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SHORT NOTE

Listening to whales and earthquakes: on exploring hydrophone recordings and Distributed Acoustic Sensing

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1. Monitoring sounds in marine environments

Sound plays a crucial role in marine environments. Biophony and geophony are key components of underwater soundscapes produced by marine fauna and natural sounds (Krause, 2008). The evolution of soniferous species depends on geophony, which has significant acoustic implications for their development and adaptation. Among biological sources, mysticetes are known for their vocal activity, produce complex acoustic repertoires, and have evolved specialised mechanisms for sound production and highly adapted auditory systems (Elemans *et al*., 2024). The analysis of earthquake signals, as a component of geophony, offers valuable insights into the Earth's internal structure and dynamic behaviour (Marra *et al*., 2019).

Passive Acoustic Monitoring (PAM) techniques enable the detection of animals through their acoustic presence and the tracking of changes in their acoustic behaviour in response to anthropogenic sound sources, and can also record the temporal and spatial distribution of earthquakes in oceanic regions (Howe *et al*., 2019). Although hydrophone networks are uniquely suited for continuous long-term monitoring, the recorded data are usually insufficiently sampled and expensive (Kowarski and Moors-Murphy, 2021). Distributed Acoustic Sensing (DAS) is showing progress in terms of data quality and spatial coverage. Also due to its ability to sample remote and inaccessible regions, DAS is increasingly used at sea to monitor whales and earthquakes (Landrø *et al*., 2022).

In this pilot study, we build on Ragland *et al*. (2022) and Wilcock *et al*. (2023), and explore examples of acoustic recordings of fin whale (*Balaenoptera physalus*) calls and earthquakes recorded by hydrophones and fibre optics from the Ocean Observatories Initiative Regional Cabled Array (OOI-RCA) network in the NE Pacific Ocean. Further studies should move towards an in-depth analysis and comparison of acoustic recordings gathered from multiple instrumentations.

2. Tuning in to fin whale calls and earthquake sounds with hydrophones and DAS

Fin whales were chosen as an example species for this pilot study because they are common off the coast of Oregon and their average call source levels is 189±4 dB re: 1 µPa at 1 m over typical frequencies of approximately 15-28 Hz [for the Southern Ocean: Širović *et al*. (2007)]. Therefore, their 20-Herz pulses are easily captured by recording devices (Garcia *et al*., 2019).

In order to study earthquakes in the area, we explored the seismicity off the coast of Oregon related to the Blanco Fracture Zone (green line in Fig. 1), a transform fault zone on the seafloor of the north-eastern Pacific Ocean, extending between the Gorda Ridge to the south and the Juan de Fuca Ridge to the north (Personius and Lidke, 2011). The main feature of the eastern portion of the zone is the Blanco Ridge, a 150 km long, right-moving fault responsible for the largest earthquakes in the region, since movement on this fault is responsible for most of the plate motion. In this region, the fault runs parallel to the movement of the plate.

Here, we collected the open-access DAS data via the OOI-RCA network using the North and South Cable offshore station in Pacific City, Oregon, each equipped with optoDAS interrogators, produced by Optasense and Alcatel Submarine Networks, respectively (http://piweb.ooirsn.uw.edu/das; Wilcock and OOI, 2023; Lipovsky and Williams, 2024). Among the 11 hydrophones that are part of the OOI-RCA sensor network, we selected the Oregon Slope Base Seafloor hydrophone and the Southern Hydrate Low Frequency (LF) HTI-90-U hydrophone (High Tech, Inc.) (https://ooinet.oceanobservatories.org/; Ragland *et al*., 2022).

A map of the study area, with the locations of the hydrophones (yellow and orange circles), the Corvallis seismic station (red diamond), the fibre optics (dotted lines), and the epicentre of the earthquake (yellow star, 43.473°N, 127.374°W), is shown in Fig. 1.

