Open Access
Journal of Maritime Science and Technology
ISSN 2961-6158
https://journal.dmi.ac.tz

Perceived Sources of Anthropogenic Underwater Noise in the Marine Ecosystem of Malindi Ward, Zanzibar

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ARTICLE HISTORY

Received 2 August 2025
Accepted 28 January 2026

KEYWORDS:
Anthropogenic noise;
Underwater noise;
Soundscape ecology;
Marine ecosystem;
Coastal management;

A B S T R A C T

Anthropogenic underwater noise is an emerging environmental pressure in coastal areas, but evidence on its local sources in tropical small-island settings remains limited. This study assessed the sources of anthropogenic noise in the marine ecosystem of Malindi Ward, Zanzibar, and examined stakeholder perceptions of their ecological implications. A convergent parallel mixed-methods design was used. Data were collected from 94 respondents comprising 70 fishers, 18 tourism operators and 6 coastal management officials through questionnaires, interviews, observations and document review. Quantitative responses were measured using a four-point Likert scale and analysed using descriptive statistics, while qualitative information was analysed thematically and integrated with survey findings. Boat traffic involving cargo and tourist vessels was the most highly rated source of noise (M = 3.62), followed by speedboats and jet skis (M = 3.13), port operations (M = 2.85), coastal infrastructure activities (M = 2.83) and fishing-vessel noise (M = 2.72). Coastal construction, recreational activities, industrial activities, underwater drilling and nighttime noise from anchored ships received lower ratings. Interview participants associated vessel and construction noise with changes in fish behaviour, disruption of fishing activities and perceived reductions in catches. The findings indicate that marine noise management in Malindi should address large commercial vessels and repeated nearshore activities, particularly tourism and port operations. The study recommends integrating acoustic considerations into marine spatial planning and environmental assessments, establishing low-noise zones around sensitive habitats, improving vessel-noise management and strengthening community participation in monitoring. The study provides a baseline for acoustic measurements and appropriate marine-noise management in Zanzibar.

1. Introduction

Underwater sound is an important component of marine ecosystems because many marine organisms use acoustic information for communication, orientation, habitat selection, feeding and predator avoidance. Human activities have altered this natural soundscape through shipping, port operations, construction, dredging, tourism, fishing and other maritime activities. The resulting anthropogenic sound, commonly described as anthrophony, can alter the acoustic environment and interfere with biologically relevant signals (Pijanowski et al., 2011; Duarte et al., 2021). The ecological significance of anthropogenic underwater noise is increasingly recognised. Vessel noise can produce chronic acoustic exposure over large areas, while construction and other impulsive sources may generate short-duration but intense disturbances. Documented or suspected responses include acoustic masking, behavioural changes, altered habitat use and physiological stress. However, effects vary with sound characteristics, species, habitat and exposure conditions, and substantial knowledge gaps remain, particularly for tropical coastal ecosystems (Erbe et al., 2019; Popper & Hawkins, 2019). The maritime industry is a vital component of global trade, facilitating the transportation of approximately 80% of the world's goods. Coastal areas of developing countries face additional challenges because maritime transport, tourism and infrastructure development are expanding while environmental monitoring capacity and locally specific acoustic data remain limited. In Zanzibar, tourism, fisheries and port-related activities are important components of the coastal economy. Their spatial overlap in nearshore waters may increase the potential for repeated exposure to anthropogenic noise, especially in shallow habitats used by fishers and marine organisms. Malindi Ward in Zanzibar is a high-activity coastal area where fishing, tourism, vessel traffic and port-related activities occur in close proximity. The original study identified stakeholder concerns about

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increasing underwater noise from cargo ships, tourist vessels, speedboats and coastal development, but noted that empirical evidence linking local activities to specific noise sources was limited. A locally grounded assessment is therefore useful for informing coastal management and future acoustic monitoring. This study was guided by Soundscape Ecology Theory, which conceptualises soundscapes in terms of biological sounds (biophony), geophysical sounds (geophony) and human-generated sounds (anthrophony) and emphasises the spatial and temporal dynamics of sound (Pijanowski et al., 2011). The study aimed to identify the major perceived sources of anthropogenic underwater noise in Malindi Ward and to document stakeholder perceptions of associated ecological and livelihood implications. The findings are intended to provide baseline information for more rigorous acoustic measurements and locally appropriate management interventions.

