

The detector found 6,387 possible fish sounds in 487 WAV files (Table 2) which were manually inspected (only 1.2% of the total data). 95.5% of the automatic detections turned out to be false positives (Fig. 5a and b), and the remaining sounds could not be positively identified to any satisfactory category (Fig. 6). Twenty-eight percent of these unidentified sounds were suspected to be of possible fish origin and will need to be further measured, classified and characterized in order to confirm their source. Half of these possible fish sounds were stereotyped and sounded like a deck of cards being shuffled (Fig. 7). While verifying these detections, more card-shuffle sounds that had not been marked by the detector were observed on the 15-second screen, indicating that they were missed by the detector and suggesting that the detector needs to be tuned to these types of sounds. Details on number of detections and their verified type per deployment are presented in Table 2.

Table 2. Automatic detector output and manual verification for acoustic data collected at SK-B MPA between July 2011 and July 2013.

Deployment	**Total WAV files**	**WAV files with at least 1 detection**	**Total detections**	**Detections per WAV file (that had detections)**	**Detector false positives**	**Unknown detections**	**Possible fish**
D1	14,101	279	5127	4-110	4,960	167	69
D2	9,404	84	263	2-27	146	117	11
D3	16,383	124	997	4-14	996	1	0
Total dataset	**39,888**	**487**	**6,387**		6,102	285	**80**

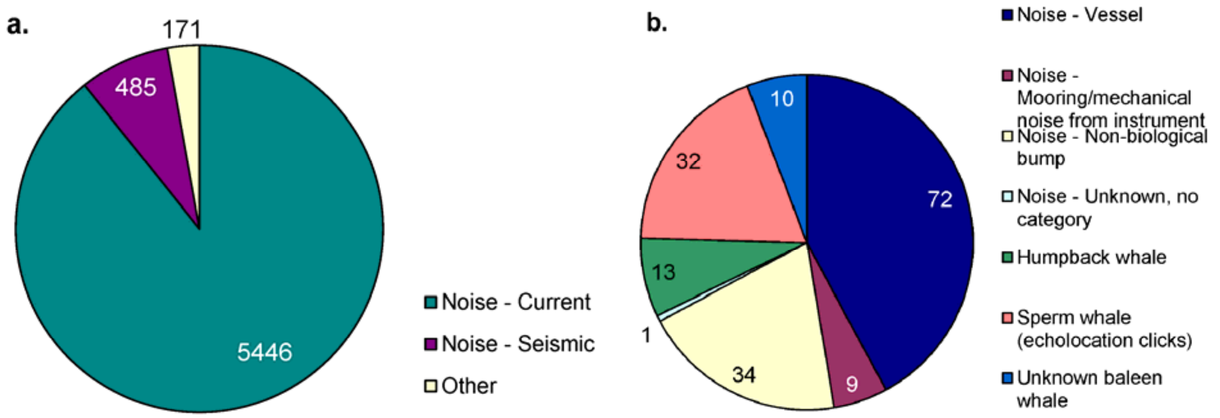

Figure 5. False Positives. a. Total number of false positives (N = 6,102). b. Details on false positives that were not attributed to current or seismic noise (N = 171).

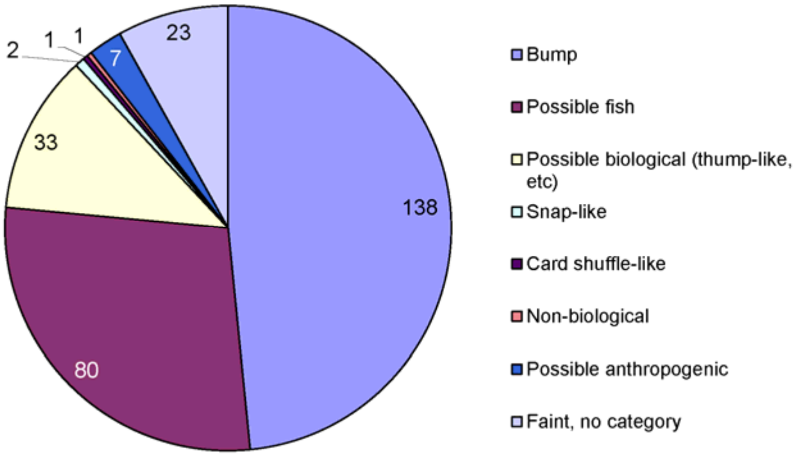

Figure 6. Unidentified Sounds (N = 285).

