

# A bio-inspired approach to sound localisation in the underwater coastal environment

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## I. INTRODUCTION

In the shallow water coastal area, visibility is comparatively restricted yet marine mammals are still able to navigate, manoeuvre, and find food without any noticeable difficulties. Our work has focused particularly on grey whales (*Eschrichtius robustus*) due to their close association with the shallow water environment [1]-[3]. These whales are exposed to high levels of ambient noise [4], highly turbid waters [5] and many underwater obstacles [4] along their migration route and in the feeding grounds. The principal food source of the Eastern Pacific grey whale along the coast of British Columbia (B.C.), Canada is the mysid crustacean (order *mysidacea*) [6], [7]. These crustaceans usually form large aggregations (swarms) which are frequently associated with underwater features (i.e., rocks and kelp beds) [6], [8], [9]. Because the usefulness of vision is limited by the turbidity of the coastal submarine environment, it is logical to believe that they rely heavily on their hearing. Unlike dolphins and porpoises, grey whales do not appear to use active echolocation techniques. We propose therefore that they are making use of the ambient noise for passive acoustic characterisation of their environment. We are investigating what sounds are available to these animals in their feeding grounds and what types of visualisation techniques they might be employing. The first part of our research examines the soundscape and the acoustical sources available to the whales when navigating within a bay in the feeding grounds, and the second part investigates how sound signals are altered when objects such as kelp beds and rocks are present, which could lead to their detection.

## II. METHODS

Between July and September 2007, ambient noise recordings were collected in two bays along the central coast of B.C. These study sites were chosen due to their frequent use by foraging grey whales in previous years. North Bay ( $51^{\circ} 02' N$ ,  $127^{\circ} 34' W$ ) has a mostly rocky bottom and has many kelp beds, composed mainly of *Nereocystis luetkeana*, which are typically associated with submerged rocks. These kelp beds are where mysids are found. North Bay is relatively sheltered from the predominant NW winds. Burnett Bay ( $51^{\circ} 07' N$ ,  $127^{\circ} 41' W$ ) on the other hand is a 3 mile long sandy beach and is exposed to the NW winds and swell. The bottom is mainly sand with a few submerged rocks with kelp beds.

We used a fixed 2-hydrophone array, with elements horizontally separated by a small distance, analogous to a set of ears, which we deployed from a kayak. The hydrophone cables were run inside a 2 m long PVC pipe to the surface where they were connected to a M-Audio Microtrack 24/96 digital recorder (sampling at a frequency of 44.1 kHz). The acoustic signals were recorded at a broadband frequency range of 20 Hz to 20 kHz near the surface in water of approximately 1.5 m to 70 m depth, in several distinct environments (deep water, shallow water with kelp beds, shallow water with bare seabed, and surf zone).

Over a period of 2 months, approximately 200 acoustical recordings were taken throughout the two bays in order to create composite maps of the sound fields in each bay. These were created using the root mean square (rms) values of the received noise signals. The values were calculated and plotted with respect to GPS position in Matlab. In order to create a continuous map of the areas, values were interpolated between actual sampling positions. The sound field maps are then superimposed onto a nautical chart of the area in order to compare with the topography. A few whale tracks were also superimposed onto the sound maps to infer whether there is any correlation between their movements and the sound field.

The second part of the research involved the kayak remaining stationary while an inflatable boat passed by the array emitting a broadband signal. This was done to examine how the sound produced by the boat changes along the track due to the presence

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of rocks and kelp beds between the boat and the hydrophones. In a way this is similar to a simplified version of Acoustic Daylight Imaging, where the noise of the boat highlights objects in the bay. We used the boat as the source of ‘ambient noise’ in order to intensify the difference in sound as the source moved behind objects. The spectra of the received signals along the track were analysed to examine the change in the frequencies and intensity as a function of the objects that were present. Numerous dinghy tracks were performed with different kelp beds varying in expanse and density.

### III. RESULTS

The preliminary sound maps of the bays appear to be consistent with the prediction that there is an increase in the noise levels where rocks are exposed at the surface, near kelp beds, in shallow water, and along the shore where surf is present.