2. Methodology

2.1 Study area

The study was conducted in Malindi Ward, within the Urban District of Zanzibar, Tanzania. Malindi is a high-activity coastal area where fishing, tourism and port-related activities occur within a relatively confined marine environment. The area includes shallow fishing grounds and ecologically sensitive coastal habitats, including coral reefs and seagrass areas. These ecological and socio-economic characteristics make Malindi an appropriate case study for examining interactions between maritime activities, underwater sound and coastal livelihoods.

2.2 Research design

A convergent parallel mixed-methods design was adopted. Quantitative and qualitative data were collected during the same study period and analysed separately before being compared and integrated. The quantitative component was used to describe and rank respondents' perceptions of different noise sources, whereas the qualitative component provided contextual explanations of perceived ecological and livelihood effects. Mixed-methods integration was appropriate because the research question required both measurable patterns and stakeholder experience (Creswell & Plano Clark, 2018).

2.3 Research design

The target population comprised three stakeholder groups directly involved in or exposed to marine activities associated with underwater noise: local fishers, tourism operators and coastal management officials. A stratified purposive sampling approach was used to obtain information from these groups. Of 100 individuals approached, 94 participated, giving a response rate of 94%. The final sample comprised 70 fishers (74.5%), 18 tourism operators (19.1%) and 6 coastal management officials (6.4%). The relatively large representation of fishers reflected their direct and frequent interaction with the nearshore marine environment.

2.4 Data collection

Structured questionnaires were administered to fishers and tourism operators. Perceptions of noise sources were measured using a four-point Likert scale ranging from 1 = strongly disagree to 4 = strongly agree. Semi-structured interviews were conducted with coastal officials and selected key informants to obtain detailed explanations of observed changes, management concerns and potential mitigation measures. Direct observations were also undertaken, and relevant secondary documents, including marine activity records and environmental reports, were reviewed. The use of multiple sources supported triangulation of the evidence (Creswell & Creswell, 2018).

2.5 Data analysis

Quantitative data were analysed using descriptive statistics in SPSS version 25. Means and standard deviations were calculated for each Likert-scale item. Mean scores were interpreted using the following intervals: 1.00-1.75 = very low, 1.76-2.50 = low, 2.51-3.25 = high, and 3.26-4.00 = very high. Qualitative interview and observation data were analysed thematically by identifying recurring concepts and grouping them into themes related to noise sources, ecological effects, livelihood effects and management responses. Thematic analysis followed a systematic coding and theme-development approach consistent with Nowell et al. (2017).

2.6 Methodological limitation

An important limitation is that the study assessed perceived sources of noise rather than measuring sound pressure levels, frequency spectra or exposure duration using calibrated hydrophones. Consequently, the findings should be interpreted as stakeholder-based evidence of the relative prominence of noise sources rather than as direct measurements of underwater acoustic intensity. Future studies should combine stakeholder assessments with instrument-based acoustic monitoring.

3. Results and Discussion

3.1 Perceived sources of anthropogenic underwater noise

Table 1 presents respondents' ratings of potential sources and patterns of anthropogenic underwater noise in Malindi Ward. Boat traffic involving cargo and tourist vessels recorded the highest mean score (M = 3.62, SD = 0.49), corresponding to a very high rating. Speedboats and jet skis used for tourism activities were rated high (M = 3.13, SD = 0.94). Port operations (M = 2.85, SD = 0.36), coastal infrastructure projects (M = 2.83, SD = 0.43), seasonal increases in activity (M = 2.79, SD = 0.79) and fishing-vessel noise (M = 2.72, SD = 0.72) were also rated high.