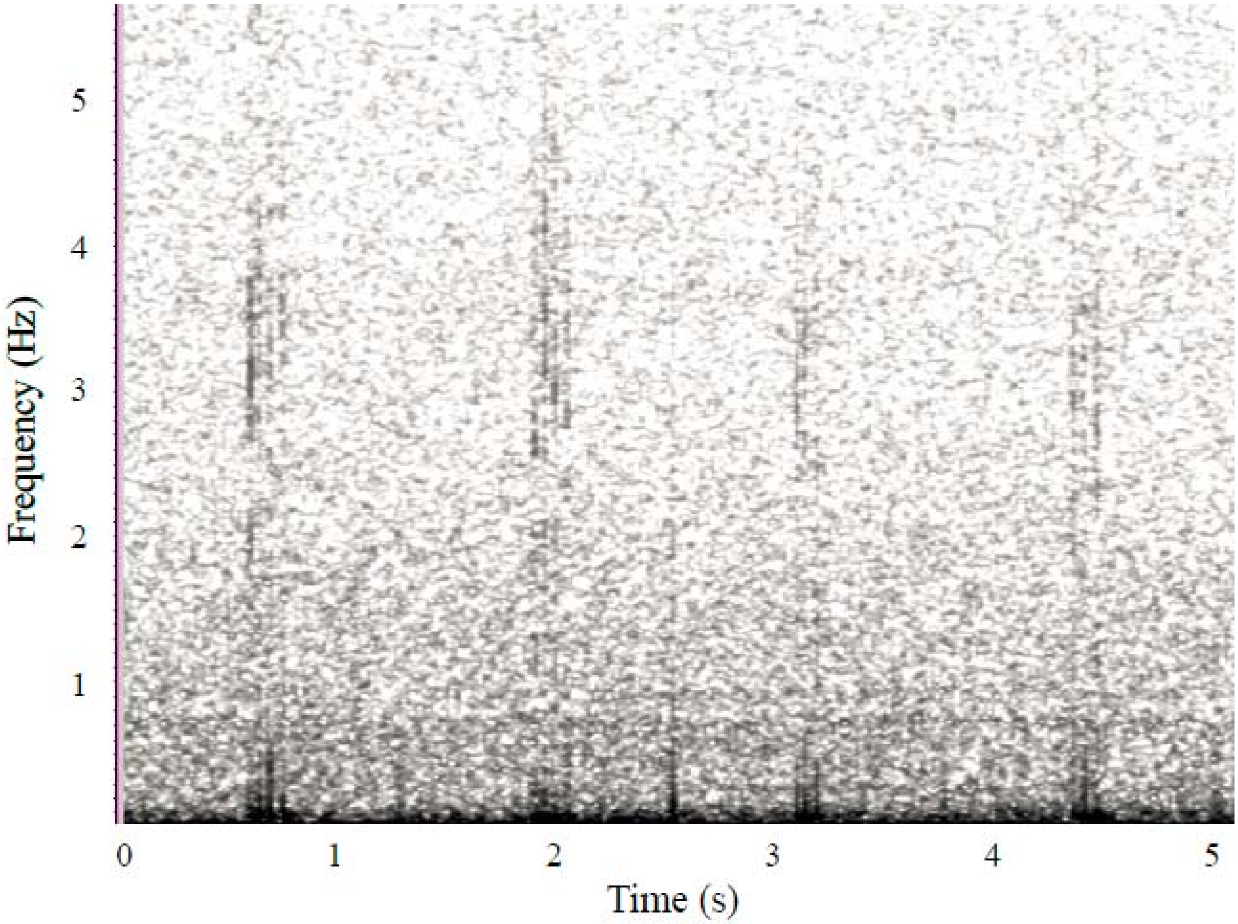

Figure 7. Compilation of four card shuffle sounds. These were originally separated by more than half a second. Sound between signals has been removed to show several examples together. Mean peak frequency is 83.3 Hz, bandwidth 16-2704 Hz, mean duration 0.2 s. N=40.

4.CONCLUSION AND NEXT STEPS

There are more than 32,000 known species of fishes (www.fishbase.org) but not all of them have the ability to produce sound. The mechanisms for fish sound production include sonic muscles attached to the swim bladder and stridulation mechanisms consisting in rubbing skeletal elements such as teeth, fin rays, and vertebrae which lead to a great variation of sounds (Ladich, 2015). This variation combined with the very limited knowledge about which species of fishes are soniferous and what their sounds are like (Hawkins et al., 2015), particularly in waters of British Columbia (Wall et al., 2014), makes it difficult to identify fish sounds captured by passive acoustic recorders (Rountree et al., 2006; Rountree, 2008).

The complete lack of confirmed fish sounds found within the SK-B MPA acoustic recordings does not necessarily indicate absence of sound-producing fish, although it highlights the challenges of using passive acoustic methods to detect fish sounds and it potentially affects the next stage of the study which is to compare patterns in fish sound production to the anthropogenic soundscape. However, the analysis has not been finalized yet. The unknown sounds found by the detector that are possible fish need to be further measured, classified, and investigated in order to confirm their source, especially the potential thump or knock sounds referred to in Fig. 6 and the card shuffle-like sounds (Fig. 7).

In addition, systematic manual inspection of acoustic data and comparison with automated detections is yet to be performed in order to also quantify false negatives (fish-like sounds that the detector may have missed). For example, several additional cards-shuffle-like sounds that had not been marked by the detector were observed, and there might be more. The detector might not have highlighted all card-shuffle sounds present in the dataset because it was tuned primarily to knock and groan types of sound. Our preliminary results indicate that these types of sounds may be uncommon in the study site, while other types of sounds like the card-shuffle sound were more common. Retuning the detector to optimize for these types of sounds may improve our ability to detect suspected deep-sea fish sounds. It is also our intention to look for similar type of sounds in other datasets to assess their occurrence, and use them to better tune the detector for deep-sea fishes. The more examples we can get of fish sounds produced in the deep sea, the better we can train the detector.

Since the peak energy of typical fish sounds is most often encountered in the 20-200 Hz frequency range, these sounds may have been masked by flow noise that was present throughout a major part of the recordings. Future deployments should select areas based on the presence of known fish habitat occurrence, rather than solely on geology, and install autonomous recorders optimized to reduce equipment self-noise and flow noise biases.

Unfortunately, attempts to evaluate the impact of noise on fishes and invertebrates is compounded by our limited data on sound production in marine and aquatic ecosystems (Rountree et al., 2002; Rountree et al., 2006; Luczkovich et al., 2008). Sound reference collections are particularly limited in the eastern Pacific (Wall et al., 2014) and more generally in deep-sea habitats (Rountree et al., 2012). Therefore, we need more information on sound-producing fish species, particularly in the northeastern Pacific area, and we need catalogues of vocalizations produced by known fish species in order to identify sounds captured by passive acoustic methods. Addressing knowledge gaps on sound type, conditions, and seasonality of fish sound production will be highly valuable for future studies.

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