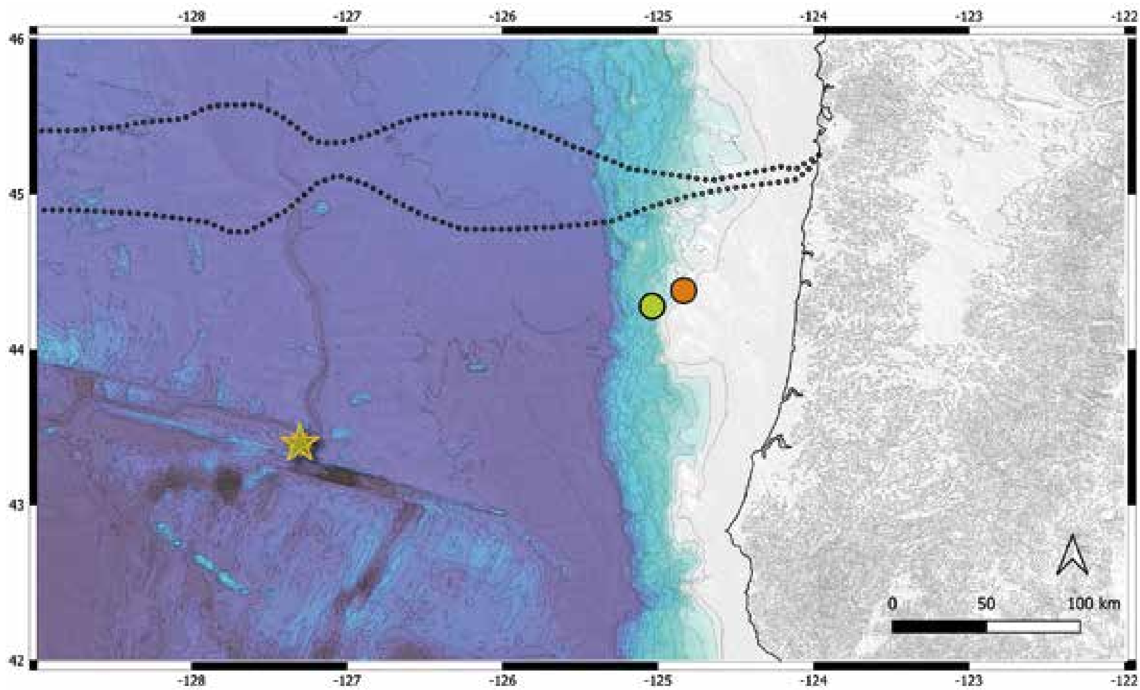

Fig. 1 - Map of the study area with the location of the Oregon Slope Base Seafloor, the southern Hydrate hydrophones (yellow and orange circles, respectively; sampling 200 Hz frequency) and cable position of the North and South DAS cables (dotted lines). The yellow star represents the earthquake epicentre (43.473° N, 127.374° W), the red diamond shows the Corvallis station (IU, COR; 44.59° N, 123.30° W), and the purple triangle marks Pacific City. The bathymetry of the area was extracted from GEBCO bathymetry (https://www.gebco.net/data_and_products/gridded_bathymetry_data/).

The preliminary data analysis confirmed the ability of the hydrophones and the DAS network to detect sounds produced by fin whales and earthquakes. DAS data analysis was performed by adapting freely available Python packages (Schwock *et al.*, 2021; Bouffaut, 2023; https://www.iris.edu/). Dedicated Butterworth bandpass filters were created based on the main frequencies of fin whale vocalisations and earthquakes. We manually scanned acoustic recordings for fin whale vocalisations that were present throughout the data set during November 2021. As an example, spectrograms and a *t-x* plot of their sounds obtained from data recorded by the Oregon Slope Base Seafloor hydrophone and the North Cable fibres are shown in Fig. 2.