Lower-rated items included underwater drilling (M = 2.48, SD = 1.46), recreational activities (M = 2.23, SD = 0.69), coastal construction (M = 2.22, SD = 0.83), industrial activities (M = 2.20, SD = 1.14) and nighttime noise from anchored ships (M = 2.18, SD = 0.82). These results suggest that mobile vessel activity is perceived as a more persistent source of underwater noise than less frequent or spatially concentrated activities.

One item requires careful interpretation: respondents agreed at a relatively high level with the statement that small boats contribute minimally to noise pollution compared with larger vessels (M = 2.72). Therefore, this score should not be interpreted as evidence that small boats are themselves a major source. Rather, it indicates that respondents viewed small boats as less important than larger vessels, although their repeated operation in shallow waters may still warrant further investigation.

***Table 1**. Potential sources and patterns of anthropogenic underwater noise (n = 94).*

Noise source / indicator	Mean	SD	Interpretation
Boat traffic: cargo ships and tourist boats	3.62	0.49	Very high
Speedboats and jet skis used for tourism	3.13	0.94	High
Port operations	2.85	0.36	High
Coastal infrastructure projects	2.83	0.43	High
Seasonal variation in noise	2.79	0.79	High
Fishing-vessel noise	2.72	0.72	High
Small boats contribute minimally compared with larger vessels	2.72	1.18	High*
Underwater drilling	2.48	1.46	Low
Coastal construction	2.22	0.83	Low
Recreational activities	2.23	0.69	Low
Industrial activities	2.20	1.14	Low
Nighttime noise from anchored ships	2.18	0.82	Low

For the small-boat item, a high score indicates agreement with the statement that small boats contribute minimally relative to larger vessels; it should therefore not be ranked as a major source on the basis of this item alone.

3.2 Boat traffic and tourism vessels

The dominance of boat traffic is consistent with broader evidence that shipping is a major contributor to chronic underwater noise. Ship engines and propeller systems generate sound that can propagate over substantial distances, potentially increasing background noise and masking biologically important signals (Erbe et al., 2019; Merchant et al., 2020). The Malindi finding is therefore plausible given the concentration of commercial and tourism-related vessel movements in the study area.

Tourism vessels, including speedboats and jet skis, were the second-highest rated source. Unlike large ships, these vessels may produce intense and intermittent noise close to shore. Such exposure may be particularly relevant in shallow coastal habitats where fish and other organisms occur close to navigation routes. Research on fishes indicates that anthropogenic sound can influence behaviour, habitat selection, foraging and communication, although responses are species- and context-dependent (Popper & Hawkins, 2019).

3.3 Port operations, construction and infrastructure

Port operations and coastal infrastructure activities were also rated highly. Loading and unloading, vessel engines and associated machinery can contribute continuous background noise, while dredging, piling and construction may generate more impulsive sounds. The distinction between continuous and impulsive noise is important because ecological responses depend not only on perceived loudness but also on frequency, duration, repetition and proximity to sensitive organisms (Popper & Hastings, 2009).

The findings also suggest that coastal development should be considered within marine spatial planning. Area-based management can reduce exposure by separating sensitive habitats from intensive human activities, while protecting existing relatively quiet areas may be more practical than attempting to restore heavily disturbed soundscapes (Williams et al., 2015).

3.4. Stakeholder perceptions of ecological and livelihood effects

Interview evidence complemented the quantitative results. Fishers reported that cargo ships and tourist vessels disturbed fishing grounds and were associated with changes in fish behaviour and reduced catches. Tourism operators acknowledged that speedboats and jet skis generate noise but emphasised their economic importance. They nevertheless suggested that zoning could reduce interactions between tourism activities and sensitive areas. Coastal management officials highlighted concerns about construction and development near coral reefs and seagrass habitats.