From the boat tracks done in the summer of 2006, the analysis shows that the higher frequencies of the boat’s signal are scattered or dissipated by the kelp, but the lower frequencies (<1 kHz) are less attenuated. There is always a peak in the spectra between 430 and 600 Hz when a kelp bed is present between the source and the receivers, but when a rock that was exposed at the surface was present, all frequencies were blocked. This leads to the suggestion that with an acute hearing capability, it is plausible that the masking of the ambient noise by various objects would allow the whale to identify the objects and hence map its surroundings. This work presents field experiments performed during the first two years of a PhD, and the analyses are ongoing for data recently collected during the 2007 field season.

### IV. DISCUSSION

It is likely that marine mammals, in particular those that do not use active echolocation, use passive acoustic navigation. In this area grey whales are focused on locating prey, which in this case is found in kelp beds. We are investigating how they are achieving this without the use of active acoustics. First we examined the ambient noise field in a shallow water area used by these foraging whales to determine what the sound field is like and to identify the sources. We also looked at how noise is affected by the presence of objects located in the bays. From the preliminary sound maps of the two bays, rocks and kelp beds are the main sources of ambient noise, and thus it would seem that the whales are cuing in on this when locating prey.

The boat tracks show that certain frequencies are altered depending on the object present. This draws on the passive acoustic technique of Acoustical Daylight Imaging, where ambient noise is used to acoustically illuminate objects that are silent or relatively quiet. Certain obstacles cancel noise altogether and some filter particular frequencies, allowing them to be identified and classified due to this difference. Another possible mechanism available to the whales for mapping their environment is based on passive synthetic aperture, where with only two receivers they can exploit their motion to create a large array.

The ultimate aim of this research is to create a 2-hydrophone acoustic navigation system which makes use of these techniques. The development and testing of this bio-inspired system will further our understanding of noise in this particular environment. Additionally, its implementation will improve our understanding of the whales’ ability to navigate and locate prey in the noisy nearshore environment.

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### REFERENCES

- [1] H. W. Braham, “Migration and distribution of gray whales in Alaska” in *The Gray Whale*, M.L. Jones, S. Leatherwood and S. Swartz, Ed. New York: Academic Press, 1984, pp. 249-266.
- [2] B. R. Mate and J. T. Harvey, “Ocean movements of radio-tagged gray whales” in *The Gray Whale*, M.L. Jones, S. Leatherwood and S. Swartz, Ed. New York: Academic Press, 1984, pp. 577-589.
- [3] G. C. Pike, “Migration and feeding of the gray whale (*Eschrichtius gibbosus*),” *J. Fish. Res. Bd. Canada*, 19 (5), 815-838.
- [4] N. L. Crane and K. Lashkari, “Sound production of the gray whales, *Eschrichtius robustus*, along their migration route: A new approach to signal analysis,” *J. Acoust. Soc. Am.*, 100 (3), 1878-1886.
- [5] M. J. Buckingham and J. R. Potter, “Acoustic daylight imaging: Vision in the ocean,” *GSA Today*, 4 (4), 97-102.
- [6] L. D. Murison, D. J. Murie, K.R. Morin, and J. Da Silva Curiel, “Foraging of the gray whale along the west coast of Vancouver Island, British Columbia” in *The Gray Whale*, M.L. Jones, S. Leatherwood and S. Swartz, Ed. New York: Academic Press, 1984, pp. 451-463.
- [7] J. S. Oliver, P. N. Slattery, M. A. Silberstein, and E. F. O’Connor, “Gray whale feeding on dense amphipod communities near Bamfield, British Columbia,” *Can. J. Zool.*, 62, 41-49.
- [8] S. L. Kim and J. S. Oliver, “Swarming benthic crustaceans in the Bering and Chukchi Seas and their relation to geographic patterns in gray whale feeding,” *Can. J. Zool.*, 67, 1531-1542.
- [9] L. Stelle, “Behavioral ecology of summer resident gray whales (*Eschrichtius robustus*) feeding on mysids in British Columbia, Canada,” unpublished.