Fin whales generally produce stereotyped, loud, and short (approximately 1 s) down sweeps influenced by season, related to breeding, and centred at 20 Hz (e.g. Watkins, 1981).

a)

b)

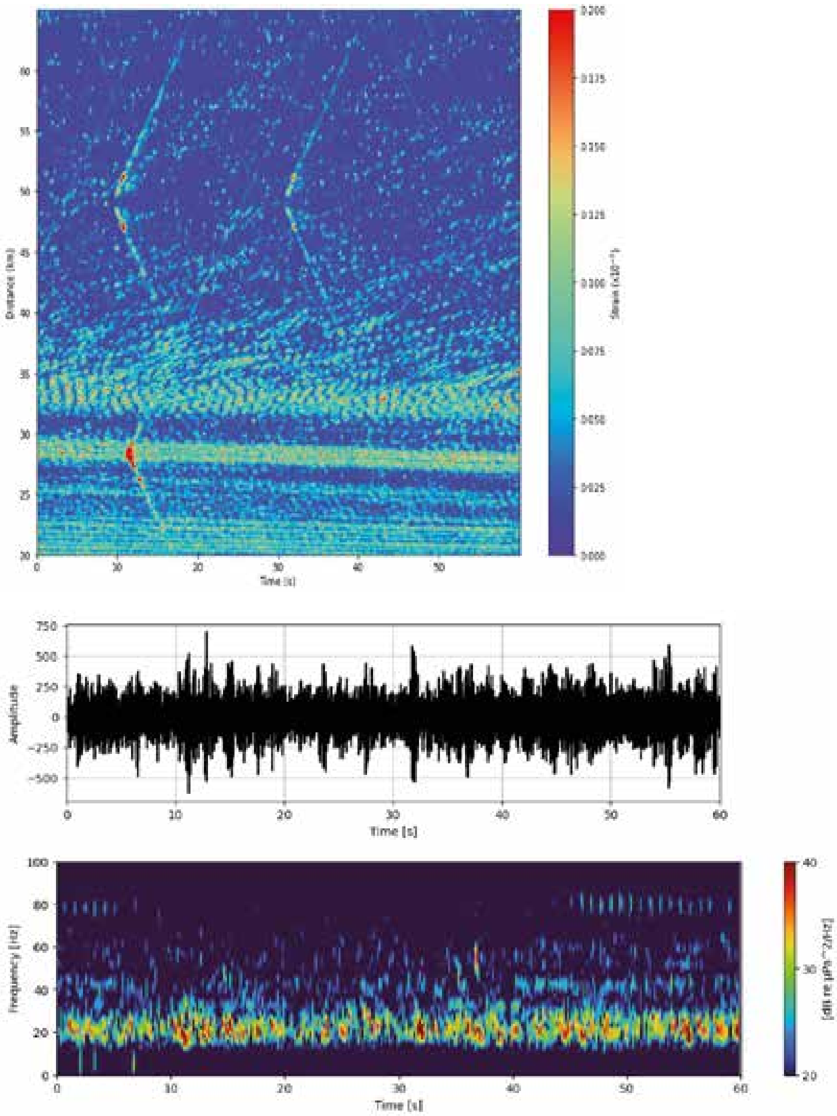

Fig. 2 - Fin whale vocalisations recorded with the optic fibre and hydrophone: a) Optasense North fibre (4 November 2021, 02:01:02 a.m. UTC) filtered using a Butterworth bandpass from 10 to 30 Hz; b) Oregon Slope Base Seafloor hydrophone (1 November 2021, 02:18:20 a.m. UTC with: window = hann, nfft = 8192, 50% overlap, sampling rate = 200 Hz). The band of low frequency (around 20 Hz) fin whale signals is spaced too closely in time to identify single pulses.

These signals are produced in long bouts of repeated series of single or double pulses used in reproductive displays and shorter series with irregular interpulse intervals which occur when feeding, socialising, and travelling (Watkins *et al.*, 1987; McDonald *et al.*, 1995). In this data set, we also found calls produced at higher frequencies, the 40-Herz calls, related to feeding and prey biomass (Širović *et al.*, 2013; Romagosa *et al.*, 2021). Understanding the function of these calls may inform stakeholders about habitat use and predict the effects of anthropogenic stressors.