These accounts provide useful local knowledge, but they should not be interpreted as direct evidence that noise alone caused changes in fish abundance or fishing yields. Catch levels are influenced by multiple factors, including fishing effort, seasonality, weather, habitat condition and stock dynamics. The stakeholder reports are therefore best regarded as indicators of perceived effects that should be tested through ecological and acoustic monitoring. This distinction strengthens the scientific interpretation of the study.

The findings are consistent with Soundscape Ecology Theory, which emphasises interactions among biological, geophysical and anthropogenic sounds and their consequences for organisms and ecosystems (Pijanowski et al., 2011). They also support the broader observation that human-generated sound has become an increasingly important component of the ocean soundscape (Duarte et al., 2021).

3.5 Implications for marine management

The results point to a management approach that addresses both high-volume commercial activities and frequent nearshore activities. First, vessel traffic should be incorporated into acoustic risk assessments, particularly around sensitive habitats and fishing grounds. Second, tourism operators should be involved in developing navigation routes and operating practices that reduce repeated disturbance. Third, environmental assessments for coastal and port developments should consider underwater noise as a potential environmental pressure rather than treating it only as a terrestrial construction issue.

The study also supports community participation. Fishers possess long-term observations of changes in fishing grounds and marine conditions, while tourism operators understand the operational constraints of marine activities. Combining this knowledge with instrument-based acoustic measurements could provide a practical basis for locally relevant marine-noise management.

4. Conclusion

This study assessed perceived sources of anthropogenic underwater noise in Malindi Ward, Zanzibar, using quantitative and qualitative evidence from 94 stakeholders. Boat traffic involving cargo and tourist vessels was the most prominent perceived source, followed by speedboats and jet skis, port operations, coastal infrastructure activities, seasonal variation and fishing-vessel noise. Stakeholder interviews further indicated concerns about changes in fish behaviour, disturbance of fishing grounds and perceived reductions in catches.

The findings provide useful baseline evidence for a coastal area where

maritime transport, tourism, fishing and development activities overlap. However, because the study did not measure underwater sound directly, the results should be interpreted as evidence of perceived source prominence rather than measured acoustic exposure or demonstrated ecological causation. Future research should therefore combine stakeholder knowledge with calibrated acoustic monitoring, ecological observations and spatial analysis. Such an integrated approach would provide stronger evidence for marine spatial planning and noise-management decisions in Zanzibar.

5. Recommendations

Based on the findings, the following are recommended;

i. Integrate underwater noise into marine spatial planning and environmental assessment procedures for port, tourism and coastal infrastructure projects.
ii. Conduct baseline and seasonal acoustic monitoring using calibrated hydrophones to quantify sound pressure levels, frequency characteristics and temporal patterns associated with major vessel and construction activities.
iii. Assess the feasibility of low-noise or restricted-vessel zones around ecologically sensitive habitats and important fishing grounds, with stakeholder participation in their design and implementation.
iv. Promote practical vessel-noise reduction measures, including appropriate engine and propeller maintenance, operational speed management and improved routing where feasible.
v. Strengthen community-based monitoring by training fishers and other coastal stakeholders to report unusual or intensive noise events and associated ecological observations.
vi. Undertake targeted ecological studies to test whether reported changes in fish behaviour and catches are associated with underwater noise after accounting for season, fishing effort, weather and other confounding factors.

6. Study limitations

The principal limitation is the absence of instrument-based acoustic measurements. The study consequently identifies perceived sources rather than objectively quantifying sound exposure. In addition, the cross-sectional design limits assessment of temporal trends and causal relationships between noise and ecological or fishery outcomes. These limitations do not invalidate the stakeholder evidence but indicate the need for follow-up monitoring and longitudinal studies.

Acknowledgements

The authors extend appreciation to the Dar es Salaam Maritime Institute (DMI) for success of this study.

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