FINE-SCALE MAPPING OF MARINE SOUND POLLUTION USING SONIC KAYAKS AND CITIZEN SCIENCE

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Abstract: *Underwater noise pollution directly impacts a wide variety of marine species. Falmouth Bay, UK is an active commercial port with a nearby shipping lane. Ship traffic predominantly transits the centre of the bay affecting the sound levels as recorded from a single location [1]). The degree to which this extends throughout Falmouth Bay is unknown. Understanding the characteristics of underwater noise that marine organisms are exposed to is vital in assessing the impact.*

To date, fine-scale mapping of marine and estuarine noise pollution has been constrained due to a lack of appropriate technology. As such, our understanding of the impacts of noise pollution on wildlife remains limited, and localised conservation management options remain unexplored. Data on the spatial variability of marine noise pollution can inform marine conservation and management strategies. For example, quiet regions may be identified which could then be protected through mitigation measures. Furthermore, biological noise data is increasingly being considered as a measure of biodiversity and fine-scale data offers advantages in this respect.

FoAM Kernow, in collaboration with sound artist Kaffe Matthews, have developed a "Sonic Kayak" system to record GPS-located underwater sound while kayaking. The kayak system offers advantages in fine-scale, directed spatial coverage as compared to traditional systems and causes limited disturbance. In addition, the person recording the data does not need professional training, enabling a citizen-science approach.

We present preliminary findings from developing and testing the Sonic Kayak system. This research will build on previous work on the underwater noise pollution in Falmouth Bay from a single location [1-3] and allow a detailed assessment of the potential impact on marine species throughout Falmouth Bay. With a sufficient volume of data, current levels can be established from which future trends may be identified.

Keywords: *Citizen science, Kayak, Underwater sound, Mapping*

1. INTRODUCTION

A kayak-based system, called a "Sonic Kayak", was initially developed for fine-scale temperature recording and sonification (conveying information using sound). Changes in temperature detected by a thermistor on a cable underneath the kayak were sonified and played through speakers fixed to the top of the kayak. An on-board GPS allows the subsequent mapping of the logged temperature data. A low-cost hydrophone was also attached to the system, allowing the sounds received to be played through the speakers in real-time in addition to the temperature sonification. The Sonic Kayaks were launched at the British Science Association Festival in Swansea in 2016 where participants collected temperature data in Swansea Bay [4]. The fine-scale temperature data is intended to provide information useful in the research of such topics as climate change and harmful algal blooms.

The Sonic Kayak system also has the potential to collect fine-scale underwater sound recordings. Typically, underwater sound data is collected either from static passive acoustic monitoring devices (as in [1, 3, 5]) or from drifting devices which travel with the prevailing current. Drifting devices have been used to record variations in underwater sound with habitat [6] and are used in high tidal flow environments to reduce flow noise [7]. Underwater sound recordings are also made from towed devices from boats although these are typically used in research topics such as cetacean detection (e.g. [8]) as opposed to recording of the ambient sound due to the vessel noise. Recording underwater sound data while paddling a kayak offers an advantage in a greater spatial coverage as compared to static devices. In contrast to drifting devices, which also offer increased spatial coverage, the locations of data collection are chosen. Additionally, a kayak causes minimal disturbance to wildlife as compared to a vessel with an engine and the person recording the data does not need professional training, enabling a citizen-science approach.

Shipping noise affects shallow coastal locations, such as in [1]. Sound propagation can be very complex in such shallow areas as there are as a variety of sources and increased interactions with the sea surface and seabed by the sound waves [9]. The sound levels therefore may vary considerably spatially throughout the area. Understanding the characteristics of underwater noise that marine organisms are exposed to is vital in assessing the impact on marine species. The Sonic Kayaks have the potential to gather data to be used in mapping marine noise in such areas.

Given the potential applications we therefore developed the Sonic Kayak to record underwater sound and tested the concept in the region of Falmouth, Cornwall, UK.

