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Passive acoustic underwater sensing for persistent large-scale environment monitoring

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BACKGROUND AND APPROACH

Singapore's coastal waters boast rich biodiversity, hosting diverse coral reefs, seagrasses, fish, crustaceans and several marine mammals including dolphins and dugongs. Climate change and anthropogenic activities pose significant threats to this biodiversity. Reliable baseline data on key indicator species, including marine mammals, fish, and crustaceans, remain limited, hindering conservation [1]. Reefs, which support a quarter of all marine life, have suffered extensive global losses due to climate change and human impacts [2,3]. Recent events such as oil spills, coral bleaching, and land reclamation, underscore the need for continuous monitoring to understand these impacts and inform policy.

Traditional visual monitoring methods are costly, labor-intensive, and provide only snapshots of ecosystem health. Passive Acoustic Monitoring offers a non-invasive, inexpensive and scalable alternative capable of operating continuously and independent of water clarity or weather conditions [4]. Many marine organisms rely on sound, making underwater soundscapes rich sources of ecological information. For species like dugongs and dolphins, which are hard to spot in Singapore's turbid waters, passive acoustics enables detection over larger ranges via their vocalizations. Additionally, reef soundscapes are increasingly recognized as indicators of ecosystem health, with specific acoustic patterns correlating with coral, fish and invertebrate diversity [5,6].

METHODOLOGY, RESULTS AND CONCLUSION

To study the reef health and marine-mammal populations in the waters around Singapore, we collected 54.2 months of ambient noise recordings (2019-2022) from 10 island sites using single-hydrophone systems. Automated machine learning (ML) methods were developed to process large volumes of acoustic data, identifying key indices for reef health and detecting marine mammal vocalizations. To address persistent low-frequency noise from shipping and tidal currents that masks the low-frequency reef soundscapes, we trained an ML-based "Reef denoiser". This revealed the presence of daily acoustic "choruses" linked to fish and shrimp activity, with denoised acoustic indices showing clear correlations with reef health metrics, such as live coral cover and richness and algal cover, obtained through diver-based survey transects. The shrimp snap rate, derived from

high-frequency bands, was strongly associated with reef health both temporally and spatially.

Detection of marine mammal vocalizations in the recordings can yield an understanding of their presence, visitation patterns, and behavioral insights crucial to conservation efforts. However, the detection is impeded by the high shrimp noise, which we mitigated using a specific ML-based shrimp noise denoising technique, greatly improving detection performance. We use this robust detector on the long-term acoustic dataset, and showcase a variety of dolphin vocalizations detected over three years of recordings.

Overall, our study demonstrates that passive acoustics holds valuable information that can enable vital, scalable insights into marine diversity including reefs and megafauna, provided the data is effectively denoised and interpreted, supporting ongoing conservation in noisy marine environments.

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