Fig. 3 shows the DAS profile of the *M* 3.0 earthquake (yellow star in Fig. 1) that occurred on 10 May 2024 at 02:48:35 (UTC), 243 km west of Bandon, Oregon (Fig. 3a) and a waveform and spectrogram plotted using hydrophone recordings (Fig. 3b).

a)

b)

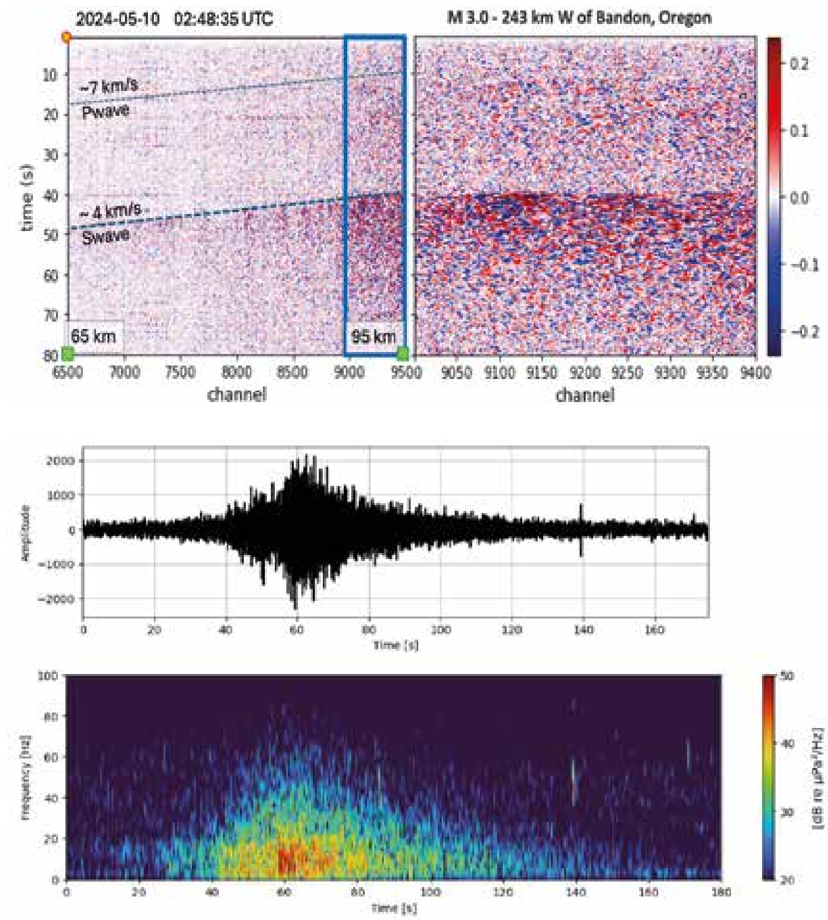

Fig. 3 - 10 May 2024 (02:48:35 UTC) earthquake: a) P- and S-seismic wave arrivals recorded by the optic fibre; b) waveform and spectrogram recordings from the southern hydrate hydrophone (window = hann, nfft = 8192, 25% overlap, sampling rate = 200 Hz).

The earthquake magnitude (*M* = 3.0) is modest, and the epicentre distance from the submarine cable eastern end is about 250 km. In Fig. 3a (left side), we zoom in on the part of the cable between 65 and 95 km (channel spacing of 10 m); while the arrival of the P waves is only fleetingly visible, the arrival of the S waves is very clear. On the right (Fig. 3a), a further zoom in on the last 5 km (channels 9000 to 9500, right side of the figure) shows the arrival of the seismic waves. The arrival times are fully compatible with the times recorded by the Corvallis station, located less than 100 km SE of Pacific City, red diamond in Fig. 1).