2. METHOD

The Sonic Kayak system consists of a Raspberry Pi 2, temperature sensors, a GPS, speakers, pre-Amp, sound card, a battery and a hydrophone (Fig. 1). Audio from a DolphinEar DE-PRO Balanced Hydrophone was recorded continuously through Pure Data (an open source visual programming language) to a USB flash drive (16 bit recording, 0 dB gain, single .wav audio file per kayak trip). The hydrophone has a recording bandwidth of 10 Hz – 22.5 kHz with an approximately flat (±2 dB) response 20 Hz - 20 kHz (-6 dB at 10 Hz and 24 kHz).

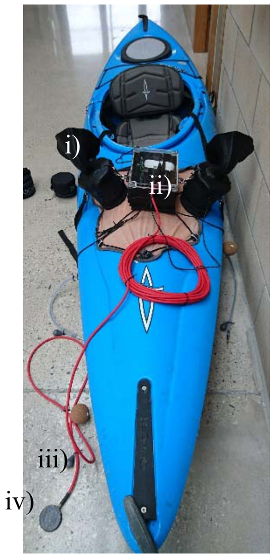

Fig.1: Sonic Kayak system consisting of: i) speakers, ii) box containing electronics, iii) weight and iv) hydrophone

Recording of underwater noise from two Sonic Kayak systems was tested in Penryn river, Cornwall in March 2017 on an incoming tide (Fig. 2). Initial tests indicated that paddling noise could be detected. Therefore, the sampling procedure was to collect unpolluted samples by pausing paddling periodically. However, the conditions were windy (> 20 mph gusts forecast) and pausing paddling for recording proved challenging. The speakers on board the kayak allow underwater noise to be heard in real time. For our purposes of testing, this allowed us to pause paddling when hearing sounds of interest, for example, boats.

Data processing

Tones at frequencies 10 Hz, 60 Hz, 200 Hz, 1 k Hz, 10 kHz and 20 kHz were recorded through the entire recording system (Raspberry Pi, pre-Amp and sound card). The voltages of these tones were assessed using an oscilloscope and correction factors calculated. The values were interpolated using a linear interpolation method in MATLAB (2016b; The Mathworks) to provide a value per 1 Hz (10 Hz – 20 kHz).

The hydrophone sensitivity is not available (but the response is approximately flat), therefore only relative dB levels are calculated. A fast Fourier transform was applied sequentially to 1 s segments (Hann window, 50% overlap). The calculated correction factor is applied during this process. The results are converted into dB with reference to 1 μPa once all calculations are complete.

The root-mean-square Sound Pressure Levels (SPL_{RMS}) were also calculated (1 s segments, 50 % overlap) for the frequency range 10 Hz – 20 kHz for the periods of paused paddling. The mean SPL_{RMS} was calculated per period of paused paddling and then converted to dB.

3. RESULTS

Recordings were made from two separate Sonic Kayak systems on the same trip resulting in two audio files of ~2 hours each. However, there was an error with one of the kayak's GPS and this one did not record.

During power-up there is some electrical noise which requires exclusion. There was also some additional self-noise at several specific frequencies present throughout the recordings (peaks at the frequencies 3,798 Hz, 4,138 Hz, 7,925 Hz, 8,679 Hz, 11,712 Hz, 12,809 Hz, and 20,679 Hz). The source of this is unclear but possibly from the Raspberry Pi itself, or the GPS, as other potential sources, such as the sound card, were excluded.

Paddling produces sound in a wide frequency range from 10 Hz -5 kHz. We paused paddling periodically to collected unpolluted recordings and when sounds of interest were heard, such as vessels, through the onboard speakers.

Vessels were detected several times. Often, they were heard through the speakers before they were seen. The vessels were at a range of distances from the kayak. Fig. 2 gives the sound characteristics of one such vessel event. The mean SPL_{RMS}s for each section of paused paddling varied considerably by ~15 dB re 1 µPa throughout the test trip.