3. Towards global shared networks and integrated approaches for conservation using acoustics

Here, we built on sample open data from the OOI-RCA network and explored fin whales and earthquake sounds recorded by hydrophones and DAS. These technologies can complement each other in providing insight into acoustic monitoring of whale vocalisations and earthquakes. PAM is largely used to study wildlife, monitor ecosystem health, and observe underwater seismicity (Gibb *et al*., 2018; Affatati, 2020). Long-term monitoring has historically used archival tools, from which data can only be obtained upon retrieval of the recording device. Passive acoustic data may now be gathered, analysed, and transmitted to shore in almost real time.

Anthropogenic stressors impact global biodiversity and are not uniformly and globally distributed (Halpern *et al*., 2015). The underwater acoustic environment has undergone significant change as a result of increased human activity in the ocean and global climate change. By monitoring biophony and geophony using acoustics, stakeholders can identify the most vulnerable ecosystems and define acoustic hotspots for the implementation of conservation measures. DAS techniques can provide high spatial coverage and resolution data and, in combination with hydrophones, can aid in boosting conservation efforts. In particular, DAS techniques can enhance the rapid detection and characterisation of earthquakes, potentially improving our capacity of early warning detections (Farghal *et al*., 2022). However, these systems can only assess sound-producing taxa and acoustic signals generated by geological events. This bias in detectability needs to be considered when designing a study and can be lessened by integrating different observation tools (Mann and Würsig, 2014).

Research efforts on PAM contribute to creating global acoustic networks and databases, such as the International Quiet Ocean Experiment, OPUS (Open Portal to Underwater Soundscapes), and the Passive Acoustic Cetacean Map. These platforms play an essential role in decoding underwater signals and facilitate the open sharing of scientific outputs and recordings collected worldwide. Results should be available to policy-makers and stakeholders already working on setting thresholds for underwater noise (e.g. the Technical Group on Underwater Noise). Due to the vast amount of data, transdisciplinary collaboration and a holistic approach are essential for studying the marine environment and supporting informed decision-making.

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REFERENCES

Bouffaut L.; 2023: *DAS4Whales: a Python package to analyze Distributed Acoustic Sensing (DAS) data for marine bioacoustics (v0.1.0).* Zenodo, doi: 10.5281/zenodo.7760187.

Farghal N.S., Saunders J.K. and Parker G.A.; 2022: *The potential of using fiber optic Distributed Acoustic Sensing (DAS) in earthquake early warning applications*. Bull. Seismol. Soc. Am., 112, 1416-1435, doi: 10.1785/0120210214.

Garcia H.A., Zhu C., Schinault M.E., Kaplan A.I., Handegard N.O., Godø O.R. and Ratilal P.; 2019: *Temporal-spatial, spectral, and source level distributions of fin whale vocalizations in the Norwegian Sea observed with a coherent hydrophone array*. ICES J. Mar. Sci., 76, 268-283, doi: 10.1093/icesjms/fsy127.

Gibb R., Browning E., Glover-Kapfer P. and Jones K.E.; 2018: *Emerging opportunities and challenges for passive acoustics in ecological assessment and monitoring.* Methods Ecol. Evol., 10, 169-185, doi: 10.1111/2041-210X.13101.

Halpern B.S., Frazier M., Potapenko J., Casey K.S., Koenig K., Longo C. and Walbridge S.; 2015: *Spatial and temporal changes in cumulative human impacts on the world's ocean*. Nat. Commun., 6, 1-7.

Howe B.M., Miksis-Olds J., Rehm E., Sagen H., Worcester P.F. and Haralabus G.; 2019: *Observing the oceans acoustically.* Front. Mar. Sci., 6, doi: 10.3389/fmars.2019.00426.

Kowarski K.A. and Moors-Murphy H.; 2021: *A review of big data analysis methods for Baleen Whale Passive Acoustic Monitoring.* Mar. Mammal Sci., 37, 652-673, doi: 10.1111/mms.12758.

Krause B.; 2008: *Anatomy of the soundscape: evolving perspectives*. J. Audio Eng. Soc., 56, 73-80.