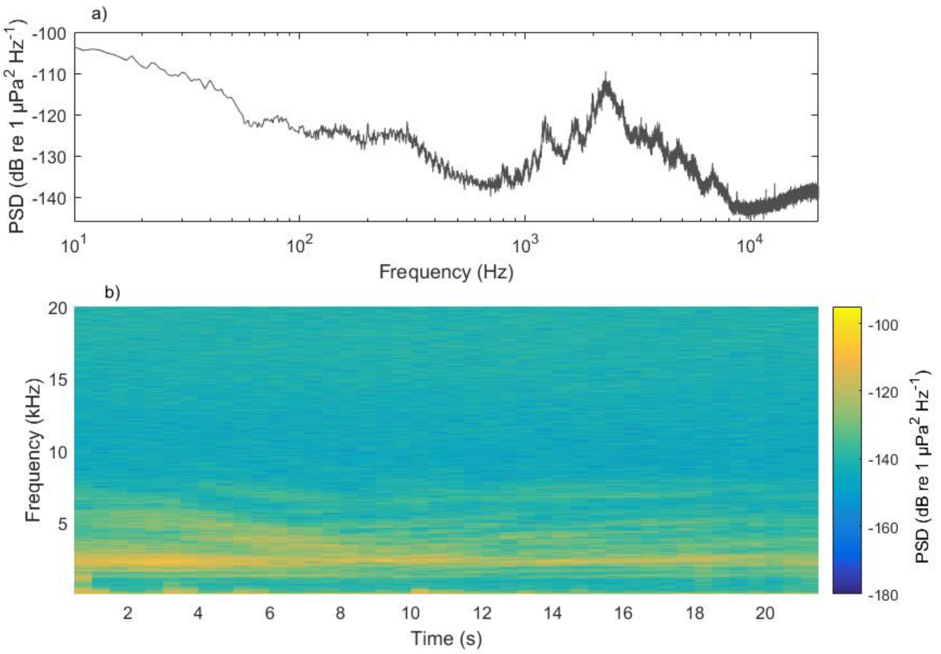

Fig. 2: a) Mean power spectral density of the vessel noise given in b) giving the average relative sound levels per 1 Hz. b) Spectrogram of vessel noise displaying the sound levels per 1 Hz over time.

4. DISCUSSION

We collected a continuous sound recording, with associated GPS locations, from kayaks using low-cost equipment. During a test kayak on Penryn river, we found a range in broadband sound levels of ~15 dB demonstrating the potential of this system in mapping underwater sound.

The paddling noise was found to be a limitation as it masked other sources of sound within a broad frequency range. Taking short unpolluted recordings was possible by pausing paddling. It is not uncommon for short samples to be taken during research e.g. 5 second samples from 3 minute recordings in [10] and 2 minute recordings per 30-mins in [11]. Drips from the paddles while pausing also pollute the recordings, this can be prevented by keeping the paddles inside the kayak. Electrical self-noise within several narrow frequency ranges were identified during testing. These occurred at frequencies higher than typically occurring from shipping, however, some biological sounds, such as from snapping shrimp, does occur at these frequencies. Therefore, particularly for the purposes of eco-acoustics, further work to identify the sources and eliminate them would be beneficial.

The hydrophone was deployed with a weight 1 m below the surface. While a kayaker is paddling, the hydrophone will not be vertical. However, when pausing to record samples, the hydrophone is expected to be approximating the full depth. Tidal flow may also affect the depth and sound recording. When pausing paddling, the kayak will drift a little with the tide, therefore reducing tidal flow and associated pseudo-noise. Changes in temperature are sonified which also can be heard in realtime through the speakers. This provides some indication of the location of the hydrophone in the water column – a decrease in temperature is heard when the hydrophone sinks when pausing paddling.

In addition to mapping shipping and other anthropogenic sources of sound, there is potential for the Sonic Kayak to be used for mapping biological noise. Underwater sound can provide information regarding the organisms present and physical characteristics and, at the scale of metres to kilometres, is thought to be an environmental cue for larval settlement [6]. Therefore, variations in sound over this scale are important for ecosystems. Eco-acoustics is an emerging field in the marine environment whereby acoustic indices are used as indicators of biodiversity [12]. Such acoustic indices have been used in the terrestrial environment (e.g. [13-15]). The Sonic Kayak system could be used to record underwater ambient sound over a variety of habitats.

Future research includes further refinement and data collection. The Sonic Kayak system has great potential in mapping anthropogenic and biological noise. Furthermore, as the speakers allow a kayaker to hear underwater sounds in realtime, the system could also be a valuable public engagement tool.

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