Landrø M., Bouffaut L., Kriesell H.J., Potter J.R., Rørstadbotnen R.A., Taweesintananon K. and Storvik F.; 2022: *Sensing whales, storms, ships and earthquakes using an Arctic fibre optic cable*. Sci. Rep., 12, 19226, doi: 10.1038/s41598-022-23606-x.

Lipovsky B. and Williams E.; 2024: *RAPID: multiplexed Distributed Acoustic Sensing (DAS) at the Ocean Observatory Initiative (OOI) Regional Cabled Array (RCA) [Data set]*. Ocean Obs. Initiative, doi: 10.58046/4WEF-A282.

Mann J. and Würsig B.; 2014: *Observing and quantifying cetacean behavior in the wild: current problems, limitations, and future directions.* In: Yamagiwa J. and Karczmarski L. (eds), Primates and cetaceans: field research and conservation of complex mammalian societies, Springer, Berlin, Germany, pp. 335-344, doi: 10.1007/978-4-431-54523-1.

Marra G., Clivati C., Luckett R., Tampellini A., Kronjäger J., Wright L. and Calonico D.; 2019: *A global network for underwater earthquake detection using the existing submarine optical fibre network*. Geophys. Res. Abstr., 21, EGU2019-5473.

McDonald M.A., Hildebrand J.A. and Webb S.C.; 1995: *Blue and fin whales observed on a seafloor array in the northeast Pacific.* J. Acoust. Soc. Am., 98, 712-721, doi: 10.1121/1.413565.

Personius S.F. and Lidke D.J.; 2011: *Fault number 782, Blanco transform fault zone, in Quaternary fault and fold database of the United States*. U.S. Geol. Surv. website, <earthquakes.usgs.gov/hazards/qfaults> (accessed 26 October 2024).

Ragland J., Schwock F., Munson M. and Abadi S.; 2022: *An overview of ambient sound using Ocean Observatories Initiative hydrophones*. J. Acoust. Soc. Am., 151, 2085-2100, doi: 10.1121/10.0009836.

Romagosa M., Pérez-Jorge S., Cascão I., Mouriño H., Lehodey P., Pereira A., Marques Tiago A., Matias L. and Silva M.A.; 2021: *Food talk: 40-Hz fin whale calls are associated with prey biomass*. Proc. R. Soc. B, 288, 20211156, doi: 10.1098/rspb.2021.1156.

Schwock F., Ragland J., Setiawan L., Munson M., Volodin D. and Abadi S.; 2021: *OOIPy v1.1.3: a Python toolbox designed to aid in the scientific analysis of Ocean Observatories Initiative (OOI) data*. Doi: 10.5281/zenodo.5165389.

Širović A., Hildebrand J.A. and Wiggins S.M.; 2007: *Blue and fin whale call source levels and propagation range in the southern Ocean.* J. Acoust. Soc. Am., 122, 1208-1215, doi: 10.1121/1.2749452.

Širović A., Williams L.N., Kerosky S.M., Wiggins S.M. and Hildebrand J.A.; 2013: *Temporal separation of two fin whale call types across the eastern North Pacific.* Mar. Biol., 160, 47-57, doi: 10.1007/s00227-012-2061-z.

Watkins W.A.; 1981: *Activities and underwater sounds of fin whales*. Sci. Rep. Whales Res. Inst., 33, 83-117.

Watkins W.A., Tyack P., Moore K.E. and Bird J.E.; 1987: *The 20-Hz signals of finback whales (Balaenoptera physalus).* J. Acoust. Soc. Am., 82, 1901-1912, doi: 10.1121/1.395685.

Wilcock W. and OOI (Ocean Observatories Initiative); 2023: *Rapid: a community test of Distributed Acoustic Sensing on the Ocean Observatories Initiative regional cabled array [data set].* Ocean Obs. Initiative, doi: 10.58046/5J60-FJ89.

Wilcock W.S., Abadi S. and Lipovsky B.P.; 2023: *Distributed Acoustic Sensing recordings of low-frequency whale calls and ship noise offshore central Oregon*. JASA Express Lett., 3, 026002, doi: 10.1121/10.0017104.

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